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Archaeo-mented Reality: A study of the use of Augmented Reality as a tool for archaeological interpretation

by

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ABSTRACT

By understanding the effects that augmented reality could have on the archaeological process, archaeologists can have a better understanding on where the technology can best be applied to the field. There have been a few recent advancements with AR as an archaeological tool but unfortunately that is where the information ends, the impact of these advancements has not been assessed.

By taking an archaeological standard tool, the boat plan, and enhancing it with Augmented Reality capabilities some of the inherent downsides of the boat plan can be addressed as well as adding a new dimension of data within the same paper space. By doing this we can link multiple forms of meta-data directly to the object in question.

The goal of this study is to investigate the impact that augmented reality has on the typical use of a boat plan. This will be done by using multiple groups in a controlled environment with different tools allotted to each group to complete a series of tasks and questions that represent the typical usage of a boat plan. By monitoring the groups and deriving relationships from the interactions we can begin to investigate the impact augmented reality will have on the archaeological process.

HUMANITIES

Archaeology

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ARCHAEO-MENTED REALITY: A STUDY OF THE USE OF AUGMENTED REALITY AS A TOOL FOR ARCHAEOLOGICAL INTERPRETATION

Trevor Wayne Rowe

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DECLARATION OF AUTHORSHIP

I, Trevor Wayne Rowe declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

Archaeo-mented Reality: A study of the use of Augmented Reality as a tool for archaeological interpretation

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
5. I have acknowledged all main sources of help;
6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
7. None of this work has been published before submission.

Date: 9/18/19..

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I would, or rather need to express personal gratitude to the many individuals that acted not just as technical experts but subject experts as well. So thank you deeply Amandeep Mahal, Carlos Garrandés, Donald Sutherland, Joseph Hearn, and Rodrigo Ortiz. This work may have come from me but it was accomplished through us.

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Abbreviations

AR – Augmented Reality

GPS – Global Positioning System

GIS – Graphical Imaging System

HMD – Head Mounted Display

HUD – Heads Up Display

POV – Point Of View

SAT (A, B, and C) – Satellite (A, B, and C)

VR – Virtual Reality

Chapter 1: Introduction

1.1 Introduction

Augmented reality (AR), in brief, involves altering one's perception of the physical with the digital. Augmented reality is part of the mixed reality spectrum (figure 1.1). This spectrum covers various forms of reality ranging from that of the completely virtual to that of the completely physical, this will be discussed more in depth in Chapter 2. Mixed reality is in the middle of the spectrum; this is where augmented reality falls into place. One of the key components, again this will be discussed in greater detail, is the seamless interaction between the user, the digital, and the physical.

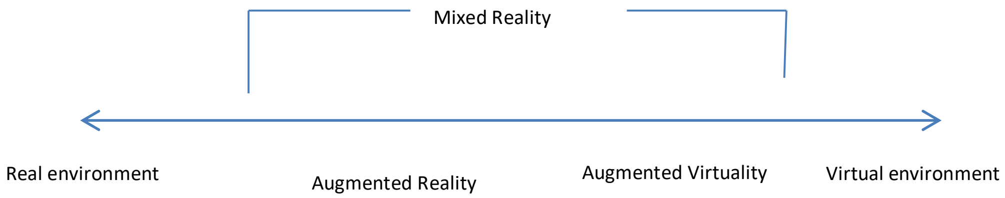


Figure 1.1 Mixed reality spectrum. Figure courtesy of author.

At the far right of the spectrum, we find the virtual environment. The virtual environment section would include virtual reality (VR). Within the field of archaeology, a quick investigation into the subjects of projects one would find a considerable amount of projects involved with virtual reality already (Renfrew, 1997; Gillings, 1999; Barceló et al., 2000; Ryan, 2001; Zhukovsky, 2001; Gillings, 2005; Bruno et al., 2010). However, within Archaeology, there are not as many projects involved with augmented reality (Wang et al., 2011; Garagnani and Manferdini, 2011; Niedermair and Ferschin, 2012; Jiménez Fernández-Palacios, 2015; Eve, 2014), especially within the last decade, when augmented reality technologies have become widely available to the public.

The before mentioned AR projects of the last decade are examined in Chapter 2, but in short, they offered insight into various uses of the technology as a means of archaeological tourism and the projection of archaeological information to the general public, but very few of them are used as part of the research process. The ones that are used as a tool by an archaeologist (Benko et al., 2004; Jiménez Fernández-Palacios, 2015; Eve, 2014) fail to answer the overall effects of the technology on the discipline (discussed in great detail in Chapter 2). This gap of knowledge on the subject of effects of IT on archaeology has been the topic of discussion by Lock and Brown (2000) and more recently by Eve (2014) but there is still a great deal of work to be done (Further detail on this gap and the work done by Lock and Brown and EVE is found in Chapter 2.).

This gap is what my research is directed towards. In short, the aims and objectives of this research were to investigate whether, and if so the extent to which augmented reality has a place within the field of maritime archaeology specifically if it can be used as a tool for interpretation and if so, how? To investigate the can's, and how's of AR as a tool for interpretation, three research questions were developed. First of these was to analyze the possible role of AR technology in common maritime archaeological interpretation tools and techniques. The second aim was to investigate the potential ramifications of AR on both the tools and techniques and on the field of maritime archaeology. The final aim of the research was to investigate the sustainability of AR technology as an archaeological tool. The specifics of these research goals are discussed at length later in the chapter.

The rationale behind the choice of augmented reality over that of other related technologies is three-fold. First and foremost, it is the next step in reality perception that is already being used in archaeology, meaning virtual reality. The choice of AR over VR is simply that the field of archaeology already has an abundance of projects, and data pertaining to its use, involved with VR (Renfrew, 1997; Gillings, 1999; Barceló et al., 2000; Ryan, 2001; Zhukovsky, 2001; Gillings, 2005; Bruno et al., 2010). Secondly, some of the groundwork for its usefulness with archaeological data has already been done (Barceló, 2000; Vlahakis et al., 2002; Allen et al., 2004a; El-hakim et al., 2004; Caarls et al., 2009; Garagnani and Manferdini, 2011; Wang et al., 2011; Niedermair and Ferschin, 2012; Eve, 2014). The final reasoning for the choice of AR is that of its projected growth as a mainstream technology. According to Gartner's Hype Cycle for Emerging Technologies (figure 1.2) AR is a leading technology, which means that AR is beginning to be more and more commonplace across many different fields. A 'Leading Technology' on the Hype Cycle is a technology that has already progressed through the peak of inflated expectations and through the trough of disillusionment, meaning that it's past the stage of being early publicity hype and there are plenty of failed projects surrounding the technology. However, with this growing failure comes what works with the AR technology and it can then be adapted in those ways, this is the slope of enlightenment phase of the Hype Cycle (figure 1.2). According to Mike Walker, a Research Director for Gartner, "This Hype Cycle specifically focuses on the set of technologies that are showing promise in delivering a high degree of competitive advantage over the next five to 10 years". The AR technology projection presented in the Hype Cycle is a key reason for the choice of augmented reality over that of other technologies such as virtual reality and augmented virtuality. Augmented reality is a promising technology that is worthy of study to determine its effects on the discipline and its sustainability of an archaeological tool, again this will be discussed in great detail in Chapter 2.

1.2 Historical and Technological Background

In 1970, James Doran asked archaeologists to look beyond the potential of the computer to store, organize, and query archaeological data and to consider instead its power to generate explanations of the archaeological record. Since then, this has remained true; there have been multiple projects involving the simulation of virtual worlds (Renfrew, 1997; Gillings, 1999; Barceló

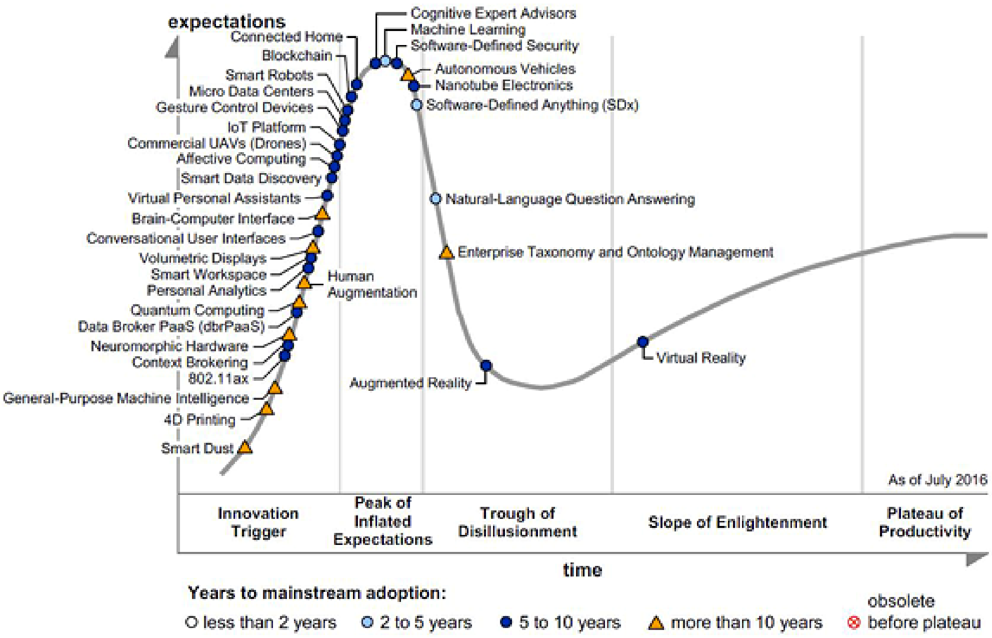


Figure 1.2 Gartner's 2016 Hype Cycle for Emerging Technologies. Image courtesy of Gartner.com, 2016

et al., 2000; Ryan, 2001; Zhukovsky, 2001; Gillings, 2005; Bruno et al., 2010). In continuing this trend of computational advancement, I believe that augmented reality is the next step. This technology is currently being widely used in many different areas, including archaeological tourism. However, what I am interested in is where AR can take archaeological interpretation. However, before we can examine this question, we must first familiarize ourselves with what exactly augmented reality is and how it came to be, so that we can understand where it can take us next.

To gain better understandings of augmented reality, we should not think of it as a technology at first. The best way to wrap one's mind around the concept of AR in its entirety is to abandon the notion that it is just another piece of technology, just a tool. Rather think of augmented reality in the same way that one would think of paint in a painting, it is a medium. If augmented reality is thought of as solely a tool, then it would be dealt with in the same manner as a tool just—used. Tools are designed to complete a task, whereas with more artful media tasks are still being accomplished; entice emotional response, entertainingly pass the time, and so forth; but with a deeper more personalized approach. If we take the stance that AR is on par with other more artful media, such as movies, books, and music we can expect a more meaningful outcome. We watch, read, and listen to movies, books, and music; augmented reality is the same. Because Augmented Reality is a sensory immersive technology, we engage with it in a give and take type of relationship.

Augmented Reality is an interactive technology it requires input and actions from the user to be experienced. One must engage AR; it cannot be just listened to or watched. If an Augmented Reality application projected an image onto the physical environment of a dancing figure with zero interactive capabilities from the user, this would not be true AR. Taking the same instance but adding the ability for the dancing figure to receive voice commands to change the type of dance or if the figure reacted to the user's movements, danced with the user, this would be a true AR application. Augmented reality can support many different areas of application, from the medical field to the classroom and the private home. However, they all have a single element in common. They all produce an augmented reality experience. This AR experience has been described by Alan Craig (2013, pg.2) as “the essence of an augmented reality experience is that you, the participant, engage in an activity in the same physical world that you engage with whether AR is involved or not, but AR adds digital information to the world that you can interact with in the same manner that you interact with the physical world.” So, in short, imagine that you are involved with a normal action in the real world, but there are “digital” additions superimposed onto the real world action you are involved with. A classic example would be a tourist visiting London, England. The tourist had a smartphone equipped with an AR tourism application (Wikitude, 2008). As the tourist walked through London, their phone was syncing visually with the buildings and offered pinpoints of local interests as well as directions to typical tourist locations such as Big Ben and Parliament, and the London Eye (figure 1.3).

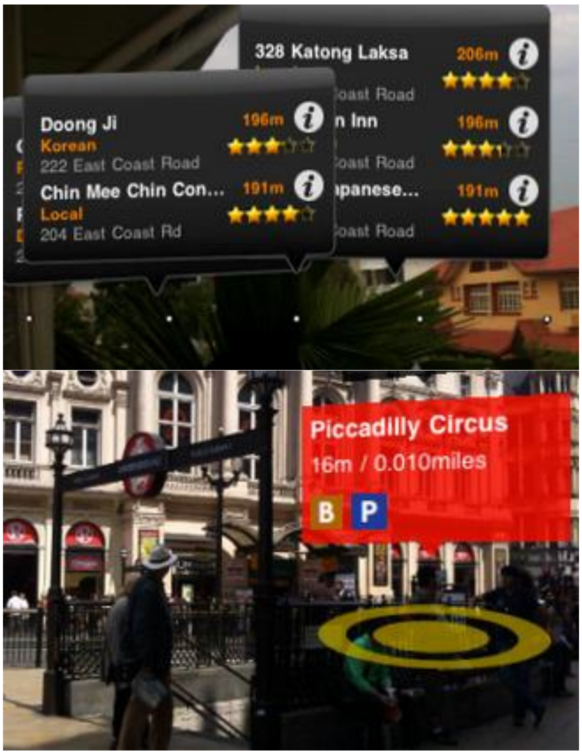


Figure 1.3 Above: buUuk augmented reality touring application. Below: London Tube: augmented reality application used to locate tube stations. Images courtesy of iphoneness.com.

Augmented reality uses a variety of sensors, displays, and computer processors to augment the world around you with various types of data. This data can take on the form of but is not limited to; information about the local, interactive entertainment such as a game, or reconstructions of a historic site. The use of input devices such as microphones, keyboards, and cameras allow the user to interact with the digital information that is being displayed in the same way that the user would interact with the objects as if they were part of the physical world. A more in-depth explanation on the process of augmenting the physical world and the AR “experience” is discussed in the second chapter.

1.2.1 Technological advancement that lead to the current AR Technology

Now with a basic understanding of what augmented reality is, let us consider AR’s origin story. With decreased cost to produce computers and the increase in those computers processing capabilities, the ability to create and render three-dimensional computer generated graphics in real time lead to the creation of scenes depicting aspects of the physical world and the world of impossible imagination, for example, the computer world depicted in TRON (1982).

In the past, there have been a plethora of advancements towards user immersion. This is a key step towards the creation of augmented reality since the primary concern of AR is user immersion. An example of this, something that is familiar to most people today, are 3D movies. With a 3D movie, the characters from said movie appear to jump off the two-dimensional movie screen into the physical, three-dimensional, world. This is a small step towards user immersion. However, with a 3D movie come certain restraints. For instance, it was developed to be viewed from a single viewpoint. No matter the position of the viewer's head the image remains the same. The gaming industry has also contributed steps towards user immersion as well. They offered user interactivity through the use of a joystick or keyboard. However, that is very limited. Of course, Nintendo, Microsoft, and Sony have given users the ability to use their bodies as the joystick by having gamers interface with cameras designed to detect the user's movement and translate that into in-game actions. Examples of this would include the Nintendo Wii, Microsoft Kinect, and the Sony PlayStation's EyeMove. However, this too is only a fraction of user immersion. Another area related to user immersion are the advancements in global positioning satellites, now everything can use these satellites built in, from cars to phones. With this comes various phone applications that utilize this technology. For example, you could have an application on your smartphone or tablet that shows you where all the restaurants are located around your current position. Each of these before mentioned steps all take a step towards user immersion, but individually he or she do not allow for the user to be engaged interactively in the physical world with the computer graphic enhancements that are geospatially registered with the real world (Heeter, 1992; Turner, 2007).

1.3 Contributions of the thesis

As academics we ask ourselves before and after every project, where does my project fit in to the overall field? We ask this in hopes that we are in fact answering some questions that have popped up in our field so that our work has a purpose. There have been two prominent questions that have risen within the framework of my research, one being the detachment between archaeological lab data and the field (Banning, 2000; Eve, 2014). The other is a bit more philosophical but still measurable. As it is becoming progressively obvious that theory and practice are joining to make archaeology a study of 'digital pasts' where data and information are rendered through the interactive medium of electronic mouse clicks and inputs (Lock, 2003, pg.13). What will the impact be on the way archaeologists interpret archaeological data? My project will utilize methods of augmenting the physical locations of archaeological and heritage sites and objects with the laboratory data to redefine the relationship between the two sets of data (lab and field). By doing so, we examined the impact, AR is having on the way archaeologists have been interpreting archaeological data by giving them a new perspective utilizing various forms of augmented reality technologies. This research answered the questions posed by Jeremy

Huggett (2000) and other essays within Lock and Brown's edited collection on the theory and practice of archaeological computing (2000). By answering these two questions, the theoretical framework surrounding IT in archaeology will be closer to being complete and have greater insight into the role of augmented reality and how it affects the disciplines current methods of archaeological data interpretation.

Furthermore, the field of archaeology already has a considerable amount of projects involved with virtual reality (Renfrew, 1997; Gillings, 1999; Barceló et al., 2000; Ryan, 2001; Zhukovsky, 2001; Gillings, 2005; Bruno et al., 2010) and the next step in the mixed reality spectrum is augmented reality, a step that archaeology has already begun to take (Barceló, 2000; Vlahakis and Ioannidis, 2003; Vlahakis et al., 2003; Allen et al., 2004; Benko et al., 2004; Papagiannakis et al., 2005; Caarls et al., 2009; Noh et al., 2009; Wang et al., 2011; Garagnani and Manferdini, 2011; Niedermair and Ferschin, 2012; Jiménez Fernández-Palacios, 2015; Eve, 2014). However with the exception of Benko et al. (2004) and Eve (2014), the trend in these applications is in tourism or displaying old data in new ways, "There is a surprising lack of archaeological applications that use AR to do anything except present data to be consumed by visitors to sites or museums" (Eve, 2014, pg.32). This research will begin to fill the void in research stated by Huggett (2000), Lock and Brown (2000), Banning (2000), and Eve (2014) addressing the gap between field and lab data as well as addressing the effects of augmented reality on the field of archaeology. A more in-depth examination of these publications and projects will be in Chapter 2.

1.4 Aims and Objectives

1.4.1 Aims

Augmented reality has proven itself as a means for displaying existing information in new visually pleasing ways, which is discussed in greater detail in Chapter 2, but how does augmented reality stack up as a means of producing new information? Can we use AR technologies to enhance how archaeologists see datasets and models to influence new thoughts or interpretations of archaeological remains, data, and sites? With the introduction of AR as a tool can new procedures and standards of practice be developed in a way that produces more accurate interpretations of the past? In other words, could augmented reality provide archaeologists with new innovative ways to look at the past, and if so, how? According to investigations conducted by myself, which will be discussed in detail in Chapter 2, as well as investigations conducted by Stuart Eve, in 2014, where he states;

> It appears that, beyond VITA, which is constrained to the computer lab, no application has yet been produced that uses AR to expand our archaeological knowledge or use it as a tool for investigation and exploration of ideas and the production of new interpretations. Instead, previous AR applications have been solely for use for presentation or explanation of existing ideas, essentially a passive experience (Eve, 2014, pg.33)

The study of these questions has been ignored (Lock and Brown, 2000). To address this, I have constructed this project to investigate the effects augmented reality has on the field of maritime archaeology specifically how it can be used as a tool for interpretation. One of the key roles of the archaeologist is to reconstruct and understand past cultures. We do this through the systematic recovery and analysis of physical and environmental remains. Archaeologists use a variety of tools to accomplish this task most of these tools offer archaeologists a way to see each piece of the puzzle in its own light as well as with all the other pieces to see how they all fit together (i.e. an archaeological interpretation). For this thesis, the type of interpretation was that of the object, find, and site interpretation. To do this, I developed three research questions, each designed with a holistic view in mind. This is a stepping-stone to understanding further the full potential of AR as more than just means of presenting existing ideas.

The first aim of my research was to analyze the possible role of augmented reality technology in common maritime archaeological interpretation tools and techniques. To define this further, the common maritime instruments and techniques of interpretation that I used to investigate this were the boat plan. This was chosen based on multiple factors, including, size, scope, availability, and familiarity. These factors are discussed in greater detail in Chapter 3. The extent of this question encompasses the following questions:

- Can augmented reality improve the tools and techniques of interpretation?
- Does augmented reality complicate the tools and techniques of interpretation?
- Does the creation process of transferring the typical tool into an augmented tool, require a greater amount of effort than that of what is gained by the product?
- What effect could augmented reality have directly on the typical boat plan

The second aim of my research was to investigate the potential ramifications of augmented reality on not just the tools and techniques but in the field of maritime archaeology as well. Again, as with the first, to define this further, the scope of this was, looking into how the technology could be adopted by the field of maritime archaeology, its potential for changing theory, and how it could alter future research.

The final aim of this research was to investigate sustainability. Does augmented reality offer a sustainable solution to the issues present in traditional tools and techniques for maritime interpretation? In other words, is this going to provide a new method with many avenues for placement or is this an isolated solution for limited use? With keeping to structure, the scope of this will be looking at the life span of the technology as well as investigating the equation of ‘effort of creation ≤ knowledge gained.'

As mentioned at the start of this section the goal of this research was to investigate if augmented reality has a place within the field of maritime archaeology specifically if it can be used as a tool for interpretation and if so, how? The three research aims outlined above were designed with a holistic view in mind. That is, by investigating these three avenues we will gain a complete understanding as to how maritime archaeology will be effected by applying augmented reality as a tool for discovering new ideas and not just regurgitating existing ones in a new way.

1.4.2 Objectives

Before the first objective is addressed, there were key areas of study that needed to take place beforehand. This study was to gain a full working knowledge of essential concepts and technologies that were to be utilized within the research; such as a complete breakdown of how augmented reality works must be outlined. This study included not only components of the physical technologies, such as displays and processors, but also concepts of the non-physical as well, such as how users experience perception and dimensionality. From that point, investigations turned towards the current state of the field. This entailed outlining all current uses of augmented reality within the field of archaeology as well as other key related fields. This outline extended into relations of the field itself such as archaeology to anthropology or archaeology to history, and by the techniques used in the augmentation itself, such as similar uses of technological specifications (e.g., processors and algorithms), or the same user interface (e.g., handheld screens and mounted displays).

By re-examining the first research question, we can break it down into its individual parts. From here a series of objectives were developed to guide the research to a conclusive result. The first research question is to “analyze the potential role of augmented reality technology in common maritime archaeological interpretation tools and techniques,” broken down into its individual parts there are two key components, the word “role” and the words” common maritime interpretation tools and techniques.” The roles in this case refer to any actions that come as a result of this. Looking back at the scope outlined with this research question these actions becomes self-evident. The effects in this case are improving and/or complicating the process and are it even worth the effort. As for the common maritime interpretation tools and techniques, this would involve the tools mentioned previously as the boat plan, finds database, and the site map but also the skills and techniques developed by archaeologists through study and practice, for instance, knowing how to derive a cultures subsistence patterns from the analysis of their tools and middens.

To address each component of this research question objectives must be devised around them while keeping objectivity and scope parameters in mind. Since it would be an impossibility to study the role of augmented reality on each and every instance in which archaeologists must interpret something. A case study approach was used; this offered a holistic view of the area by only testing aspects of the whole. More information on this is discussed in Chapter 3. The first objective was to design a case study that offered a holistic approach to these tools of interpretation. The case study addresses ways in which augmented reality improve and complicate the tools used by archaeologists as a means of interpretation.

The second research question discussed in the Aims section is "What are the ramifications of augmented reality on maritime archaeological interpretation?" Again, breaking this research question down to its base components, we notice the key word of "ramifications." This denotes a more in-depth scrutiny of what happens when AR is implemented, the prospects of its continued use in the field. By investigating the ramifications or potential ramifications, we as developers and researchers can gear projects for success instead of the unknown.

To address this several integrated objectives were devised. Investigating how maritime archaeology was affected by the introduction and continued use of a technological advancement in the past was the first objective. Once this technology was selected, the research looked at how the technology was adapted. How long did it take for that technology to become common place (if it ever did)? Was the technology well received or strongly debated? Once these aspects of the technology were researched, the next objective was to investigate how theory and practice are altered by the technology, and how trends in future research projects evolved after the technologies introduction.

The third and final research question discussed in the Aims section above is "Does augmented reality provide a sustainable solution to the issues presented in tradition tools and techniques of interpretation?" These issues will be discussed later in this chapter. By breaking this research question down into its key components, we see that there are two major pieces. The first being "sustainable" and the second being "issues." In order to address these a series of objectives were developed working from the latter to the former. The first objective was to identify these key issues. Once these issues were clearly defined and established sustainability was addressed. The next objective was to investigate how augmented reality offers a solution to these matters without assuming a sustainable outcome. This has been studied through different avenues. The first was through the case study developed for the first research question. This gave a first-hand account of augmented reality within the maritime archaeology field. By addressing the concept of 'effort of creation ≤ knowledge gained' within the case study as well as other projects that use AR as a tool for primary data acquisition (which will be discussed in Chapter 2). Another key objective was to investigate other fields' usage of augmented reality in order to establish a lifespan of the technology as well as its usage, purpose, success, and evolution of the field since AR's introduction. This last objective was important because augmented reality has not existed in archaeology long enough to establish these aspects of itself yet, a topic that will be discussed in greater detail in Chapter 3.

The issues mentioned previously throughout this section will now be outlined and again addressed in further context in the case study chapter. The key issues being addressed by this research are the "what you see is what you get" nature of the boat plan, how the creator draws it is all that will be present for later uses. The next issue is the human element can be lost. This loss of human interactions and impacts on the archaeological site/object is one of the primary investigations done by Stuart Eve (2014) with his work on GIS and phenomenology and work conducted by Rennel (2012) on the goals of visibility study. Which leads into the next two issues that I will be addressing the first is the loss of spatial relationships and awareness. Archaeologists cannot, practically speaking, make recordings in 1:1 scales of all archaeological finds. It is because of this scaling that it is possible to lose the relationships between size and spatial awareness around the archaeological site, another point made by Eve's work with phenomenology (2014). The final issue that I would like to specifically address is the fact that archaeologist record 3D objects in a 2D medium to later be interpreted back into 3D. Specific cases of these issues and the evidence of their existence will be outlined in the Case Study chapter.

Most of the issue being presented here as well as the research questions that are the subject of this thesis involve archaeological interpretation. More specifically, how archaeologists interpret archaeological data to come to conclusions in their own research. It is important to clearly identify what interpretation is, what the aims of interpretation are, how interpretation is done, the limitations and challenges associated with interpretation and how all of that relates to this thesis and the research questions therein.

To interpret something is to figure out what that something means, however this is a subjective act. Interpretations can be based in hard science and backed with many well-formulated facts but that still doesn't change the fact that one scientist's interpretation of a set of data could be different from another's. Archaeological interpretations are organic, in the sense that archaeologists are not taught interpretation in a class room, at least to the extent of if this is found it means specifically this happened, but rather it is a skill that has evolved over a long course of experiences and interactions with site/data relationships. The interpretation of archaeological data is about exploration and making connections. This concept was best explained by Alexandri, "Interpretation involves a perceived gap between the known and the unknown, desire and a result, which is to be bridged somehow… Interpretation implies an extension or building from what there is here to something beyond" (2013, pg.26-27). To clearly define interpretation in terms of this thesis I am defining it as the process in which an archaeologist interacts with various data sets to draw forth conclusions and relationships.

Archaeological interpretation happens throughout the entire archaeological process, from initial site findings and field note insights to laboratory processing and finds analysis to report construction and final research interpretations of the site or subject (Childe, 2016). It is within this process where exploration and connection building come into play. If during an excavation a uniform series of dark soil forming a straight line is uncovered, the field archaeologist initial interpretation of that discovery could be that a house once stood here, and they discovered the post molds left behind from one of the walls. Further on in the archaeological process during the laboratory analysis of finds, the archaeologist could find that the soil samples from the post molds came from wood not indigenous to the area or used in the rest of the structures built around the site, this archaeologist would use the information gathered in the field notes as well as their own findings to interpret that this was not the site of a house. Each step of the archaeological process has its own bases on how interpretation is done. In the field interpretation is done based off what they see and when they see it. How each object is found and where it is found. During the find processing and lab analysis, interpretation is done differently. Once the finds are processed (cleaned, sorted, and catalogued) the lab interpretation would follow the numbers. How many of this artifact, what is the density of this object versus this object. Statistical analysis leads where interpretation can go. Where as in the field visual and spatial relationships lead where interpretation goes (Childe, 2016).

There are many methods of interpretation involved with archaeology, I would say an infinite number because of the subjective nature that is interpretation, and each archaeologist would have developed their own method for interpreting archaeological data. Because of this, combined with the subjective nature of interpretation there are certain levels of uncertainty. Interpretation has archaeologists attempting to fill gaps between what we already know and what we do not. This uncertainty is present at the beginning of the interpretation process and at the end. No matter the basis of your interpretation there could always be another, equally valid interpretation of the same archaeological data set (Alexandri, 2013). For example, an archaeologist may be examining a ground stone axe. They would examine it as a whole and part-by-part picking out diagnostic traits (size, type of stone, manufacturing marks) and this would lead to an identification of sorts of the ground stone axe. This examination of traits leads them to select the ground stone axe's identity from various other options. This process involves drawing meaning and possibilities from this gap of unknown information or uncertainty and turn it into the known.

"Archaeological interpretation requires that some things be connected with others in order to make sense of what remains of the past. Circular features in earth of contrasting colour are associated with removed wooden stakes, and then in turn associated with other post-holes to trace the structural members of a building. To interpret is in this way a creative act. Putting things together and so creating sense, meaning or knowledge" (Alexandri, 2013 pg.37).

This creative and subjective process is also its biggest challenge and limitation, because everyone has the potential to interpret observations in their own way and different conclusions from this each proposed interpretation could be debated another way.

Other limiting factors involved with interpretation are lack of physical evidence or archaeological data to bridge certain gaps. Simply not having enough data to back a claim is enough to shut down an interpretation made too soon. However, on the other end of this spectrum is what happens when an interpretation is accepted and no longer contested. In the 2013 book Interpreting Archaeology: Finding meaning in the past the term black boxed is used, "When an interpretation or set of interpretations is accepted, treated as un-controversial and no longer even seen for what it is, the term black-boxed can be used. Interpretation is made, accepted and then put away, out of sight and often out of mind, in a black box" (Alexandri 2013, pg.30). Having a single interpretation that you hold on to unwavering can cause later interpretations and understandings built upon it fall apart. An example is you know an object square in shape with sides is a box, if you hold onto that and refuse to re-examine that particular interpretation you could find yourself browsing the Internet on your box instead of a computer monitor.

Generally speaking, all archaeological work can be seen as interpretive. Past cultures have existed in an area, lived their course of life, and then ceased to exist. The people are gone but the stuff remains and decays in the ground. An archaeologist uncovers these remains and works towards making something of them. In essence the excavation process is discovery of the unknown and the archaeological processing of the remains found turns the unknown into the known. "The archaeological 'record' is, concomitantly, not a record at all, not given, 'data', but made. 'The past' is gone and lost, and a fortiori, through the equivocality of things and the character of society as constituted through meaning, never existed as a definitive entity 'the present' anyway" (Alexandri 2013, pg. 38).

The purpose of this research is to investigate how augmented reality effects interpretation. Having established the subjective nature of interpretation and touched on how interpretation is used throughout the archaeological process we can see that the interpretation of archaeological data is a key aspect to archaeological research. By looking at this key aspect we can begin to draw conclusion on the effects AR will have on archaeology.

The research questions of this thesis are as follows; Can AR improve the tools and techniques of interpretation, Can AR complicate the tools and techniques of interpretation, does the creation process of transferring the typical tool into an AR tool, require a greater amount of effort than that of what is gained by the product, and finally what effect could AR have directly on the typical boat plan? Most of these research questions directly are influenced by interpretation or influence how archaeologists interpret data. So, by looking at how the individual archaeologist interacts with standard tools of the trade and how they interact with the tools augmented counterparts could lead to powerful insights into how augmented reality could affect the discipline and the individual archaeologist.

By observing how the individual interacts with archaeological data both in the un-augmented and augmented form we can see how AR improves/complicates the interpretation process. Lending insights into answering the first two research questions. The outcomes of how the interpretation of augmented data versus un-augmented data as well as how the individual interacts with the data sets will indicate whether the effort put into the creation of augmented data is worth the extra information received form the immersion of AR, thus answering the third research question. Similar could be said about the final research question, looking at how the individual utilizes an un-augmented versus an augmented boat plan we can learn about the ramifications of using AR on the typical boat plan.

Which brings us to the question of audience. The augmented tools would have different outcomes and in turn, different interpretations derived from them if given to different audiences. The general public given these tools would develop a different story about archaeological data than that of an archaeologist given the same tools. It is the purpose of this research to investigate if and how augmented reality could affect archaeological interpretation. For this the target audience of these investigations would be not the general public but rather archaeologists. That is why the objectives outlined in this chapter indicate using typical tools and techniques used by archaeologists to interpret archaeological data to aid in bridging the gap between field data and lab data.

To summarize, the objectives that were created to guide the research conducted in the chapters to follow are; first, design the methodology of the research in this instance a case study and comparative analysis methods will be designed and implemented. The next objective was to see how the field of maritime archaeology has adopted new advances in technology in the past to draw conclusions on how it will be received in the future. From here the research identified sustainability of the technology by looking at how the issues addressed in the case study was affected by augmented reality. Through these research objectives, the three research aims discussed previously will be addressed.

1.5 Concluding Remarks

In addition to addressing my specific research goal of investigating the role augmented reality has on common maritime interpretation tools and techniques, investigating the potential ramifications of augmented reality on not just the tools and techniques but in the field of maritime archaeology as well, and investigating whether or not augmented reality offers a sustainable solution to the issues present in traditional tools and techniques for maritime interpretation, the ultimate goal of this research is to provide a stepping stone, an origin point to branch out and study the effects of augmented reality and to begin to utilize AR as primary tool for archaeological data acquisition and not just as how Eve puts it as a “use for presentation or explanation of existing ideas” ”(Eve, 2014, pg.33).

Chapter 2: Mixed Reality Theoretical framework

2.1 Mixed Reality Theory

Mixed reality is exactly what it sounds like it is the various forms of reality that exist between the one end of the spectrum, the physical world, and the other end of the spectrum, the virtual world. The left end of the mixed reality spectrum is the physical world, this consists of both physical objects and the physical environment. Moving to the right of the mixed reality spectrum is where we find Augmented Reality. Augmented reality is the blending of virtual objects into a physical environment. Moving even further to the right is augmented virtuality; this consists of a virtual environment being augmented by physical objects. Finally, to the far-right end of the spectrum is the virtual world. This consists of virtual objects and a virtual environment.

Various popular media popularized the idea of cyberspace and the Metaverse in the 1990's. In 1992 Neal Stephenson published his novel Snow Crash (Stephenson, 1992). Snow Crash depicted life in the "Metaverse" where Hiro, pizza delivery guy for the Mafia, and Y.T., skateboard courier, can alter information using computational algorithms and general computer hacking methods but in their physical world, to exploit that same world around them. Within the Metaverse, one could interact with the physical world in the same manner as one could with a computer program. This first description of the Metaverse sparked the creation of the Acceleration Studies Foundation. The ASF has since then created a roadmap (figure 2.1) of the Metaverse to help plot current technologies on to relate the progression of current technologies to the Metaverse. Put simply; the Metaverse is a collective environment made up of all the virtual realities, augmented realities and the internet that is interactive to users in the same way the physical world is, and the roadmap in figure 2.1 is used to track technological progress to that point.

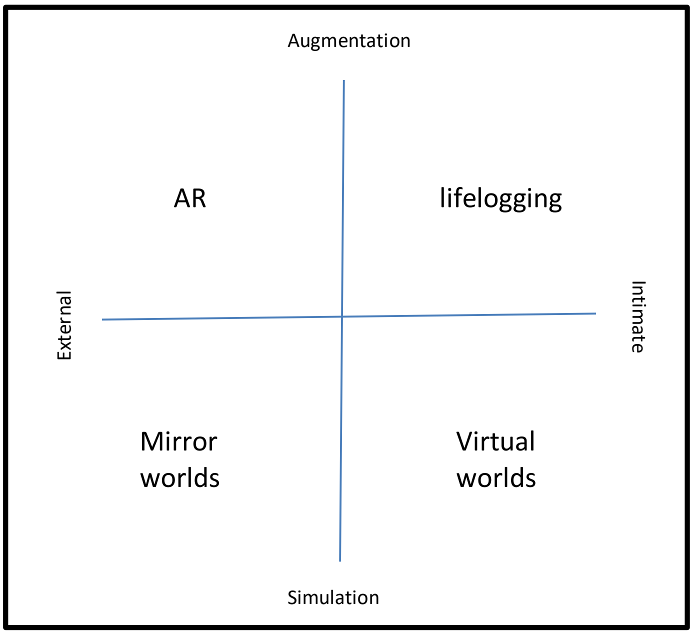


Figure 2.1 Metaverse Roadmap. After Craig 2013.

The other concept of cyberspace was popularized by various forms of pop culture; from the movie TRON (1982) and the animated movie Ghost in the Shell (1995) to the novel that originated the word cyberspace Neuromancer (Gibson, 1985). Each of these examples depicted the main characters able to take their physical form into the virtual world. Once in the virtual world, they could interact with data and various virtual technologies in a way that was the same as digital programs interacting with virtual interfaces. Looking at the Metaverse roadmap in figure 2.1 we can see that cyberspace or virtual worlds would fall somewhere between the intimate and simulation axis. If we examine some of the work written by Donna Haraway, a feminist theorist on cyberspace and its role, we can begin to get a better picture of what it is.

> I like to corral all kinds of things together in cyberspace; not just computers and software, but also digital devices such as MP3 players, or BlackBerrys, or new medical imaging technologies, cyberpets, digital animations and simulations of all kinds – and so the list goes on. All these things and much more besides are connected, in some way or another. They are part of the same kin group…. However, cyberspace also exists in the imagination, in fiction, in the stories we tell ourselves about this world. (Bell, 2007 pg.1-2)

What she is describing here is the interconnectivity that has sprung up in various technological devices, their ability to sync with each other to share information across this invisible terrain. It is from here where she goes on to describe that the task of defining cyberspace has been fallen to countless minds, and yet, the task has been stretched even further by "arguing about competing definitions and about the usefulness of the term" (Bell, 2007 pg.2). This point is illustrated further by Michael Benedikt's book Cyberspace: First steps (1992). The first few pages are filled with different explanations and definitions of cyberspace. These range from the philosophical "Cyberspace: The tablet become a page become a screen become a world, a virtual world. Everywhere and nowhere, a place where nothing is forgotten and yet everything changes"

(Benedikt, 1992 pg.1); to the technical "Cyberspace: Accessed through any computer linked into the system; a place, one place, limitless; entered equally from a basement in Vancouver, a boat in Portau-Prince, a cab in New York, a garage in Texas City, an apartment in Rome, an office in Hong Kong, a bar in Kyoto, a cafe in Kinshasa, a laboratory on the Moon" (Benedikt, 1992 pg.1). The point is that regardless of the definition or point of view on cyberspace they all have a single element in common, interconnectivity. It is this ability to have multiple forms of data all linked together and available at your physical fingertips that make up the essence of cyberspace, and it is the melding of the Metaverse and cyberspace where we find augmented reality. We see elements present in both the Metaverse and cyberspace interactions that can only be possible, with the current state of technology, today.

2.2 Defining Characteristics of Augmented Reality

There are three characteristics that define augmented reality. The first is that it combines the physical world and the virtual world. When experiencing a reality that has been augmented, you should experience the physical world in the same manner that you normally would: see, hear, smell, taste, touch should remain the same as if it were not augmented. The only difference should be a seamless superimposition of the digital information (Craig, 2013, pg.16-17). There are two basic methods to do this. The first method is the most common of the two and involves several processes to gather the information that is to be digitized, then generate the objects and information in the computer, and then there is a melding of the digital information and the physical world together in a computer to be displayed. The second method involves the first method, but instead of a screen display, it involves a type of projection straight onto the physical world using actual projectors that react in real time to input (Craig, 2013, pg.17; Kreylos, 2016).

The second characteristic is that the digital information can be registered in a three-dimensional coordinate system. In the physical world, if there is a teapot on the kitchen table it will remain in the same place regardless of where the viewer is standing. If the viewer moves to the other side of the teapot, you see the other side of the teapot. The same must be true for a digital teapot.

The final characteristic is that this physical and virtual world combination is interactive with the user in real time. The augmented reality experience must be interactive, in the sense that the user can sense the information, by whatever means (sight, touch, hearing), and make alterations or interactions to that information. This falls into the realm of registration. This type of temporal registration can be difficult to achieve for a number of reasons, the prominent being the time it takes for the digital information to be processed then displayed. Increased processing time creates a lag between the users' actions and the augmented objects and displays response to those actions. For example, since the view of the previous examples teapot depends on the location of the viewer's position, the teapot must be re-rendered each time the user changes location no matter how minuscule that change may be.

2.3 The Mechanics of Augmented Reality

In this section we will be examining the mechanics of AR, which includes what the AR experience is, the processes involved with AR, and the components needed to bring it all together. First and foremost is the AR experience, which is discussed in full detail at the end of this section, but worth mentioning briefly here. This is the most important concept of augmented reality. As mentioned previously, music is heard, art is viewed, and augmented reality is experienced. The point of AR is the interaction between the user, the physical, and the digital. The AR experience relies on this three-way interaction to be successful. In order to understand how the AR experience is created and ultimately how it relates to this research, a base knowledge of the mechanics of augmented reality is required. The next important distinction that must be made, and this cannot be stressed enough, is the difference between augmented reality and virtual reality. VR takes place entirely in a virtual environment; there are zero physical world overlays, whereas AR takes place in the physical world and has virtual elements overlaid into the environment. Understanding that the digital is being integrated into the physical world in a way that has users interacting with it as if it were physical, as discussed in the previous section *Defining Characteristics of Augmented Reality,* is a concept that is the foundation of the AR experience and is one of the main focuses of the case study conducted as part of this research. By looking at the AR experience, via a case study approach, three of my four research questions can (in part) be addressed. Can AR improve the tools and techniques of interpretation?; Can AR complicate the tools and techniques of interpretation?; and what effect could augmented reality have directly on the typical boat plan? Each question is directly affected by the AR experience. Which makes understanding the processes and components involved in making augmented reality programs important and essential to understanding the research conducted in the case study.

There are two major processes taking place (see table 2.1) within an augmented reality application; the first process (green) is composed of two steps. First, the application needs to establish the conditions of the real world or the physical plane. The second step of the first process is like that of the first, but instead of checking the conditions of the physical world it is checking the state of the virtual world. The second process (purple) is composed of multiple steps that ensure that the application displays the previously checked state of the virtual world is displayed, with correct registration, in the physical world. The key function of this process is to ensure that the virtual world is displayed in a way that the senses of the user make them believe that the virtual world elements are in the physical world (Craig, 2013, pg.39).

In order to do this, there are three major components involved to support these processes. The three components are sensors, processors, and displays. Each will be discussed in detail later in the chapter. Sensors are used to scan and take in information about the conditions of the physical world where the application is going to be implemented. A processor is needed to assess and compile the data collected by the sensors. This is done to ensure that the laws of nature and physics or any other rules dictated in the virtual world can be issued to generate the signals required for the next component the display. The display is responsible for creating a world that imposes the crafted virtual world onto the physical world in a way that makes the user's senses believe that the two exist in such a manner that the user’s senses are not rejecting the union of the physical and virtual worlds. In other words, the combining of the two worlds must be comprehensible to the user's senses (Caudell and Mizell, 1992; Craig, 2013, pg.40).

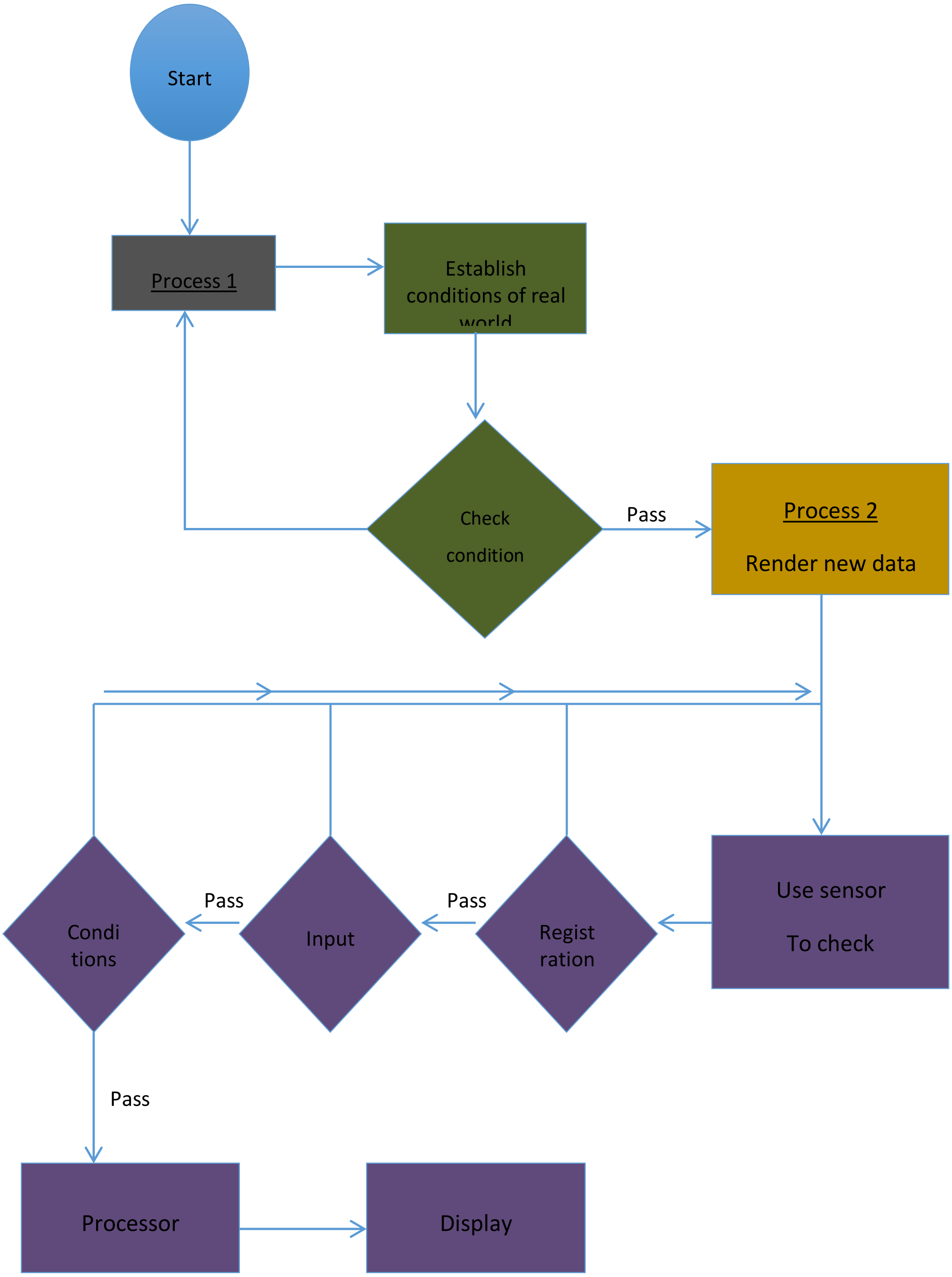


Table 2.1 Workflow of AR processes.

2.3.1 Components

2.3.1.1 Sensors

In order for the augmented reality application to respond in a fashion that is both correct and with the proper registration to the physical world, it needs to implement a variety of sensors. There are three primary categories of sensors; sensors used for tracking, gathering environmental information, gathering user input. All are needed for a successful AR application, but they do not have to be multifaceted high-end sensors, they can be as simple as a joystick.

2.3.1.2 Tracking sensors

A major aspect of augmented reality applications is the spatial registration. This aspect must be “on track” or, aligned with the user's input to match the visual output, so the utilization of sensors to track the movement of the user is essential. The sensor must be able to track the movement of the AR device as well as the user and the physical world around the user. It is important to note that this movement tracking is to include the location and orientation in a three-dimensional plane (Figure 2.2). (Bimber,and Raskar, 2005; Craig, 2013, pg.40).

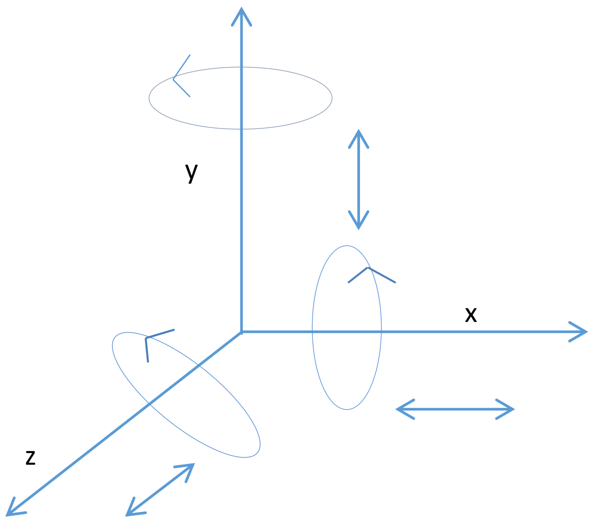


Figure 2.2 XYZ coordinate plane. Camera vision.

A common and most often the primary way this is achieved is through a camera utilizing computer vision. “Many current augmented reality applications use techniques from computer vision to determine the participant’s location and perspective with respect to the real world” (Bimber,and Raskar, 2005; Craig, 2013, pg.41). Something to keep in mind with computer vision is that the position determined can be either absolute or relative. For example, a Tumi or Incan sacrificial ceremonial axe is being rendered on an altar. This can have an absolute position in space or a relative position on the altar. Meaning that if the Tumi has an absolute position then moving the altar would have no impact on the Tumi, whereas if the Tumi had a relative position associated with the altar if the alter the Tumi moves with it. (Figure 2.3).

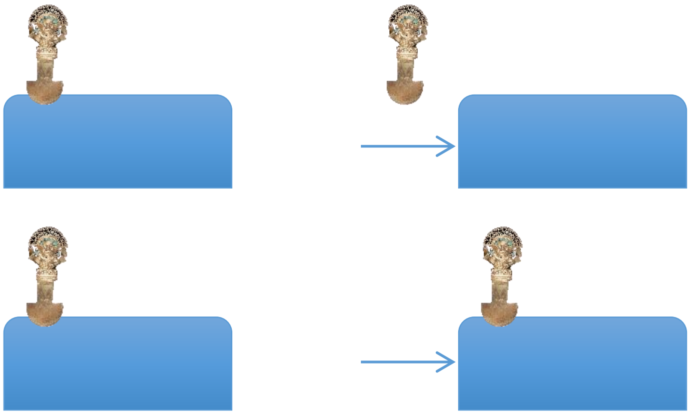


Figure 2.3 Above: Absolute positioning. Below: Relative positioning.

In order for computer vision to work, there are a few requirements; one is the presence of a sensor (in this case a camera), and the other is software to process the images. The camera records a 2-D projection of the surrounding physical world. What and how the camera is viewing can determine the camera's location and orientation in relation to the recorded scene; this is done by using software to analyze the recorded images to determine what the camera has 'seen.' From this information, the software can calculate the exact position and orientation of the camera in order to have produced such a picture, where the data was derived from. Targets are needed to aid in this process. With a view to helping rectify the positioning problem inherent with computer vision, many augmented reality applications use some form of targets or markings that have been placed into the physical landscape that the computer application can clearly recognize (Lo´pez de Ipin˜a, Mendonça and Hopper, 2002). The Nintendo Company for their 3DS handheld gaming system created an example of this. It utilizes dual cameras mounted on the back of the device (Nintendo 3DS, 2011) to read specific AR cards that activate different games and functions. Images used specifically for this purpose are called fiducial markers or fiducial symbols and commonly resemble the object in figure 2.4.

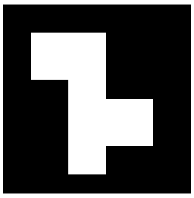


Figure 2.4 Fiducial marker

Traditionally the fiducial marker was used to communicate two types of information to the augmented reality system. One was to define what object was to be digitally displayed and the second was that object's position and orientation (Kato and Billinghurst, 1999). That being said, the fiducial marker is not limited to just this type of information. Take the before mentioned object: instead of having that object stored locally, the fiducial marker could have a web address linked to it rather than a saved file. Or moreover, that same fiducial marker that is linked to the web address could have conditional algorithms attached to it to call different objects based on certain conditions (MacIntyre et al., 2011). In other words, the augmented reality system when scanning the fiducial marker could run a series of queries to the server system and depending on the outcome produce a different object that was dependent upon the current state of being at the fiducial marker. For example, the London Tube (2013) application is used to show the most efficient routes through London but what it displays is dependent on the underground schedules and delays, thus depending on certain factors and conditions what is displayed may be out of the norm.

There is a special type of fiducial marker that is being used to increase the amount of data that can be embedded within a single marker, and that is the quick response or QR code (figure 2.5) (Kan, Teng, and Chou, 2009). The QR code is not in itself a fiducial marker, but rather they have been used as them; similar to the sense that every square is a rectangle but not every rectangle is a square.

Figure 2.5 Quick response code (QR Code).
Image courtesy of www.qrstuff.com.

It is also possible to use actual physical three-dimensional objects as fiducial markers within an AR application instead of just the standard black and white image depicted in figure 2.4. Both natural and artificial structures can be made into fiducial markers, as long as they meet the same criteria as the standard marker. They must be asymmetrical across a vertical and horizontal axis, meaning you must be able to tell if the object is upside-down or not, it cannot look the same no matter the orientation (Yuan, Ong, and Nee, 2006). A common example for this is the human face; it has been used in numerous AR applications primarily as marketing new products such as hats, glasses, and clothing, however, it has also been used in museums and for fun such as the Ray Ban Virtual Mirror (2009). The use of natural and artificial structures as a means of visual tracking versus using the traditional fiducial marker seen in figure 2.4 is becoming the industry standard, based on the increase of applications that are not dependent on them to function. Natural feature tracking has had a significant amount of effort put into the research and development of it, and as a result, NFT can be a useful solution to many tracking issues beyond just what was described here (Yuan, Ong, and Nee, 2006).

2.3.1.3 GPS

In terms of fine-tuning, the position of the augmented reality system the global position satellite lacks the capabilities to determine orientation in terms of the pitch, roll, and yaw. That being said the GPS system does offer other benefits. It can be used to tell the AR system approximately where it is on Earth and by using this information, going back to the natural feature tracking, know what natural markers to scan for if the system is using computer vision. For example, there are limitless archaeological sites around the world, and to have the fiducial markers for each one stored locally is not feasible. To have the system first check the GPS location and load the appropriate fiducial markers is a better option. By doing this, they AR system can significantly reduce the amount of searching and sorting it must do to apply the correct NFT features. That being said GPS is not appropriate to be the only sensor for determining the point of view or POV (Djuknic and Richton, 2001; Craig, 2013). How this GPS systems work is the device, a smartphone, for example, links to a network of satellites that then can send a signal between itself (Sat A) and the smartphone, another satellite (Sat B) or even available cell towers, since this example uses a smartphone. By communicating between Sat A, the Device, Sat B and, sat C, the position can be calculated using trigonometry algorithms to a certain degree of accuracy, but not to the accuracy of archaeological precision (Physics.org, 2016).

2.3.1.4 Beacons and near field communication

Traditionally, beacons were large signal fires that had a singular meaning, so that when lit all that could see the fire would immediately be conveyed its message. A classic example of this would be in J.R.R. Tolkien's novel The Lord of The Rings when Gondor calls for aid by lighting the beacons between the borders of Gondor and Rohan. Their specific purpose was to alert one another when military aid was required (Tolkien, 1967). The modern beacon serves the same purpose but without the need for a mountain and fire. A beacon sends a small data packet that can be picked up by anyone within its vicinity. This data can be navigational data, emergency alerts, and even retail advertisements and discounts (Future of Privacy Forum, 2016).

A beacon can take the form of a small inconspicuous device that transmits data through radio frequency or WiFi (figure 2.6) or even the rotating lights on the top of emergency vehicles. In the case of augmented reality, a beacon can be used to transmit a model or URL of a model to a handheld device that can then implement the augmentation process.

Near field communication (NFC) is a similar technology in the sense that it sends data within proximity, but it differs greatly in the fact that it can receive and act on the data as well. Where beacons are a one-way transmission NFC is a two-way transmission. NFC is a derivative of radio frequency identification technology meaning that proximity is key (Faulkner, 2016). NFC devices are widely used in marketing as a quick and easy means to conduct funds transactions. For example, an iOS application by the name of Apple Pay. This application allows the user to transmit funds from their bank account to retailers by simply touching their phones to card machines (Apple Pay, 2014).

Figure 2.6 Various beacons. Image courtesy of Future of Privacy Forum,

2.3.1.5 Data and input sensors

There is an immense number of sensors that can be used with an AR system. Essentially the role of the sensor is to gather data, whether it is physics (e.g. direction and heading), environmental (e.g. temperature and wind speed), or user input (e.g. commands and actions). Once that data is collected, it is then transmitted to the AR system to be processed and applied to the display. Some of the more common sensors used for gathering physical information are gyroscopes, compasses, and accelerometers. All do similar functions, finding direction, but they all find different information about the direction. Unlike the GPS, gyroscopes do determine the pitch, roll, and yaw; however, they do not determine location or direction or speed. Compasses do not determine pitch, roll, and yaw or speed, but they do determine direction. The final piece of information can be determined by accelerometers, which does exactly what the name suggests it determines acceleration or speed, but not pitch, roll, and yaw, or direction. It is important to note that it is possible to determine direction from an accelerometer, but it by itself in terms of navigation is risky. Accelerometers work by measuring changes; in the simplest terms they take the previous state and subtract the current state. So inherently if there is an error, it gets compounded over time. So using an accelerometer alone as a direction-finding device is not advised (Bimber,and Raskar, 2005; Craig, 2013).

Environmental information that can be gathered for AR systems is almost limitless. There are sensors that measure everything from temperature to radio frequencies. A short list provided by Craig (2013), include; temperature sensors, humidity sensors, sensors to overlay atmospheric information, pH, voltage, and radio frequency information.

User input can be tracked in numerous ways. We use the devices every day in very mundane ways; we are just not thinking of them as an AR system input sensor. Common user input sensors include buttons, keyboards, and touchscreen devices. Tablets and smartphones all have sensors in place to act as buttons for the user to interface with to make decisions on how the programs should run. AR systems could easily be programmed to utilize these sensors to control 'user choices' within the augmented reality experience.

Buttons and touchscreens are not the only user input sensor available to use. Cameras that are tuned to track the user's movements and gestures can be used as an input sensor, a common example of this outside of AR systems that most are familiar with is the Xbox Kinect. Certain movements and gestures can be assigned to do certain things within the application. For example, while on site, the swiping for your arm could upload the next set of digital field notes or images. The camera is not just limited to making movements and gestures mean certain commands, but it can be used to create 'virtual buttons.' This is a cross between the technology that you see on a smartphone that produces a keyboard on the screen when you need to insert text, and the Kinect (2010) tracking your movements and gestures. What happens is a virtual button is created and inserted into the display where then the camera tracks your movements in order to determine which (if any) button is 'pressed.' Using this process anything in the physical world could be a 'virtual button' (Craig, 2013, pg.50-51).

The use of gesture control to select and or activate various application features is a common practice in virtual reality, and the same can be said for various archaeological and heritage-based AR applications. The VITA project (Benko et al., 2004), which is discussed in detail further into the reading, is such an example. It uses gloves and tracking software to allow the user to use gestures as a form of software control as well as navigation. In the broadest sense of the term all augmented reality programs use gestures and movement as a type of user input device, your bodies movement with the device or camera is being communicated with the applications processor to be interpreted and responded to.

2.3.1.6 Processor and computer

One of the most important components of the AR system is the processor. The processor is in charge of coordinating and analyzing all of the data collected by the sensors. The processor is also responsible for storing and retrieving data and carrying out tasks that are dictated by the user or by the AR program itself, and finally, it is responsible for creating and sending the proper signals to be displayed.

Something that all augmented reality systems have in some form or another is a computer. This computer can range in size from a small handheld smartphone to massive workstation computers (Bajura and Neumann, 1995; Craig, 2013, pg.51). It may even be a necessity to utilize both ends of the spectrum in computer size, especially in archaeology. It would be quite impossible to have a large workstation computer taken out to remote archaeological sites, but to have a small handheld device that is transmitting and receiving to and from a larger computer off site is a much more likely possibility.

The most important capability of the processor to be able to perform is to maintain a sufficient frame rate, around 150 frames per second (fps). Anything higher than that and the human eye cannot pick it up, but anything less than that can be visually seen as lag (Read and Meyer, 2000). The computational capabilities of the processor must be strong enough to this in real time. The ability to maintain a sufficient fps is key to the quality of the AR experience. The sufficient fps will change depending upon what object is being seen. The bare minimum, according to Craig (2013), is 15fps. However, this number is significantly increased if the object being viewed is meant to be a solid.

Something that is not in the forethought of needing to be rendered sufficiently, mainly due to its nature, is the physical world itself. The physical world needs to be rendered in real time just as the virtual world. The two entities need to coexist in a manner that they move simultaneously with the renderings caused by the movements of the user. “In cases where the physical world is mediated by the computer, the displays can be synchronized, but in cases where the physical world is perceived directly, any lag in the creation and display of the virtual components becomes obvious” (Craig, 2013, pg.52).

2.3.1.7 Display

When we think of the word “display” the immediate thought that comes to mind is a computer screen and the sort, however, with augmented reality, a display can refer to numerous other devices. The computer screen, in this case, would be a visual display; there are also audio displays such as speakers and headphones. For each of the senses, there is an appropriate display including olfactory displays and haptics displays used to feel some objects physically. Something to note with the terminology of display is that in augmented reality systems, as well in other areas of visual technologies, the word display can refer to the physical device that is being used to convey to the senses (the screen), or it can refer to the actual 'signal' that is being sent (the rendering). For example, if you are using a heads-up display (HUD) to look at the skull found in another country, the HUD is the display but so is the skull.

There are numerous types of displays, and they are usually grouped by what they do, meaning which of the senses they are designed to stimulate. We are familiar with visual, and auditory displays as most of us use them on a daily basis in the form of computers and headphones. However, there are also categories of displays used to stimulate olfactory senses, haptics or touch, and even displays that stimulate gustation.

Another common method of grouping displays is whether or not they are attached to the user or not. This is also often done as a sub-group under the first method of what they stimulate. For example, going back to the computer screen and HUD. The standard computer screen is not attached to the user, however, using a head mounted screen to produce a HUD such as Google Glass (2013) would be considered an attached display or something we are all familiar with the smartphone; this is considered an attached display since the user must hold the device in hand to use.

2.3.2 Themes and concepts of augmented reality

Now that we have discussed the physical components that are used in augmented reality systems there are more 'theoretical' or themes of concepts that must be discussed in order to convey properly how augmented reality works with the physical and the virtual to fool the brain into thinking they are coexisting, such as computer graphics, dimensionality, depth cues and with that visual depth cues, monoscopic image depth, and stereoscopic image depth, as well as motion, physiological depth cues, and auditory depth cues. Then we must discuss in depth registration and latency, which we brushed over previously.

2.3.2.1 Computer generated graphics

The primary use in archaeological augmented reality systems is computer graphics more commonly called CG in the film industry, to superimpose three-dimensional models created in a virtual environment into the physical world. This is also the primary form of augmentation that is done in AR systems, so it is important to gain a solid understanding of where these CG images come from.

According to Craig (2013, pg.54), graphical objects such as CG images are simply visually expressed mathematical algorithms. Simply put, there is a matrix of numbers or set of mathematical expressions that describe the object that was designed by the graphic designer so that the processor can determine what signals need to be sent to the visual display to produce the same object that was originally designed. In an augmented reality system, the CG object is typically a 3D object that must be rendered in relation to a specific location in the physical world with a predetermined POV based on the user's specific location in that physical world then there must be appropriate textures, lighting, and material properties applied to ensure a believable object has been created.

In order to do this, the field of computer graphics has developed numerous methods and techniques to produce these 3D models and the AR system's designer to produce the necessary 3D objects can use most of the methods. The most widely used method to create a 3D object is to use meshes. A mesh is a series of connected points in a three-dimensional plane to form a series of polygons. These polygons describe the surface of the 3D object. The mesh can be created using many different techniques. The two most common ways to create a mesh I will discuss, but it is important to note that these are not the only ways. The first has the potential to be very tedious. It involves the creation of the mesh cloud by plotting the individual points in three-dimensional space. This process can be very time-consuming but may also be the only option for very complex objects. There is computer software that allows the objects boundaries to be plotted and then the rest 'filled' in with the polygon mesh, such as 3DS Max or AutoCAD. For instance, if the desired object was an amphora and the designer knew the shape of the profile of the amphora they could use a tool within each of the before mentioned programs to draw the profile shape then 'rotate' around a predetermined axis to create the mesh. The other method to create a mesh of a three-dimensional object involves scanning the object. This method is the most common for 'digitizing' real world objects to be put into the virtual environment. The object(s) or landscape can be scanned using various methods such as laser scanning or the more cost-efficient technique of photogrammetry. The scan of the object must be pieced together within a virtual environment than a mesh of the final form can be created. If the object being scanned is large, the use of targets might be needed to help 'stitch' the various scans together into a single file. From here the waste plots or, plotted points in the point cloud that are not needed for the creation of the object such as plots on the background are removed leaving behind only points of the object. Then using computer software and predetermined distance thresholds the point cloud is connected to produce a mesh.

Once the mesh has been created the process does not end, the creation of a surface must be done and applied to the mesh. This process can be thought of as wrapping a brown box in wrapping paper. The brown box is boring and has no properties it is just a shape. Using the wrapping paper (surface) to cover the brown box (mesh) you give the box texture and properties and it comes to life as a beautiful present. As with wrapping paper, surfaces have properties, such as color, reflective characteristics, and texture. Each of these properties helps increase the realism of the mesh object.

There is also a technique called texture mapping that is commonly used when creating AR applications. Essentially the use of a 2D graphical image creates the surface of an object. The graphical designer can take a 2D image whether it was created digitally, or a photograph taken of a physical object, and then apply this image directly to the polygon mesh. This has some drawbacks. This has the potential to cause mosaic patterns or tiling in the object if the image is repeated over an area. It can also cause blending problems with other objects not created using this method, however, with this method, there are some benefits. It gives the opportunity for photo-realistic objects to be created while at the same time reducing a number of polygons needed within the mesh. This reduction in polygon quantity will help with the processing speed of the object aiding in increasing the FPS of the scene (Figure 2.7).

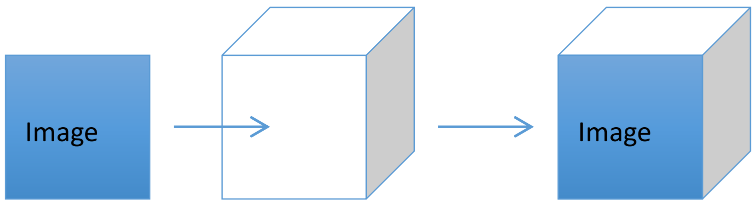


Figure 2.7 Texture mapping.

2.3.2.2 Dimensionality

The physical world exists in three dimensions. There are an x-axis, a y-axis, and a z-axis. However, when dealing with the AR system's world it can exist in two dimensions, three dimensions or more, and this can be hard to visualize and conceptualize, being how humans are part of the third dimension.

To explain this, we must first look at displaying an object that exists in one set of dimensions, in or on a display that exists in another set of dimensions. For example, the human world exists in three dimensions. If we were to examine a television on depicting a live-action drama, we would know and perceive that program in three dimensions. That is the actors and set exist in an x, y, and z-axis, despite the fact that a television's display is two-dimensional. Humans can perceive three dimensions within a two-dimensional space. Humans can do this by detecting depth cues, which will be discussed later in this section. Inside each of our eyes rests a retina that has two dimensions that it uses to perceive the three-dimensional world around us (Heeter 1992; Craig, 2013, pg.57).

If we were to examine films that are labeled as '3D' movies one would expect to see the three dimensions of the film displayed on a three-dimensional space this is not true. This type of visual trickery is not a true three-dimensional space but rather a 2.5-dimensional space, due to the fact that the imagery that is displayed does not have a true z-axis; this is done by exploiting certain depth cues that our eyes have been trained to pick up on to judge things such as distance and depth of objects. Stereopsis is used to do this, which will be discussed in the following section.

2.3.2.3 Depth cues

As mentioned previously the eyes pick up on various depth cues to help indicate to the brain the concept of distance and depth between various objects within view. Depth cues come in many different forms, and because of that, they are grouped by how they work the relationship between what is being viewed and your brain.

2.3.2.4 Visual cues

Visual depth cues are cues that our eyes and brain pick up on to visually judge distance and depth. Painters have used these cues to trick their audiences into 'seeing' depth within their two-dimensional pieces ever since the first painting depicting perspective was painted in the late 1200's to early 1300's.

> "The Italian masters Giotto (c. 1267 – 1337) and Duccio (c. 1255-1260 – c. 1318-1319) began to explore the idea of depth and volume in their art and can be credited with introducing an early form of perspective, using shadowing to great effect to create an illusion of depth, but it was still far from the kind of perspective we are used to seeing in art today" (Op-art.co.uk, 2016).

These are small subtle cues like making recognizably large objects small to show that they are a distance away like a large oak tree painted small in the background. There is also the use of shadows and shading to show depth as well as blurring the background and crisping the foreground to show a point of focus or POF. Much of the CG editing software available today has these features built in. The artist is able to create whatever object(s) they are creating and place it within a three-dimensional plane inside of the virtual workspace and the software while converting the 3D space to a 2D image will auto-overlay these visual cues based on algorithms relating to the natural world's laws and physics (Craig, 2013). There are multiple sub-categories of visual depth cues; there are monoscopic and stereoscopic image depth, motion cues, and physiological cues.

2.3.2.5 Monoscopic and Stereoscopic image depth cues

There are visual cues that rely on the fact that humans inherently have two eyes that are in two separate locations and then there are some that only require a single eye; these are called monoscopic image depth cues. A brief list of monoscopic image depth cues includes; atmospheric effects, brightness, height in the visual field, interposition, linear perspective, shading, size, and surface texture gradient.

In the sense that monoscopic deals with a single eye, stereoscopic image depth cues rely on having both eyes to pick up on cues for visual effect. Stereopsis relies on the fact that human eyes are located a distance apart, so they see the world from two slightly different angles. This difference in angle allows our brains to analyze the separate images and piece them together using other cues to formulate different distances for different objects within the total scene. This effect is much more prominent the close up than it is further away, and at a certain distance, it becomes non-existent (Craig, 2013; Sollenberger and Milgram, 1991). Certain 3D movies take advantage of this effect. There are layered graphics of the same images that are slightly offset from each other, each done in separate hues, traditionally red and blue. This produces a three-dimensional effect.

2.3.2.6 Motion cues

Motion cues are one of the eye's most prominent cues for visualizing distance. Visualize looking up into the sky and seeing an airplane. From the observer's position that plane is moving quite slow. However, the minimum speed for an aircraft to maintain flight is 300 miles per hour (depending on the aircraft). The motion cue works based on the fact that every time a person shifts, walks, moves, or slightly tilts their body or head they see the world from a different perspective. "The way this works is that there is a parallax that leads to closer objects appearing to move faster than more distant objects in the view" (Craig, 2013, pg.61). With this parallax or change in viewpoint also comes a change in the other depth cues that the eyes and brain are using to help the motion cue. The cues that are used to support the motion cue are 'hard-wired' into the brain to understand the relationship between the human's body and its movement with the world around them, and its movement. It is because of this fact that the AR system needs measures in place that can track the movement and the position of the users' head and/or eyes (Craig, 2013).

2.3.2.7 Physiological cues

Physiological depth cues are a special type of visual cue that occur based on certain physical changes that happen to the person's body, in order for their brain to fully comprehend what the eyes are seeing. Physiological depth cues come in two different types, accommodation and convergence. Accommodation refers to the physical changes in the muscles of the eye needed to refocus on a specific object at a specified distance. Convergence refers to the rotational movement of the eyes that takes place when the two eyes try to focus in on different objects at different distances (Reichelt et. al., 2010).

2.3.2.8 Auditory cues

Auditory depth cues work in the same way that visual depth cues work, in the sense that they are used to help us judge distance from ourselves to a specific stimulus. "Physical acoustics reveals a number of stimulus correlates of sound source distance. Quantitative estimates of these stimulus correlates are compared with appropriate psychophysical thresholds. Such comparisons show that most of these stimulus correlates can, with various restrictions, provide distance information detectable by the ear(s)" (Coleman, 1963). Just like with the visual depth cues that there are some that are monoscopic and stereoscopic, auditory depth cues also have some that require a single ear (monaural) to pick up on them, and there are some that require both ears (binaural) to pick up on the cues these would include; amplitude, echoes and reverberation, filtering, and Interaural delay (Craig, 2013).

2.3.2.9 System registration and latency

As mentioned previously with sensors, registration and an appropriate frame rate are very important with augmented reality. Both of the terms latency and registration refer to the relationship between the physical world and the virtual world in terms of speed and positioning, but one is dependent upon the other. The word registration was thrown around a lot while discussing tracking sensors, but what exactly is meant by registration. In Understanding Augmented Reality: Concepts and Applications, Craig defines registration as "how accurately the virtual world aligns spatially with the physical world (2013, pg.63)." Almost hand in hand comes the issue of latency with registration. Latency is the temporal aspect of registration. Latency is the time it takes for one part of the system to communicate with the main part and then for the main part to respond back. In terms of an AR system the time it would take for movement noticed from the tracking sensor to transmit to the processor and then for the processor to send corrections to the display would refer to latency. The higher the latency, the lower the FPS and the worse the visual lag will be, and with an increase in lag, the AR experience is diminished (Bajura and Neumann, 1995).

2.3.3 What makes up the AR experience

Now that all of the components of an AR system have been covered we must now discuss the most important aspect of an augmented reality application, and that is the AR experience. As mentioned previously, paintings are to be seen; music is to be heard, and augmented reality is meant to be experienced. In order for an augmented reality system to produce an acceptable experience for the user, there are certain aspects that are required.

First and foremost, what is needed is the augmented reality application itself. This is the core of the experience; it coordinates everything that goes into the experience the user has. The application is responsible for controlling all of the sensors including the user's input note that it is important that the content of the application is different than the application itself, user friendliness goes a long way with software and how well it is received by the general public.

The content its self is very important to the AR experience, this would include all of the ideas and stories, the sensory cues, the virtual objects created to be overlaid on the physical environment and any physics parameters that have been defined for the application. With the content, there must be a certain level of user immersion in the form of the next aspect, interaction.

The user’s ability to interact with the augmentations is key to the experience; otherwise, it is just a picture and not an augmentation to their reality. This interaction does not need to be extravagant, but it does need to be integrated into the application in a manner that is befitting of the situation. The actions must seem natural for the task at hand, similar to how the user would handle the situation in the physical world. Let us look back at the archaeologist looking at the skull example, if the archaeologist wanted to rotate the skull or move it they would not control these commands with foot or head movements they would use their hands, this should remain true for the augmented reality application as well. Using a tangible analog of the skull in the user's hand, that has the image superimposed onto it, would allow the object to be moved similarly to that of the real skull because the user is actually holding something. Similarly, tracking motions of the hand that indicates rotation and spin can also be used to imitate the real-life actions of moving a physical object. Interaction can also come in the forms of bisecting objects for profile views, pressing buttons (physical or virtual), or verbal commands. But with each of these interactions, as well as what goes into the AR application itself comes a certain level of technology.

By its very nature, all AR systems have technology. Some require more complex technology than others, but all have it nonetheless. As discussed in the components of AR systems sections, each AR system does need at minimum, sensors, a computer, and display.

The next required piece of the AR experience is not part of the AR system per say but still very important, and that is the physical world itself. With the physical world in an AR system it does not need to be a specific geographical location, but instead could be any room or laboratory large enough to accommodate the given applications augmentations.

The final required piece of the AR experience is the users themselves. Without a user to give commands to the application or to move around and view the virtual environment that has been created to augment the physical environment the AR application is nothing but a glorified 3D movie. Users are needed to make decisions and interact with the virtual as well as the physical. The user's activities affect the AR system in a way that changes the system.

It is with all of these aspects combined come together to make up the augmented reality experience. Knowing how these systems and application are created will bring a greater understanding of how they were created, are being used today, and where they are going next. Many AR applications are being used by marketing campaigns to promote products or in the gaming industry to innovate new ideas on what is the future of gaming. There is also a great deal of AR research done in historical tourism and scientific research. Here is where we can look at what augmented reality has done so far so that we can see where it can take us next.

2.4 Human computer interaction and augmented reality

With the advancements of the human interface come the advancements of computer supported cooperative work (CSCW). The concept of CSCW is something that is both straightforward and intensive. Meaning that in its early stages CSCW could be defined as the use of email (Schmidt and Bannon, 2013) to share business ideas and proposals and currently the ability to have a video conference with multiple people each from different parts of the globe and interact with them physically through an augmented workspace using AR technologies and command cards (Kato and Billinghurst, 1999). The idea of CSCW started in 1984 as a workshop organized by Irene Greif and Paul Cashman, two years after this workshop the first CSCW conference was held in Austin, Texas (Krasner and Greif, 1986). Since then the field of CSCW has evolved and changed just as the technologies that were used evolved and changed. With this evolution of computer supported work the way IT was being utilized changed with it, becoming even more integrated into everyday tasks (Schmidt and Bannon, 2013).

With the introduction of “smart” *everything*, it can stand to reason that the progression of the digital and physical would only become more integrated. The perfect example for this is the Xbox SmartGlass (2012) application, and an example of where this integration is heading could be seen in Corning’s symposium video on smart glass entitled A Day Made of Glass (Corning, 2011). The concept of human interface is evolving in much the same way. Traditionally, humans would interact with computer technology by using some device such as a keyboard, mouse, and toggles, but with the advancement in human interfaces, these input devices are being eliminated. New forms of technology are being developed every day as alternatives to traditional means of interaction with computing devices.

The Kirifuki system developed by the Keio Research Institute at SFC University in Japan utilizes varying degrees of inhalation and exhaling to perform various tasks on screen (Iga, Abowd, and Dey, 2001). The Ubi Finger system developed by the Graduate School of Media and Governance at the Keio University in Japan developed a device that is worn on the hand that measures movement in the wrist and fingers to receive input from the user (Tsukada et al., 2001). Another, more novel, system that is used to alert co-workers in an office that others are gathering for a break is “the meeting pot.” This device, when coffee is brewed, alerts others by releasing coffee aroma to remote locations (Siio et al., 2001). These are just a few examples of how the human interface is changing.

More sophisticated advancements are also being developed such as replacing the touchscreen with the human body, at the CHI 2013 Research Conference in Paris, two distinct research projects took on this notion. Sean Gustafson, Bernhard Rabe, and Patrick Baudisch from the Hasso Plattner Institute in Germany have developed an “imaginary interface,” an invisible interface in the palm of the hand. Pressing and or sliding the finger across different parts of the hand give different commands (Gustafson et al., 2013). The other project presented from the Technical University of Darmstadt, Germany, presented the idea of using the ear as an input device. “EarPut” developed by Roman Lissermann, Jochen Huber, Aristotelis Hadjakos, and Max Mühlhäuser, the EarPut can receive input from touching, tugging, and sliding across the ear in different places, as well as covering the ear (Lissermann et al. 2013).

HCI in the form of augmented reality has also found its way into the Mental Health field. Mental health professionals have started utilizing a method of treatment called Augmented Reality Exposure Therapy or ARET. ARET is the process in which a patient, under therapist supervision, will be exposed to a fear stimulus in order to help overcome that fear. For instance, if a patient is seeking professional help to deal with their arachnophobia, fear of spiders, the therapist may prescribe exposure therapy. This would entail the patient exposing themselves to spiders in different settings in the hopes of acclimatizing the patient to spiders and ultimately abating some of their fears. By utilizing ARET Therapists can do this in a safe and controlled setting without the risk of danger to the patient or animal. The ARET system would include a viewing headset and a target for the AR system to call the digital ‘fear stimulus’ (spider). This system of HCI allows the human user a direct connection to the computer element. In this case, the patient (human) can hold a digital spider (computer) in their hand though the use of an AR headset and target image (interface). This interaction offers great strides towards a better connection between human users and the computer tools that have become such an integral part of our everyday. In fact, this interaction is the basis for gesture commands for HCI.

Gesturing is a basic form of human communication present in almost every culture. So if a goal of HCI studies is to find a way for humans to communicate with computers more naturally then gesture commands are a must. This point was punctuated by a survey of HCI gesture technologies by Rautaray and Agrawal (2012, pg. 1), where they said “The ultimate aim is to bring HCI to a regime where interactions with computers will be as natural as an interaction between humans, and to this end, incorporating gestures in HCI is an important research area.” HCI is attempting to make the interaction between humans and computers more user-friendly. Our gestures communicate more than just words or commands; they are a non-verbal que that can express a wide range of instances. Gestures can communicate, intention, mood, sarcasm, depth, and so much more. The current standard interface is the mouse. A mouse has two degrees of freedom, the X-axis and the y-axis, but it cannot travel on the z-axis. To illustrate this, your computers desktop will have several icons on it. You can use your mouse to travel to the top and bottom of the screen as well as from the left to the right of the screen, to reach any icon you have on display. However, you cannot “push” your mouse’s cursor back into the depths of your desktop; but with the work done in HCI, specifically gesture commands, your hand becomes the mouse and it will have three degrees of freedom, the X, Y, and Z axes.

The ARET trial’s main goal was to see if the system could allow for the therapist and the client to work together during the exposure therapy sessions (Wrzesien et al. 2011). How the exposure therapy worked was, the patient had to interact with the stimulant while the therapist controlled attributes of the stimulant such as size and quantity. This study did provide a strong trend towards that AR was very beneficial to the human interaction in exposure therapy (Wrzesien et al. 2011). That said, there are two aspects of this study that should be addressed. First, the number of participants vs. the number of sessions. I would have liked to of seen a larger sample size. This could have been more sessions per patient or just more patients; and second, the lack of a control group. Having a set of patients participating in the traditional method to compare to another set using the ARET method would have provided a better picture of the results. However, the comparison would not have been accurate or useful with the current sample size, again punctuating my first point. As an aside, both of these points (sample size and a control group) are discussed and utilized in Chapters 3 and 4.

In the field of HCI, combining the physical with digital information and allowing those digital objects the ability to interact with the user are primary aspects that add a new dimension of experience to presentations and events. Combine this with the previous discussion on gesturing’s place in HCI and that gives you the Augmented Mirror. The Augmented Mirror was developed by Lucia Vera, Jesus Gimeno, Inmaculada Coma and Marcos Fernandex (2011). The Augmented Mirror “allows the audience to interact and talk with a virtual character through a large screen” (Vera et al. 2011). Unlike the other applications mentioned previously this system uses a MoCap system or motion control system. MoCap systems can use a wide range of technologies, from highly sophisticated exo-skeletal suites to optical systems with markers and cameras. The augmented Mirror utilizes a marker-less optical system (Vera et al. 2011).

The HCI component of this application utilizes a MoCap system, in this case a Kinect, to control the interaction between physical user and digital objects. The Kinect uses an image recognition algorithm to detect positions and movements. However, the Augmented Mirror also tracked space, lighting condition, facial expressions, and lip movements. In order to track all of these human interfaces the Augmented Mirror used additional technology aside from the Kinect, such as; a gyroscope and WiiMote, but the Kinect remains the main MoCap device (Vera et al. 2011).

The Augmented Mirror allows a user to interact with a digital character using an avatar of their own. The onscreen avatar is controlled with the user’s body and gestures. The user can speak, move, gesture, and touch the digital character with their avatar (Vera et al. 2011). Now, there is a bit of a classification conundrum here. I believe that a claim can be made that this augmented mirror is not really augmented reality but rather augmented virtuality or AV. Augmented virtuality is defined as a virtual environment being augmented by physical objects. Which is similar to augmented reality but opposite. AR is the physical environment being augmented by digital objects. So in the case of the Augmented Mirror the environment is the mirror, a digital world, that is augmented by the human controlled avatar, the human being a physical object. So we have the digital augmented by the physical. All that being said, it could be argued that the mirror is displaying the physical world and that the interactions are taking place there and not in the digital, much like an AR game on a mobile device the mirror is taking the place of the phone’s screen. There is a gray area with the classifying of AR and AV. It is my frame of mind that it depends on the viewpoint of the user that is ultimately the deciding factor. If you are looking though a device to the physical world then it is augmented reality, but if you are interacting inside and looking inside of the device then it is not augmented reality and either augmented virtuality or virtual reality. In either perspective, the Augmented Mirror is a formidable progression of HCI studies to a more natural interaction between humans and computers.

All of these advancements show that the projected course of human interface is moving towards just that a 'human' interface. This progression of moving towards using the body as an input device is all about immersion and integration, the very essence of 'augmenting' the IT of the day-to-day into a more natural feeling experience.

2.4.1 The progression of AR and its underlying technologies

The integration of IT into our personal lives would only naturally fall into our professional lives also. This remains true for archaeologists as well. Archaeology involves, in very basic terms, processing data for patterns (Lock and Brown, 2000; Banning, 2000 Lock, 2003). The main topic of discussion in Using Computers In Archaeology: towards virtual pasts (Lock, 2003), is the use of IT in archaeology. Within which they discuss how all areas of archaeological work are being required to spend more time using a computer and mouse rather than shovel and trowels. As a result of this action, new modes of work and opportunities for investigation have been created altering the discipline (Lock and Brown, 2000). For a more in-depth look at the relationship between the increase in IT usage and archaeology, there are a collection of essays that have been edited by Lock and Brown. In brief, the topics of discussion illustrate the usage and methods of usage on site and in the lab (Martlew, 1984, Cooper and Richards, 1985, Reilly and Rahtz, 1992, Lock and Stancic, 1995). A question keeps coming to mind and is reconfirmed by Lock and Brown, "for something that is so increasingly important to archaeology, it is curious that there has been so little discussion about why computers are used, in what contexts, and with what effect (2000, pg.5)." Within the archaeological discipline, we primarily see the publications on IT usage regarding manuals of application and methodologies.

Utilizing augmented reality, as an archaeological tool is not unheard of (Benko et al., 2004; Allen et al., 2004b; El-hakim et al., 2004; Niedermair and Ferschin, 2012; Jiménez Fernández-Palacios, 2015). Publications on mixed reality development techniques for archaeology are abundant, (Azuma, 1995; Barceló, 2000; Vlahakis et al., 2002; Allen et al., 2004a; Allen et al., 2004b; El-hakim et al., 2004; Caarls et al., 2009; Garagnani and Manferdini, 2011; Wang et al., 2011; Niedermair and Ferschin, 2012), however the effects of the usage have not been investigated, sepcifically its use as an interpretative tool. There is not much evidence to support its usage as an interpretational tool, a sentiment that is expressed by work done by Stuart Eve (2014, pg.32) and investigations into the literature done by myself. One can see that there are multiple publications for the usage of, and the methods of how to use, virtual IT approaches in the archaeology discipline but the specific usage of augmented reality the publication pool is much shallower. The use of AR in archaeology primarily takes place in tourism and education, which is generally after the 'archaeology' has taken place. The abundance of literature that has been written about virtual IT approaches to archaeological tourism and education (Stricker et al., 2001; Vlahakis et al., 2001; Papagiannakis, et al., 2002; El-Hakim et al., 2004; Papagiannakis and Magnenat-Thalmann, 2005; Papagiannakis, et al., 2005; Linaza et al., 2008; Noh and Sunar, 2008) versus those that are about using it as a diagnostic tool or its effects as a tool (Renfrew, 1997; Gillings, 1999; Barceló et al., 2000; Ryan, 2001; Zhukovsky, 2001; Gillings, 2005; Bruno et al., 2010) are outnumbered. Obviously, this is not all of the texts published on the subjects just the prominent ones from the most recent decade, to illustrate the direction of the current research.

Field and laboratory analysis of the work done in said field are 'inextricably' linked. However, there cannot be a denial of the gap that lies between the lab and the field (Banning, 2000, pg.1). Archaeological analysis is the detection of relationships. Coombs, (1964) originally defined analysis as a means of finding relations, order and structure in data, and for the most part the strategy for accomplishing this consisted of "the examination and explication of phenomena that resulted from 'experiments' over which we had no control, and which took place centuries ago" (Banning, 2000, pg.3). Now if we re-examine the last part of Coombs' definition ("…structure in data"), data has become, according to Lock (2003, pg.1), synonymous with computers. It is by utilizing computers archaeologists has been able to make strides in Coombs' long time accepted definition of analysis, by using computer simulations to recognize relations, order, and structure.

The question, how archaeologists use computers has been answered, but the question of, to what extent have computers impacted archaeologists has not. IT has increasing importance in all aspects of modern life, and that includes archaeology (Lock and Brown, 2000; Lock, 2003). There is, however, a lack of discussion on the role of archaeology a concern that has already been addressed in other fields (Huggett, 2000; Lock and Brown, 2000). Through the understanding of the effects of IT on the field we can understand where it will take us next, and there already have been a few publications on reviewing the technology as a tool, which we discussed earlier, but what on the archaeological theory and practice of using mixed reality and more specifically augmented reality as a research tool. Mark Lake (2010) states that the problem with advancement in archaeological simulations is not with simulation method and theory but rather with archaeological theory and method concerning the methodology in which archaeology handles either issue remains inexperienced.

By examining the uses and effects of AR in the field of archaeology, we could derive a sense of what this technology's impact has been. There have been plenty of useful publication to discover, as an archaeologist, what augmented reality is (Craig, 2013), and how it has progressed through its lifespan so far (Swan and Gabbard, 2005), but again, I must reiterate, finding work done on how mixed reality more specifically augmented reality has been used as a research tool is lacking. There have been blogs about the advancement of augmented reality projects in archaeology (Dead Men's Eyes, 2016), but even here there is a lack of discussion on the impact of the technology, but rather it discusses the actual technology itself.

In summary, by investigating the progression of technology that has led to and the development of augmented reality technologies we can begin to see where the technology will go next, however, archaeologists are resistant to the changes that are affecting the rest of academia, business, and everyday life. The theory on IT, be it computation, simulation, AR, VR, or modelling, in archaeology has remained stagnant, while the number of innovative projects utilizing the latest technology has continued to climb. In short, the technology and theory are evolving at different rates.

2.5 Augmented reality within archaeology

Augmented reality has found its home in the niche of allowing archaeologist to view samples from a distance or fragile samples safely (Benko et al., 2004; Jiménez Fernández-Palacios, 2015). Examples of this would include the VITA and ARCube projects that will be discussed in detail in a later section, but to summarize the VITA project uses AR and Virtual technologies to take users to archaeological sites around the world where they can view and interact with archaeological data that has been linked to various stages of the excavation and or work. The ARCube is a six-sided physical box that has markers on each side that are linked to a 3D model of an object that is then overlaid onto the cube using AR technologies to allow the user to handle that object regardless of the objects location on Earth or its fragile state.

The usage of various forms of mixed reality within archaeology falls into two broad categories. The first is for tourism purposes. Whether it is on display in a museum (Mannion, 2016), or for a tour of an archaeological site (Vlahakis et al., 2003; Papagiannakis et al., 2005), and everything in-between. This category is the primary use for virtual data being displayed graphically in various forms of mixed reality. This makes sense as well; this is where having a visually pleasing representation of data can produce a significant amount of income if properly marketed. The other category is using mixed reality as an archaeological tool (Benko et al., 2004; Niedermair and Ferschin, 2012; Eve, 2014). Within the last decade, the use of computer simulation began to grow in terms of accepted usage as a scientific tool. This sparked the use of other mixed reality projects within archaeology. These projects ranged from the digitizing of individual artifacts to entire archaeological sites. If we examine each of these categories, we can see how the progression of IT has changed the discipline.

Within archaeological tourism, there are two categories that we can distinguish, on-site and off-site. On-site mixed reality tourism would include anything that is actually located at the archaeological or heritage site (Vlahakis et al., 2003; Allen et al., 2004b; Zollner et al., 2009; Garagnani and Manferdini, 2011). Off-site mixed reality tourism would include anything that is done off the site, such as in a museum or classroom (Vlahakis et al., 2002; Papagiannakis et al., 2005; Noh et al., 2009). Some of the more successful on-site mixed reality programs include the PRISMA project (Linaza et al., 2008), ARCHEAOGUIDE (Vlahakis et al., 2001), and the mixing of virtual and real scenes in Pompeii. Due to the fact that these projects are on-site, they incorporate the site itself into the virtual elements making some aspects of them augmented reality. The PRISMA project uses AR to display relevant info to the site. ARCHEOGUIDE uses AR and other virtual aspects to tailor a walking tour to the user. The project on ancient Pompeii uses various forms of mixed reality to illustrate life back in the past. As for off-site uses of mixed reality we can see different ways to engage the public trying to bring them to the site or ways to display what has been learned from the site (Papagiannakis et al., 2002; Stone and Ojika, 2002; Allen et al., 2004a; Papagiannakis et al., 2005; Noh et al., 2009). Many museums use VR to bring their patrons back to a specific time period (Papagiannakis et al., 2002; Allen et al., 2004a; Papagiannakis et al., 2005). In other cases, the museum or classroom could use AR to engage their patrons or students with actions to coincide with the virtual elements (Allen et al., 2004a; Benko et al., 2004; Noh et al., 2009). Either on or off site the trend for incorporating mixed reality technology, for archaeological or heritage tourism or education, is heading for interactivity or ways to get the user involved instead of just looking at a picture.

Mixed reality as an archaeological tool shows a much less embraced story than its tourism counterpart. In short, the majority of IT usage for archaeology is data recording and data storage, which of course is a necessity but seems like it has been taking the system for granted. There has been some significant work with simulation (Lock, 2003). As it currently stands mixed reality can serve two purposes for archaeology as a research tool. First, it can be used for data collection, or secondly as data deriving. To distinguish the two, data collection, would refer to simulations or using mixed reality as a form to produce primary data, for example, work done by Allen et al., with digitally modelling to visualize and preserve archaeological sites (2004b), as well as El-Hakim's work done in 2004 with utilizing integrated techniques to created detailed reconstructions of large scale heritage sites. Utilizing augmented reality to collect archaeological data on site has been done but the cases are sparse. Niedermir's work at the 2012 CHNT Conference entitled *An Augmented Reality Framework for on-site visualization of archaeological data* offered as the title suggested a framework for AR visualizations that adhered to established archaeological procedures, thus laying some groundwork to start improving on the current course of the technology. Which, Eve's work with GIS and phenomenology put into motion the idea of utilizing AR in the field as a data-collecting tool. Data deriving would use mixed reality to look a primary data source in a new manner to produce secondary data such as the ARCube and VITA. There are currently mixed reality systems that can take users from a supporting lab and put them in a virtual dig site (Benko et al., 2004; El-Hakim et al., 2004; Niedermair and Ferschin, 2012). These programs can vary along the Metaverse roadmap from the virtual worlds quadrant to the AR quadrant. This is because the use of virtual space varies between the AR applications. Using multiple input devices users can move around the virtual world to see different parts of the archaeological site, allowing for insight into the area without having to be there in person. This can also be tuned down to a smaller more hand-held scale in order to interact with various artifacts virtually (Allen et al., 2004b; Benko et al., 2004; Jiménez Fernández-Palacios, 2015). As seen with the tourism and educational uses of mixed reality the trend in the progression of IT usage in archaeological research is slowly moving to interaction. There are many aspects of the archaeological process that has some form of IT involved with it, but there is very little discussion on the effects of that usage.

2.5.1 Tourism

The use of augmented reality for heritage tourism is becoming increasingly popular. Whether it is done from paintings in museums or 3D reconstructions on heritage sites, there is no denying the fact that the augmented reality does serve a purpose for tourism, but to what extent exactly and how far is it or the patrons willing to go with it? There have been multiple archaeological tourism sites that have utilized three-dimensional reconstructions. The great pyramids, Pompeii, the Coliseum, all have had reconstructed renderings for tourism purposes, but some sites have taken the next step and incorporated them into augmented tours, such as the ARCHEAOGUIDE program (Stricker et al., 2001; Vlahakis et al., 2001) in Olympus Greece but what is the impact on the public and what does this mean for academics?

The Virtual Heritage System was developed to create a computer-based interactive environment in VR or virtual reality. The Virtual Heritage System creates 3D objects of various monuments artifacts and structures to be accessible to people all over the world. It was designed with the thought of enhancing the learning process and understanding events and historical elements. This program had eight requirements for the creation of its models all of which share importance with the previously discussed AR systems; application flexibility, the capture of all details, high automation level, high geometric accuracy, low cost, model size efficiency, photorealism and portability (El-Hakim et al., 2004). The Virtual Heritage System takes full advantage of mixed reality.

The purpose of virtual heritage "is to restore ancient cultures as a real environment that users can immerse and understand a culture" (Noh and Sunar, 2008, pg.314). With many of the world's historical and archaeological sites being lost or destroyed the use of mixed reality and virtual heritage may be a possible solution to this according to Vlahakis et al. (2002).

There were tourism projects in Pompeii that involved taking Head Mounted Displays (HMDs) and using them with a physically reconstructed scene and having it augmented through the HMD with virtual people and plants that told stories of life depending on the scenario. The virtual environment was implemented using AR systems with markerless tracking cameras to reconstruct in real-time (Papagiannakis et al., 2002; Papagiannakis et al., 2005; Papagiannakis and Magnenat-Thalmann, 2005). The project was met with success as a result of the team utilizing markerless tracking systems. This allowed the team to provide the AR experience to the site patrons without the need to install markers, which would damage the heritage site, and still provided an immersive experience (Papagiannakis et al., 2005).

Personalized cultural heritage tours have also been established in multiple sites the most notable one being the ARCHEOGUIDE program in Olympus, Greece. In this program, users are asked about their background and general interests then while they are touring the area. Their HMD will present reconstructions and activities based on their profile that was created prior to the tour (Stricker et al., 2001; Vlahakis et al., 2001).

One of the, if not 'the,' most notable examples of augmented reality in tourism is the PRISMA project. The PRISMA project, in short, involves taking tourist binoculars (figure 2.8) and upgrading them with augmented reality capabilities. The thought behind this project is two-fold. The first is that very few AR systems have the capabilities to perform with zoom-lens cameras. The reasons behind this are that the zoom lenses need to have an active adjustment of the position and orientation of the system. Once this is done the camera's parameters also need to be reassessed, such as the distortion, opening angle, and focus. Secondly, tourist sites often cannot have all of the available information for tourists on site, so they often redirect you to some form of multimedia. This means that the tourist must leave the site to obtain said information. According to Lianaza et al. (2008), "if tourist organisations wished to reach wider audiences, they would have to build attractive multimedia content available on site." This is where the PRISMA project comes into play.

a b

Figure 2.8 PRISMA concept (a) Actual landscape (b) Seen through tourist binoculars.

It was created using ARToolKit as the software platform. This was used to create the AR application that was used within the binocular system. It utilized graphics supported by OpenGL and incorporated a VRML import PlugIn to allow the system to import 2D and 3D objects and animations. The AR system used marker based tracking mounted on the binocular lenses.

The general objective of the usability examination of the PRISMA project has been the advancement of typologies of users and criteria. This was done to ensure that the newly developed AR applications with interactive tourist experiences could be modified at a later date to account for types of use and user-friendliness of the user interface. The usability examination used volunteers and an in-depth questionnaire at a real tourist location, Monte Urgull in San Sebastian (Spain) (figure 2.9). Of the 100 volunteers, 47 of which took the questionnaire. 61% of the sample size was males between the ages of 20 and 35 years old, whom all had a common usage of new technologies such as smartphones, tablets, laptops, digital cameras, and the Internet. Most of the 47 volunteers worked in tourism; this included content providers and destination managers. It was a general consensus that the use of advanced visualization technologies like augmented reality as seen in this example, truly improved the tourists' interactive capabilities with the experience. The volunteers determined that the PRISMA project

Figure 2.9 Map of Spain indicating Monte Urgull.Map courtesy of Google Maps.

added multimedia content in a manner that was both befitting and interactive to the tourist site. The information was more readily accessible to them with the new AR system and concluded that most of them would be willing to pay up to three euros to use the PRISMA system suggesting project sustainability (Linaza et al., 2008, pg.114-115).

These are just a few examples of augmented reality being used in the tourism of archaeological and heritage sites. The examples presented above offer archaeological researchers insights into the potential of AR as a tool for research. By looking at how the tools are currently being used researchers can start to formulate how to integrate them into their projects in new ways. For example, instead of just using the PRISMA project to show tourists how things used to look take that same concept and apply it to a village that is no longer standing to allow the site archaeologist to physically walk among the lost structures gaining insight into human object interactions, site scale and spatial relationships, as well as other phenomenological aspects.

2.5.2 Related projects not in tourism

This section discusses more closely current projects that are being used directly by archaeologists as a tool primarily for educational purposes and not for tourism purposes. The use of augmented reality in archaeology for the general public is nothing new, but the idea of being able to use it as a tool for archaeological research is still in the early stages, though the work does look very promising. There are two distinct ways that augmented reality is emerging in archaeology, and they are either using AR to look at the landscape, or they are using it to look at specific objects that they normally would not have access to, either by geographic impossibilities or through the delicate nature of the artifact or site.

An early example of the former is the VITA project or Visual Interaction Tool for Archaeology. The purpose of the VITA project was to use the forms of mixed reality to have a realistic virtual visualization of an actual archaeological dig that could be experienced offsite. In order to accomplish this VITA has taken the current archaeological analysis methods that are currently in use and allows them to be applied to an augmented process of the site, doing so, could open new ways to organize typical excavation notes. Using the VITA project, archaeologists could use existing archaeological methods with augmented reality to reinvent how the standard 2D field notes, section drawings, and pictures are visualized. Using textured 3D laser scanning methods and 3D models of objects found on site, the VITA project hopes to allow its users a means of using multiple forms of input such as touch, speech, and movement to interact with a mixed reality archaeological site from anywhere in the world (Figure 2.10) (Allen et al., 2004; Benko et al., 2004).

Figure 2.10 VITA project (a) Photograph of actual site. (b) Virtual rendering of site inside lab visible with HMD.
Photograph courtesy of the VITA project and http://monet.cs.columbia.edu/projects/ArcheoVis/.

The Embodied GIS application (Figure 2.11) takes the infographic aspects of GIS along with the accurate mapping, and layers of data and applies it to the physical landscape, allowing the typical GIS user to experience the GIS augmented landscape physically. By utilizing an Apple iPad, the user can walk through the physical landscape and look at the GIS reconstructions and data mappings while feeling the phenomena of the landscape. This according to Eve's "…brings a dimension that was not obvious from mathematical analysis alone" (2014, pg.84). Looking back at some of the works done by Gillings (2005) he discusses the role of each segment along the mixed reality spectrum within archaeology. It is my opinion, one that I share with Gillings, that past applications of virtual reality are more often than not just information surrogates. They rarely allow the user to expand and manipulate to make new discoveries, which is what augmented reality can do, as demonstrated by Eve's Embodied GIS.

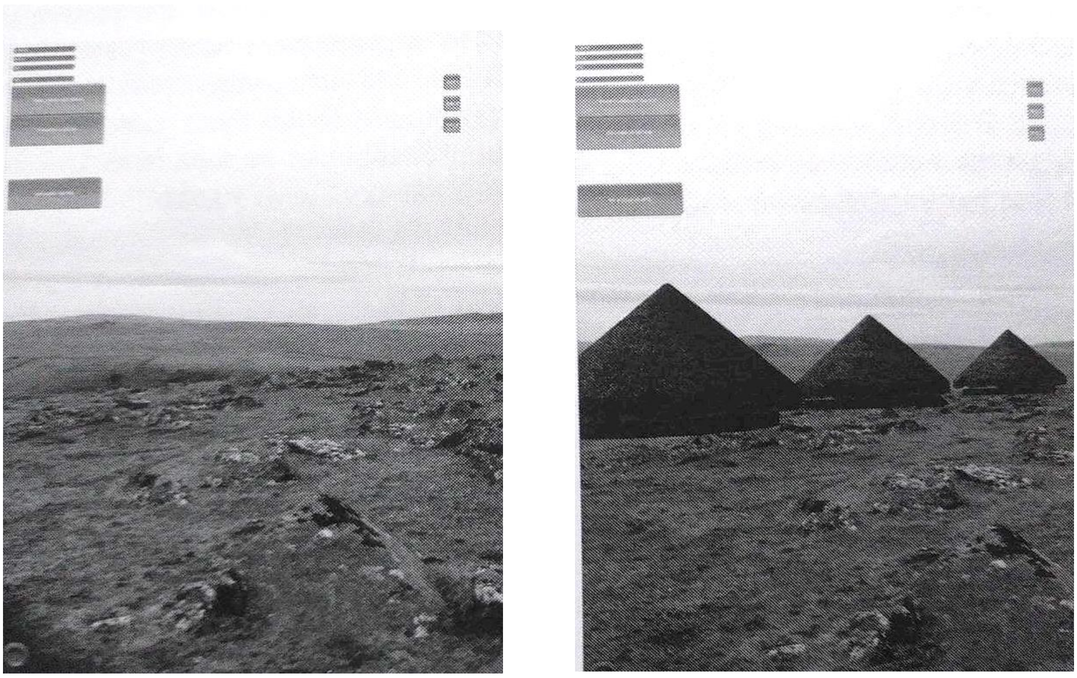


Figure 2.11 Left: Showing field as is. Right: Showing field using Embodied GIS. Images courtesy of Stuart Eve (2014).

Eve's used the Embodied GIS as an approach to visibility study at Leskernick Hill. Initially, a GIS analysis of the area was conducted, but this alone could not determine if communication would be possible around the site. From this point, a phenomenological study was undertaken around the site. This was not without issues as well. For instance, the Cairns of the Moor at one time could have been five meters in height restricting view and blocking sound, but as of today, they exist as collapsed piles of stone and because of this the results of the phenomenological study are skewed. By using Embodied GIS, the communication problems with only using a desk-based analysis can be addressed, and a reconstructed view of the landscape will provide a more accurate phenomenological analysis (Eve, 2014). Eve's work with the Embodied GIS is a monumental step forward with the applications of augmented reality as a means of collecting primary data. Instead of using AR or VR to create simulations based on data already gathered from the field, as what has been the norm for these applications in the past, archaeologists can take this to the field and collect first-hand data. However, some things are still fallible, for example, Eves conducted an extensive phenomenological study of the landscape, which included sound testing. The sound test is incredibly important; this test could not have been carried out within the lab setting using GIS software. That being said, by using AR technologies to reconstruct the original landscape, adding back structures, buildings, and other 'physical' aspects, it changes and these newly placed structures had they been made of physical matter would surely have an impact on the way sound would carry across the landscape, it may be a minute difference but a difference nonetheless. It is because of this that, the idea of adding augmented aspects to the phenomenological study may not always be necessary.

Another example of using augmented reality as a tool for archaeological research falls into the second of the two categories, examining specific artifacts. The ARCube uses advanced augmented reality methods to facilitate archaeologist with a means of 'playing' with otherwise valuable artifacts. I use the term 'playing' because the ARCube allows the user to take a fragile archaeological artifact and 'hold' it in their hand while being able to flip and rotate it and even create bifurcated cuts and breaks in the artifact without any actual damage or ramifications coming to the original artifact. This system allows for archaeologists to study artifacts with high-resolution without any risk or consequence. In hopes to overcome some camera limitations, the ARCube utilizes a simple 6-sided cube with each face having its own fiducial marker. Using ArToolkit and BuildAR, the developed platform can utilize plugins from 3DStudio Max to take 3D models and automatically split the model up into several faces that all overlap. This overlapping causes a seamless transition while the cube is rotating. The 3D Studio Max plugin loads the images into the AR environment to be seen on a display that corresponds with the cubes movements (Figure 2.12) (Jiménez Fernández-Palacios, 2015, pg.251-252).

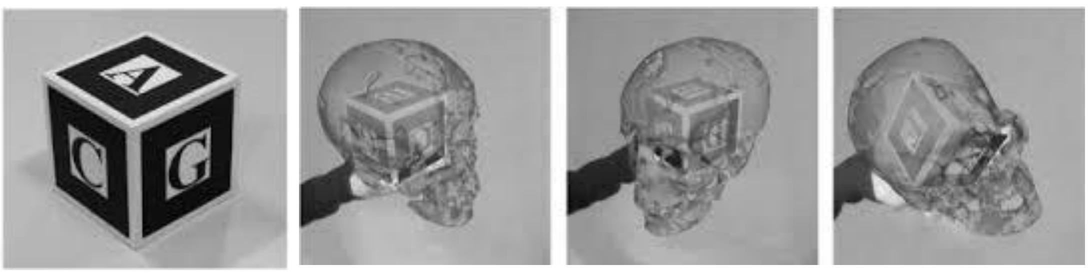


Figure 2.12 ARCube with skull rendering assigned. Images courtesy of Jiménez Fernández-Palacios 2015.

From the above, it should be evident that augmented reality has already been established in the archaeological community. This establishment comes primarily in the form of interactive tours implemented on tablets (Vlahakis and Ioannidis, 2003) and smartphones (Wang et al., 2011; Niedermair and Ferschin, 2012) as well as with specialty placed viewing devices like the PRISMA system (Linaza et al., 2008), but has also been seen as data deriving techniques as seen with the

VITA project (Benko et al., 2004), Embodied GIS (Eve, 2014), and the ARCube (Jiménez Fernández-Palacios, 2015).

They also come in the form of augmented reality pop-up books that are designed for their own exclusive software applications (Papagiannakis et al., 2005). There has also been the development of augmented reality applications that utilize special HMD's such as glasses or screens such as Race Yourself (Gamble et al., 2013), that utilizes Google Glass (2013) as an HMD to track various running routes, states and also offers games (Benko et al., 2004; Zollner et al., 2009). These, unfortunately, can be quite costly. However, most of these applications that have been developed for archaeological purposes are all geared to entertainment (Barceló, 2000; Vlahakis et al., 2003; Caarls et al., 2009; Noh et al., 2009; Garagnani and Manferdini, 2011). As far as using augmented reality as a means of a research tool, the applications for such are very limited (Eve, 2014; Benko et al., 2004; Jiménez Fernández-Palacios et al., 2015). This is due to the fact that, according to Jiménez Fernández-Palacios et al. (2015, pg.252), "AR is often considered insufficient for scientific use in the visualization of scaled, detailed and metrically correct objects." Aside from this, another common inadequacy with AR systems that only use a single webcam, that cannot pivot, as the means of tracking targets is that when the artifacts pitch is less than 50 degrees, the software loses the target; it cannot set the target back in space. As a result of this error, the 3D models that are being displayed are not being accurately created. In the archaeological field the visual accuracy is a necessity, and with this particular set up it limits archaeologists to using just planar targets. Planar targets are primarily used for flat planar surfaces. This would limit augmented reality rendering of a few very select types of artifacts such as plates or other flat artifacts, thus leaving more complex artifacts such as human remains, statues, and ornate jewelry out of the AR system leaving this information unavailable for research (Jiménez Fernández-Palacios et al., 2015). Now in slight contrast to this, work done by Stuart Eve from the Institute of Archaeology, UCL in 2013 studied the effects of using augmented reality to enhance Geographic Information Systems (GIS). Eve's created what he called "embodied GIS" (Eve, 2014). This allowed the user to combine desk-based GIS analysis with the field-based analysis of phenomenology. His work at Leskernick Hill demonstrated that the phenomenological study of landscape, a method that Hamilton et al. (2006) deemed was too subjective could, "provide solid results that can be reproduced, mapped and analyzed." (Eve, 2014, pg.83).

2.5.3 Gaps in the archaeological framework

It is hard to argue that computers do not have a distinct place within the archaeological discipline (Lock and Brown, 2000; Huggett, 2000). It is also becoming increasingly more apparent that the role computers play in archaeology is becoming more of a necessity than a luxury.

Computers are being used more and more, most likely because computers are more commonplace in our personal lives so that it would stand to reason that practice would fall over to our professional lives. The question is, however, if computers are becoming an ever increasingly important tool, then why is there such a small amount of literature on the role of computers and IT in archaeology (Lock and Brown, 2000; Huggett, 2000).

There are many books on computers in archaeology, but they primarily take on the form of manuals and how to's or the end up just being the descriptions of the devices, such as the works of Richards and Ryan (1985), and Ross, Moffett, and Henderson (1991). The majority of the books available for computers in archaeology are an edited collection of papers. These papers have been written describing the accounts of several archaeologist applications and techniques such as the work done by Martlew (1984) in archaeological information systems, or Cooper and Richards (1985) and their investigations into archaeological computing theory and the current issues associated with the practice, which is similar to the work done by Rahtz and Reilly (1992) on computational archaeology theory and archaeology's position in the Information age, and finally the work on archaeology and geographic information systems done by Lock and Stancic (1995). However, there has been very little research, and publication on the role computers have played within archaeology, and what I mean by that is how has IT changed archaeology. There are exceptions to this, the work of Cooper and Richards (1985); but there have been very few publications since then matching the contribution put forth by Cooper and Richards. According to Huggett (2000), archaeologist are using the computers, and techniques and technologies surrounding are being taken for granted.

Finding work done on the specific role of IT in the field of Archaeology and its impact on the field by comparison to other fields such as the history of science, sociology, and business studies are lacking significantly. The kinds of questions that were posed for these publications addressing the impact of IT on other fields were more extensive than that of their archaeological counterparts, but yet they still had meaning for the archaeological framework. For an example of this let's look at what Webster (1995, pg.76) poses; who is responsible for the whole process of new technology, meaning who initiates, researches, develops, and applies the new technology to the field; and with that what hurdles do they have to deal with to make it happen, or even the opposite is there significant opportunities for this process? In some other disciplines, the inquiries go even further, into the role of IT, then just the application of the specific tool and the techniques required to use said tool, but rather the political, social and economic issues involved with the impact of IT on the field as well. This absence of data is a need for the continued study of all forms of IT within the field, including that of augmented reality technologies. The before mentioned concepts are all concepts that archaeologist must deal with on nearly every project and should be quite comfortable discussing and yet, according to Huggett (2000, pg.6), they have not used these concepts to address the role of IT in archaeology. As an example of this, there was a question asked by Ross et al. as an example "Do computers change how archaeologists work? Moreover, if, so, what do these new practices look like, in what areas have results been demonstrated, and how was that work done?" (1997, pg.162). These questions were not answered as widely as one would expect like previously stated there is only a few publications addressing this (Cooper and Richards (1985)), more recent publications addressing this topic are few and far between. During the 90's when the commercialization of computers and IT became more consumer-friendly the publications again focused primarily on application and methods (Moffett, 1991; Kamermans and Fennema, 1996; Scollar, 1999). As seen with these examples again the weight of these is on the development of the technique and methodologies and not on the role IT has played to change the archaeological discipline (Huggett, 2000, pg.6). Since the 90's there has been a lot of work in archaeology with IT (Shott, M., 2010; Merrill, M., & Read, D., 2010; Barton, C., Ullah, I., & Mitasova, H., 2010; Kosiba, S., & Bauer, A., 2013; Porcelli, V et al., 2013), however work on the theory of computers, IT, and simulation in archaeology has been insufficient when you compare the amount of projects that have a focus on IT and the number of projects that address the theory and impact of IT on the field (Gold and Klein, 2016; Verhagen, 2012).

2.5.4 The progression of AR and its underlying technologies

Now that we have taken a look at augmented reality in the field of archaeology, we should look at how AR has progressed from its infancy to that of its current state. The integration of IT into our personal lives would only naturally fall into our professional lives also. This remains true for archaeologists as well. Archaeology involves, in very basic terms, processing data for patterns (Lock and Brown, 2000; Banning, 2000 Lock, 2003). The main topic of discussion in Using Computers In Archaeology: towards virtual pasts (Lock, 2003), is the use of IT in archaeology. Within which they discuss how all areas of archaeological work are being required to spend more time using a computer and mouse rather than shovel and trowels. As a result of this action, new modes of work and opportunities for investigation have been created altering the discipline (Lock and Brown, 2000). For a more in-depth look at the relationship between the increase in IT usage and archaeology, there are a collection of essays that have been edited by Lock and Brown. In brief, the topics of discussion illustrate the usage and methods of usage on site and in the lab (Martlew, 1984, Cooper and Richards, 1985, Reilly and Rahtz, 1992, Lock and Stancic, 1995). A question keeps coming to mind and is reconfirmed by Lock and Brown, "for something that is so increasingly important to archaeology, it is curious that there has been so little discussion about why computers are used, in what contexts, and with what effect (2000, pg.5)." Within the archaeological discipline, we primarily see the publications on IT usage regarding manuals of application and methodologies.

Utilizing augmented reality, as an archaeological tool is not unheard of (Benko et al., 2004; Allen et al., 2004b; El-hakim et al., 2004; Niedermair and Ferschin, 2012; Jiménez Fernández-Palacios, 2015). Publications on mixed reality development techniques for archaeology are abundant, (Azuma, 1995; Barceló, 2000; Vlahakis et al., 2002; Allen et al., 2004a; Allen et al., 2004b; El-hakim et al., 2004; Caarls et al., 2009; Garagnani and Manferdini, 2011; Wang et al., 2011; Niedermair and Ferschin, 2012), however the effects of the usage have not been investigated, sepcifically its use as an interpretative tool. There is not much evidence to support its usage as an interpretational tool, a sentiment that is expressed by work done by Stuart Eve (2014, pg.32) and investigations into the literature done by myself. One can see that there are multiple publications for the usage of, and the methods of how to use, virtual IT approaches in the archaeology discipline but the specific usage of augmented reality the publication pool is much shallower. The use of AR in archaeology primarily takes place in tourism and education, which is generally after the 'archaeology' has taken place. The abundance of literature that has been written about virtual IT approaches to archaeological tourism and education (Stricker et al., 2001; Vlahakis et al., 2001; Papagiannakis, et al., 2002; El-Hakim et al., 2004; Papagiannakis and Magnenat-Thalmann, 2005; Papagiannakis, et al., 2005; Linaza et al., 2008; Noh and Sunar, 2008) versus those that are about using it as a diagnostic tool or its effects as a tool (Renfrew, 1997; Gillings, 1999; Barceló et al., 2000; Ryan, 2001; Zhukovsky, 2001; Gillings, 2005; Bruno et al., 2010) are outnumbered. Obviously, this is not all of the texts published on the subjects just the prominent ones from the most recent decade, to illustrate the direction of the current research.

Field and laboratory analysis of the work done in said field are 'inextricably' linked. However, there cannot be a denial of the gap that lies between the lab and the field (Banning, 2000, pg.1). Archaeological analysis is the detection of relationships. Coombs, (1964) originally defined analysis as a means of finding relations, order and structure in data, and for the most part the strategy for accomplishing this consisted of "the examination and explication of phenomena that resulted from 'experiments' over which we had no control, and which took place centuries ago" (Banning, 2000, pg.3). Now if we re-examine the last part of Coombs' definition ("…structure in data"), data has become, according to Lock (2003, pg.1), synonymous with computers. It is by utilizing computers archaeologists has been able to make strides in Coombs' long time accepted definition of analysis, by using computer simulations to recognize relations, order, and structure.

The question, how archaeologists use computers has been answered, but the question of, to what extent have computers impacted archaeologists has not. IT has increasing importance in all aspects of modern life, and that includes archaeology (Lock and Brown, 2000; Lock, 2003). There is, however, a lack of discussion on the role of archaeology a concern that has already been addressed in other fields (Huggett, 2000; Lock and Brown, 2000). Through the understanding of the effects of IT on the field we can understand where it will take us next, and there already have been a few publications on reviewing the technology as a tool, which we discussed earlier, but what on the archaeological theory and practice of using mixed reality and more specifically augmented reality as a research tool. Mark Lake (2010) states that the problem with advancement in archaeological simulations is not with simulation method and theory but rather with archaeological theory and method concerning the methodology in which archaeology handles either issue remains inexperienced.

By examining the uses and effects of AR in the field of archaeology, we could derive a sense of what this technology's impact has been. There have been plenty of useful publication to discover, as an archaeologist, what augmented reality is (Craig, 2013), and how it has progressed through its lifespan so far (Swan and Gabbard, 2005), but again, I must reiterate, finding work done on how mixed reality more specifically augmented reality has been used as a research tool is lacking. There have been blogs about the advancement of augmented reality projects in archaeology (Dead Men's Eyes, 2016), but even here there is a lack of discussion on the impact of the technology, but rather it discusses the actual technology itself.

In summary, by investigating the progression of technology that has led to and the development of augmented reality technologies we can begin to see where the technology will go next, however, archaeologists are resistant to the changes that are affecting the rest of academia, business, and everyday life. The theory on IT, be it computation, simulation, AR, VR, or modelling, in archaeology has remained stagnant, while the number of innovative projects utilizing the latest technology has continued to climb. In short, the technology and theory are evolving at different rates.

2.6 Summary of the Past and Opportunities for the Future

In the previous section we discussed how augmented reality and information technology changed over time, so what are the opportunities for AR in archaeology for the future? In the following paragraphs I will summarize the previous projects, assessing their AR and HCI functionality so that we can outline future projects. As mentioned in Chapter 1 this research project is meant to be a stepping stone to pave the way for future works on assessing how AR and ultimately how IT has impacted the field of archaeology. There are plenty of instances of how-tos but very rarely is there an impact assessment alongside it. First, we will re-address some of the previously mentioned projects to assess their components and then we will discuss potential opportunities for the future.

The Meeting Pot System developed by Siio et al. in 2001, was a device that would release an aroma to remote locations throughout an office building to alert co-workers that a fresh pot of coffee had been brewed. Now, this system offered something unique compared to the other augmented systems throughout this research project, and that is that it does not utilize a visual augmentation but rather an olfactory augmentation. This AR device shows that vision is not the only thing that can be augmented.

The Augmented Mirror developed by Vera et al. in 2011, showed audiences that you could fully interact with a digital character using your body as an interface. This project was unique because it utilized a wide range of sensors to track and record the human controller for the mirror. The Augmented Mirror utilized a wide range of devices to translate a human user's actions to an avatar that can then directly interact using touch, voice, and many other commands to impact the digital character. This AR system shows the range of devices and the potential that can be used to increase functionality and user immersion.

The next system I would like to re-address is the ARET system. This AR application allowed patients a safer and more controlled alternative to classic exposure therapy. It utilized a minimalistic setup, only a headset and AR target. It essentially allowed the patient to "handle" whatever they were afraid of (Wrzesien et al. 2011). This is a classic example of the AR application; the physical being augmented with the digital in a way that can be interacted with as if it were real. Which brings me to a related project in the realm of archaeology, The AR Cube. The AR Cube functioned similar to the ARET system, in that it had a viewing apparatus and an AR target that was used to bind a digital element to. The key difference is that traditional AR targets are a 2D target and tracking systems lose the image at about a 30-degree angle, but the AR Cube is a 3D object that can be rotated 360-degrees along all three axes without having the camera lose tracking (Jiménez Fernández-Palacios, 2015). The key function of the AR Cube is that it gives you a solid 3d object for you to hold and manipulate freely as if the digital object was actually in your hand.

The VITA project was developed by Allen et al. in 2004, is a unique project in that it brings a large virtual element to the augmentation. The purpose of the VITA project was to have a visual representation of an actual archaeological dig. This, in-turn, would be used to augment standard 2D field notes, section drawings, and pictures. This system offered a new form of HCI with the standard tools of the trade, and in my opinion paved the way for other projects down the line.

The final two projects I would like to address are the PRISMA and Embodied GIS projects. Both of these projects utilize augmented reality to bring what was lost to time back to the landscape, but did so in two separate lights. The PRISMA project allowed tourists to view heritage sites that have been destroyed as digitally reconstructed structures (Linaza et al., 2008). The Embodied GIS project developed by Stuart Eve in 2014, allowed researchers to study an archaeological sites phenomenology with GIS enhanced reconstructions of past structures. It allowed the on-site researcher to see reconstructions of structures that were no longer there to better understand the sights and sounds and interactions between the inhabitants and the landscape (Eve, 2014). The user could interact with the digital here by immersing themselves in the digitally enhanced landscape and literally walk around buildings that no longer existed.

Each of these projects offers its own piece to the puzzle that is HCI and AR in Archaeology. But what is this puzzle going to look like when its finished? By looking at the trend we can start to see that things are shifting towards gesturing and complete body interfaces as well as full user immersion. Sure you can view all of the augmentations presented in these projects on your computer screen, but there is a difference between seeing a picture of the Eiffel Tower and standing in its shadow. There is a sense of grandeur that is lost on the screen. Augmented reality is a way to bring back the 1:1 ratio we have in real life. It’s a way to bring in new perspectives of old data. Looking at a digital model of a reconstructed ship is great, but having a shipwright able to walk around your reconstruction as if they were a crew member will illicit perspectives that would otherwise be lost. We see this with the PRISMA (Linaza et al., 2008) and Embodied GIS (Eve, 2014) projects.

There are two major areas of concern that is an inherently negative aspect of archaeology. First, archaeology is destructive. Once a site has been excavated it no longer exists. Yes, we have all of the artifacts and notes, but that’s it. The other negative aspect is accessibility. Often archaeological sites are not the most accessible places. This can limit research exposure. However, each of these can be overcome by utilizing various mixed reality systems, most prominently being augmented reality. We saw a taste of this with VITA (Allen et al., 2004) and the AR Cube (Jiménez Fernández-Palacios, 2015) both addressing accessibility. However, I believe the real potential in HCI and AR for Archaeology is AR’s ability to create a virtual environment of an archaeological site with all of the meta-data learned from the lab superimposed onto the landscape. In addition to this, having detailed models of structures and artifacts excavated re-imposed back in situ to their original pre-excavation locations. By doing this the archaeologist could physically walk around a 1:1 reconstruction of the site pre excavation and physically interact with all of the artifacts and data in its original context. This would allow for a greater understanding of the special relationships between objects/artifacts. Combine this with the fact that this is a digital element and it can be deployed around the world offering essentially limitless accessibility to the site, so, if your leading expert cannot make it to the site you can bring the site to them. This walkthrough artifact database as I've come to call it is a large and rather ambitious project that has great potential as a new perspective on site interpretation, but it is not the only avenue. Any of the traditional tools of the archaeologist can be augmented, site maps, section drawings, even photographs can have various forms of data embedded within them. It goes beyond simply embedding a video within a static image. With the utilization of HMD's the archaeologist can view all new perspectives on long studied sites. Augmented reality offers a unique experience to researchers. It allows us to *see* spatially associated relationships between objects. Archaeologists could reconstruct an archaeological site post dig, and walk among the buried artifacts and structures as if they were never moved. The possibilities are vast, and it all starts with a knowledge of what's *been* done and some imagination of what *could* be done.

Chapter 3: Research Methodology

3.1 Developing a Research Methodology

The Archaeomented Reality project was not something that was just drawn up in a single day. Its development was something more organic, it developed out of different interests and interviews with professionals, academics, and students alike. Below is flow chart (Table 3.1) that shows the behind the scenes thought process of the Archaeomented Reality project. Looking at the flow chart we see it starts with two personal interests, Games and Drawing, these interests are the spark that lit my forge of creativity and without them this Archaeomented would most likely never have come to be. That Aside it was the idea of "wouldn't it be cool if we could have a hologram attached to boat plans so we could see the boat in action." This simple thought sparked a much more thorough and academic investigations into this idea.

Informal interviews were conducted with several professors and boat builders in order to better understand the traditional uses of boatplans. These conversations enlightened me to the uses (A-D) of and some of the drawbacks (1-4) to the traditional boatplan. I would like to take a moment to say that the letters A-D and numbers 1-4 do not represent specific issues or uses but rather are a visual placeholder for the fact that I found useful information. The interviews were not all of like mind when I introduced the idea of adding holograms to them in an attempt to make them more useful or to help fix a before mentioned problem. Some were very excited and others could not see the point, I experienced the full range of viewpoints on the subject.

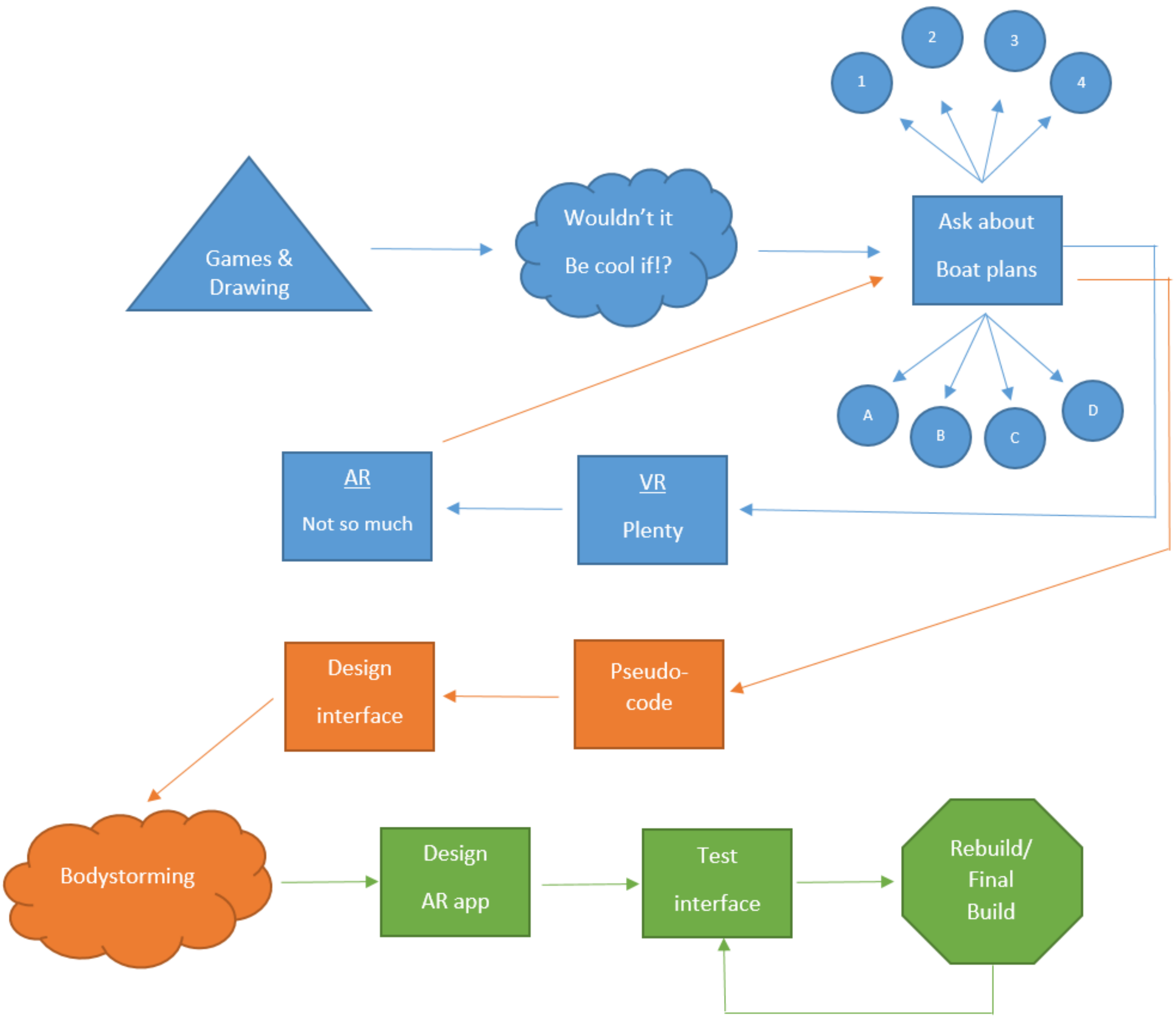


Table 3.1 Flow chart of research project design

3.1.1 VR turns into AR

During the early phases of this research project Archaeomented Reality was going to be a virtual reality system, but early investigations into the literature and existing projects revealed that the field was already flooded with VR projects. During my initial read through of the available literature on VR systems is where I learned about the mixed reality spectrum (discussed back in Chapter 1) and since the field already had an abundance of VR projects the mixed reality spectrum steered the research towards the next system, augmented reality.

Unlike the VR investigations, AR's foothold in archaeology was still very much in its infancy. After an extensive review of the current state of augmented reality in archaeology I readdressed my findings from my initial interviews. It was then that I started to realize the potential for utilizing augmented reality systems for archaeology, not only as a tool for heritage tourism but also as a direct tool for research. It was at this stage where I came up with 3 case studies for this project. The first was an augmented boatplan which will be explained in great detail later in the chapter. The other two were abandoned due to time and resource constraints, but will be explained briefly to illustrate the possibilities of this technology.

The second case study was The Walkthrough Catalogue Database. It is standard archaeological practice to map and record relevant artifactual, feature, structural, and eco-factual remains (Renfrew and Bahn, 2004; Sutton and Arkush, 2009). All of these, regardless of the type of find, are catalogued, or, in the case of features, sampled then catalogued. Depending upon the type of research being conducted, the find may be required to be reconstructed digitally. This reconstruction could come in many forms including a 3D model, simulation, or a digital database of the objects metadata, such as dimensions, find location, and materials, the latter being the most common.

The database containing each finds metadata is one of the primary methods for storing archaeological data in a way that makes it both organized and readily available for further research. The foremost use of these databases is for the preservation of archaeological data. Having a digital copy of the original increases find preservation. Secondly, online databases allow for access to the finds for archaeologists or the general public from other locations without the risk of transporting and damaging the original finds. The final use of the database is one that is inherent of the database itself. Databases allow the users to derive connections from entry to entry (Renfrew and Bahn, 2004). What this means is the user can call for a certain attribute and then link all pieces with this attribute together while still maintaining the piece to parent relationship (Date, 2000) However, depending upon the complexity navigation of the database can be quite confusing.

The Walkthrough Catalogue Database project exhibited the standard uses of the database but in a more interactive manner. By utilizing augmented reality alongside with site maps, photographs, or the site itself, the user would be able to access the data found within the database, including linked relationships, *in situ*. By utilizing a head mounted display, the user would be able to physically navigate around the site, leaving their hands free to interact with the three-dimensional model of the finds. Using virtual buttons, the user can filter the display by stratigraphic layer, by object type such as pottery, tools, structures etc., or to display the order of construction or sites statistics. Another feature of the application will allow the user, while traversing through the virtual space, to “grab” artifacts. By doing this, the rest of the model is removed leaving just the selected object with the metadata, that one would typically be seen on screen in a database, displayed next to it with a link to the actual database web page.

The third and final case study was The Augmented Site Map. All archaeological reports have at the very least two maps. One of the region the site is located in, to put the site in relation to the surrounding area, and one of the site itself (Sutton and Arkush, 2009). Site maps are often done in plan view but can also be seen in profile view. The purpose of the site map is to keep a visual record of the locations of archaeological evidence and their spatial distribution within the archaeological site as a whole. The pinpointing of archaeological finds within a regional map is an integral part of the archaeological process, "while it has been adequately recorded does it become part of the sum total of knowledge about the archaeology of a region" (Renfrew and Bahn, 2004, pg.91).

The Augmented Site Map took the standard site map and set it within three-dimensional space. By utilizing a tablet or other device, the user can view the site map. It would have a 3D rendering of the site emerging from the 2D paper. Virtual buttons along the side of the application allowed the user to interact with the site map. Other key features of the application included the ability to select archaeological features and find locations to view the attached metadata immediately. This would include site reports, photographs, or 3D models of the object. This would allow the user to see a full range of data similar to that of GIS programs but with the added dimension of being able to insert one's self into map and physically walk around the site (to varying scales) and interact with the digital data physically. Similar to that of the walkthrough catalogue database case study, being that you can select finds and examine them, but on a larger scale.

3.1.2 Bodystorming and Design

At this stage of my initial investigations into augmented reality and app development I found that the creation of such an app was a very involved process. My background in computer science did afford me the skills to undertake such a venture but there were still many steps that needed to be taken before dawning the HMD and diving into cyberspace. With a basic idea of what I wanted my case studies to look like I could start the development of the various AR applications.

The first step into designing any program is a good pseudocode. A pseudocode could best be described as an outline. Much like how a literary outline will dictate what sections will fall where within the writing, pseudocode acts like a map charting out what pieces of code will go where and what will call out what. The pseudocode does not always need to include user interface, in fact it very rarely does, however, seeing that my user will be part of the interface, my pseudocode did include a section describing user interface as well as a graphical user interface.

By utilizing my own experiences with existing AR and non-AR applications I designed a rudimentary program workflow and user interface design. The workflow illustrated how the application would work and how the user would interact with it. This workflow was the basis for the bodystorming session testing the design. Bodystorming is similar to a brainstorming session with one distinct difference. In a bodystorming session you act out and pretend to use the device that you are exploring. The following subsection is an outline detailing the events that took place during the bodystorming session.

3.1.2.1 Bodystorming outline

Body storming session (25/02/17)

- Participants- 2
- 1 archaeological phd candidate
- 1 professional artist

1. Introduced the group to how the application will work and what features will be included in the app and what hardware will be used.
    a. Showed them the boat plan (physical paper), and the head mounted display (HMD) that will be used (PlayStation VR head gear outfitted with a GoPro). *This was later replaced with the more sophisticated HoloLens.
    b. Once the initial description and introduction to the devices and application, I showed them how the app would look in practice. I did this by using a series of props and hand motions while they viewed the video feed from the HMD so that they could see what I saw while I explained how interactions would take place.
2. From this point I answered typical questions on terminology such as what is a virtual button and how they work.
3. The participants then took over with the equipment trying the HMD on and analysing it as a piece of equipment in terms of comfort and usability. They were very happy with it in both comfort and usability.
    a. Each acted out basic movements such as grabbing virtual objects, selecting buttons, and moving around the 3D models.
4. Concerns/issues
    a. Most of the concerns, initially, was still grasping how the application heads up display (HUD) or console would look. To aid in this I offered several drawings and physical gestures to illustrate as best as I could.
    b. Quickly one of the first problems that was noticed involved the virtual buttons. In order to select them you have to move across other virtual buttons. This could

cause confusion with the app or accidental selection of features just by simply passing over a button to press the one behind it.

c. Another problem involved perspective. Having the boat plan flat on a table offered perspective issues. Perhaps on an incline such as a drafting table or even attached to the wall. But then this raises the question of the typical use is flat on a desk by having it so that this isn't an option does this limit availability/usability.? And for what I'm doing does it even matter?
    i. The third main concern was that of handling the virtual content. How does the user, move, pan, rotate, and or zoom the 3D models? The use of hand motions made things seem overly complicated. The solution of using a tangible object to control the movement of the models seemed like the easiest solution. From a physical standpoint. Not from a programming stand point.
    ii. An object such as the AR Cube to move and rotate the model. However, a button to lock the model in place so that the cube can be put down without changing the model is a must.

d. The final piece of criticism, which is a big one and offered very thought provoking question. Is the tablet even needed? One of the participants said if I'm already holding the tablet why don't I just use the tablet to look at the models online without all the AR stuff. It's easier to just use the tablet the normal way to look at models than it is to handle and move around the boatplan with a tablet in one hand and doing controls with the other.

3.1.3 App testing and publication

Armed with the knowledge gained from the bodystorming session I could start to build and code the AR applications. The creation of the specific applications can be seen in Chapter 4, but the process for any application is a series of coding and testing cycles. At this stage I began the development of the AR applications, this process involved two distinct aspects. First, I would need to build the virtual environment; and second, I would have to code the interface to allow the user access to and interaction among the virtual environment.

Once I had a working application I brought the two participants back from the body storming session to test and interact with then new application. This session was geared towards user-friendliness of the application and how intuitive the gestures would be. The feedback gained from this trial would be used to debug and refine the AR application. This process was repeated several times until the final build of the application was published and rolled out onto the marketplace. This process was repeated for all applications built for the case study.

As stated at the start of this chapter Archaeomented Reality was an organic every changing process. The previous sections detailed multiple instances of investigations that directly changed the forward progression of this research project and because of these alterations a solid research methodology needed to be created. Having the AR applications was just the first piece to the puzzle. Knowing how to implement them and study the user experiences with them is the rest of the picture. The following sections outline in great detail how the participants, the field, the technology, and my self-developed AR applications would be studied and quantified into usable scientific data to answer the research questions posed in Chapter 1.

3.2 A comparative analysis methodology

A key component to the research being conducted is the examination of or potential ramifications that can come as a result of, using augmented reality as a tool for maritime archaeological interpretation. In order to do this, a comparative analysis was conducted. The primary reason for doing so is that augmented reality as an archaeological tool has not existed within the field of archaeology long enough to properly understand the ramifications of its use as established in Chapter 2 section 2.5 *Augmented reality within archaeology*. However, it has been used in other fields for extended periods, from which we can derive a parallel relationship between those fields and archaeology to understand these ramifications.

Using fields such as gaming, tourism, and marketing, the uses, applications, and lifespan of augmented reality can be examined to gain an understanding of how the technology was adapted, how practice or theory was changed by this adaptation, and how future projects were directed or impacted by the introduction of the new technology.

3.2.1 What is a comparative analysis?

A comparative analysis consists of using multiple outside sources and comparing it to the source in question in order to derive a projected result. This type of analysis has been done on multiple occasions in many different fields (Perrow, 1967; Barley, 1990; Eltigani, 2000; Klein, 2000).

During the comparative analysis, how maritime archaeology was affected in the past by the introduction of new technologies was investigated as well as how the field adapted to that change, how theory and practice were changed as a result of that adaptation, and how future projects and research were directed by the change. These facets of inquiry will be compared to that of other fields with their experiences with augmented reality.

3.2.2 A comparative analysis methodology rational

3.2.2.1 Rationale of method

A Comparative analysis has been chosen for multiple reasons. The first and foremost reason is that it offers a means of studying the ramifications of a particular piece of technology across fields. This is because the use of augmented reality within the field of archaeology as a tool for data has not existed for very long. One of the earliest uses of AR as an archaeological tool was the VITA: Visual Interaction Tool for Archaeology project in 2004 (Benko et al., 2004). Whereas in other fields the technology has been implemented for much longer (gaming, 16+ years (EyeToy, 2000; Thomas, 2000); Tourism, 15+ years (Vlahakis, et al., 2001). It is because of this lack of a longstanding relationship that we need to reach out to other fields that have relatable aspects so that we can derive a comparative understanding of the potential ramifications. The use of a comparative analysis has a proven concept of successfully being used across multiple disciplines.

3.2.2.2 Rationale of fields

The field of maritime archaeology was impacted greatly by the introduction of the ArcGIS software. By investigating how the field was affected by this technological advancement in practice, theory, and future projects a baseline can be designed to compare how other fields were impacted by augmented reality in practice, theory, and future projects. By taking what is learned from the investigation into the ramifications of the introduction of this technology and comparing it to how the gaming industry, marketing, and tourism fields have adapted to, had practice and theory changed by, and how future projects were guided by, augmented reality, one can derive a projected correlation between the three test fields and maritime archaeology.

These three fields were chosen based on the types of augmented reality applications they employ, the technology to implement, and how long they have used these AR apps. These three reasons are key to keeping a suitable correlation between the fields. The type of applications utilized by the gaming industry offers high registration with low latency (Clandestine: Anomaly, 2015; Invizimals: The Resistance, 2015), which is suitable for immersion. As far as types of medium go augmented reality is meant to be “experienced” and not just seen. The low latency exhibited in the gaming industry allows for the user to immerse themselves into the game world and it is this action that marks an AR application for success. The high levels of registration or the accuracy of the digital information aligning to the physical world, that come with the gaming industry is crucial to the field of archaeology. The field of marketing offers low impact applications that are user-friendly (IKEA AR Catalogue, 2013; The Shisedio Makeup Mirror, 2010). These attributes are crucial when being implemented in a field that has varying degrees of technical know-how. Not all archaeologists are trained the same way. Having an application that is easy to navigate and will ensure that most can use it, as seen by the work done by the Shisedio Makeup Company and the Shisedio Makeup Mirror (2010). The mirror allowed anyone to walk up and use it, with zero training, to apply digital makeup to his or her face as a means to test the products before purchasing. The field of tourism implements AR apps that offer great data display that is also not distracting (Sekai Camera, 2008; Wikitude, 2008). This is a crucial aspect for archaeology purely at its face value. Archaeologists have to process a wide range of data that include but not limited to types of materials used in artifacts, various quantities of artifacts, area distribution, object densities, settlement patterns, trade networks, subsistence patterns etc. and each of these types of data can be substantial on their own. For instance, a project studying the trade network of Mesoamerican Indians can accumulate data reaching from both South and North American tribes. By utilizing aspects of tourism applications, archaeologists gain the added ability to show those massive quantities of data in a non-distracting manner.

3.3 A qualitative case study methodology

A qualitative case study is a research method that enables the researcher to examine an aspect of their research within its framework by using a range of data sources. By doing this, the researcher ensures that the aspect that they are researching is not examined by a single point of view, but rather by a variety of viewpoints. This, in turn, will allow for multiple components of the aspect to be exposed and understood (Stake, 1995; Yin, 2006).

Robert Stake, who wrote The Art of Case Study Research (1995), and Robert Yin, who wrote Applications of Case Study Research (2006), base their guides of qualitative case study design around a constructivist paradigm. Constructivists believe that the truth depends on the individual's perspective and is, therefore, relative. This approach to qualitative case study design "recognizes the importance of the subjective human creation of meaning but does not reject outright some notion of objectivity. Pluralism, not relativism, is stressed with a focus on the circular dynamic tension of subject and object" (Miller & Crabtree, 1999, pg.10). The advantages of which, according to (Crabtree & Miller, 1999), using a constructivist approach to a qualitative case study design is the close-knit relationship between the researcher and the participant, while still allowing the participants to tell their part independently.

3.3.1 A case study methodology rational

A case study methodology should be considered when the research being conducted is geared towards “how’s” and “why’s”, the participants behavior cannot be altered in any way, specific conditions within in a controlled setting need to be examined due to their potential relevance to the aspect under study, or the parameters or scope of the aspect being studied is not clear between it and the context of the aspect itself (Yin, 2003).

Examining Robert Yin’s (2003) criteria for when to use the qualitative case study approach, the choice of using it is apparent. As discussed in the Aims and Objectives section of Chapter 1, the three primary research questions being addressed are:

1. Analyze the potential role of augmented reality technology in maritime archaeological interpretation.
2. What are the ramifications of augmented reality on maritime archaeology interpretation?
3. Does augmented reality provide a sustainable solution to the issues present in traditional tools and techniques of maritime archaeology interpretation?

The first reason to consider a case study approach proposed by Yin (2003) is how and why questions. Research question 1 is addressing how AR will affect maritime archaeology interpretation. The second reason suggested by Yin is that the researcher cannot alter participant behavior. Since the research is to determine the usefulness of a new technological tool within a field, it would be impossible to manipulate the behavior of all the users. The third reason proposed by Yin is that the research addresses specific conditions, not directly related to the research questions on hand, but by using specific conditions the researcher can take a holistic approach, this is discussed later. The final reason proposed by Yin addresses the scope and context of the research being unclear in its relationships to one another, can apply to both research question 2 and 3, as the relationships will have to be examined through a comparative theoretical analysis (Yin, 2003).

Using a qualitative multi-case-study methodology allowed for the holistic study of how augmented reality affected maritime archaeology interpretation. The multi-case-study approach allowed for a full interpretation of maritime archaeology interpretation without the need for testing each and every instance in which archaeological interpretation would take place. According to Yin, (2003), a multiple case study allows the researcher to investigate the differences across multiple cases as well as within the individual case. The key objective of the multi-case approach is to repeat outcomes and results across cases. By doing this the researcher can derive comparisons from among the different cases, and it is because of this, the cases must be chosen and designed in such a way that a comparison can be made.

This is evident in the case studies conducted by Campbell & Ahrens (1998), titled “Innovative community services for rape victims: An application of multiple case study methodology” and by Kent G. Lightfoot (1995), titled “Culture Contact Studies: Redefining the Relationship between Prehistoric and Historical Archaeology.” Each of these case studies takes multiple cases and derive a holistic view of the phenomenon being studied.

3.4 The case study

Terrestrial archaeologists use a variety of tools, techniques, and knowledge to make site or object interpretations, the same applies to the maritime archaeologist as well. The primary research that I have conducted has both a desk-based assessment on the application and the effects of augmented reality in other fields through a comparative analysis as well as a field-based investigation within the field of maritime archaeology. This consisted of a single case study with three experiments geared towards archaeological interpretation. The case study focused on tools and techniques of varying degrees of complexity and capabilities.

The subject matter of the three experiments was chosen in such a way so that they all address the same aspect (tools and techniques for interpretation) but on different subjects. By doing this, it allows for a holistic viewpoint on maritime archaeology interpretation without the need to address each tool or instance in which an archaeologist would need to make an interpretation on a site or artifact. The following sections will detail briefly what the case study will entail and the rationale behind the project. A more detailed breakdown of the case study will be supplied in the Case Study Chapter.

3.5 Criteria for Quantifying

3.5.1 Introduction

The case study involved a series of observations, surveys, tasks, and interviews to be taken in order to analyze their results. A flowchart of the events that took place during the case study can be seen in table 4.1 in the following chapter, where it will be discussed in detail. The criteria that were used to quantify each case study is defined in the preceding section.

3.5.2 Criteria

3.5.2.1 User-friendliness

The first piece of criteria set into place to address the quantification of the successfulness of the case study being conducted was user-friendliness. The applications being developed for the case study must exhibit some degree of interaction with the user that is both easy to use and understand. Elaborating further on this, the definition of user-friendly will be examined. The Oxford English dictionary defines user-friendly in regard to software as 'easy to use'; likewise, a definition from the field of technology "describes a hardware device or software interface that is easy to use. It is 'friendly' to the user, meaning it is not difficult to learn or understand" (Techterms.com, 2016).

In multiple publications, it has been revealed that the more the user needs to contribute, the more the user considers the program to be unfriendly (Hu, Pai-Chun, & Chau, 1999; Xie, 2003, 2004). It is because of this factor in order for a program to be considered friendly a good user interface (UI) is needed. The UI must be able to combine functionality and pleasantness while still allowing the users to be as minimalistic as possible but still being able to conduct the task within reasonable parameters (Vilar and Žumer, 2008).

I am defining user-friendly as a subjective term that should meet four standards in order to be classified as such. First and foremost, the software should be simple. The interface should not be 'busy' and full of buttons and menus and should allow for the easy and quick access to common actions or commands. Related to this is the second standard; the software application should be intuitive. The standard user should be able to navigate the software and use it with ease. The user should not need to read an extensive manual to use it. The third standard is the software should be organized. The actions should flow through easy to navigate menus and options. The final standard for classifying software as being user-friendly is reliability. This is the most important of all. Having a piece of software that can crash frequently is a great source of stress.

3.5.2.2 Streamlines A Process

The tool that is the focus of the case study to follow was used as part of a process. The focus of the second criterion is based on whether or not that process is expedited in any way. This is a crucial criterion in such a way that it deals specifically to the worth of the software applications designed for the case study. As with the first criterion, the Oxford English Dictionary defines streamlined as 'to make more efficient and effective by employing faster or simpler working methods.' Similarly, how a more closely relatable field would define streamlined as "to improve the efficiency of a process, business or organization by simplifying or eliminating unnecessary steps, using modernizing techniques, or taking other approaches" (BusinessDictionary.com, 2016).

Advances in technology or the introduction of technology, in general, make things faster, more efficient. A pilot project conducted in an archaeological laboratory studying the effects of using 3D scanning technology to analyze wheel-produced ceramics. The results of the study concluded several advantages to the introduction of the new technology. The most important of which was the increase in productivity. Before its introduction, the potsherds were analyzed with manual drawings that were produced at 15-20 a day. After the introduction, 100 potsherds were being able to be analyzed a day (Karasik and Smilansky, 2008).

I am defining this criterion as a more closely related phrase to that of the business definition, in that the elimination of unnecessary steps is needed. Archaeology is not always put to a rigorous time scale, and most certainly not with regards to the post-excavation processes. That being said, the advancement of the tools being used by archaeologists does, in fact, make that process easier and to keep to that trend the introduction of new technologies should follow this. Which is why the defining characteristic of this criterion is that the software applications presented within the case studies need to eliminate actions, steps, or processes with their use that would be required in their absence.

3.5.2.3 Output > Effort

The third criterion in the set of criteria for quantifying the case study relates to the worth of the application. Does the output rendered by the augmented reality application have a greater value or equal value than that of the time and effort required to create the AR application? In other words, if the creation process of the AR application is too intensive and the output is nothing more than a visualization, it was not worth the time.

This criterion's parameters included the time needed to create the augmented tool versus the time to make the standard tool. This is compared to how much is gained and to what degree the data derived from the tool is versus that of the standard tool. I am defining this criterion as a relationship based on what is gained versus time lost. This is a simple efficiency technique used by businesses to weigh new protocols and procedures (Sozofirm.com, 2016).

3.5.2.4 Redefines the Typical Use

The typical uses of the tools and techniques being examined by the case study are clearly defined within the case study chapter. What the fourth criterion is used to determine is whether or not these typical uses are added to or completely redefined. The standards for this criterion were simple and were defined for the quantification of this case study as follows: If the augmented reality application can attribute additional application purposes for the tool or open up new avenues for interpretation, then the typical uses of that tool are redefined.

An example of this would be mobile phone technology, in its extreme ends you have the Motorola DynaTac 8000X and iPhone7 (figure 3.1). Looking at the DynaTac 8000X's specifications, it offers a charge time of 10 hours and 30 minutes of talk time. Complete with a LED display to dial phone numbers and recall capabilities of 1-30 different phone numbers (Redorbit, 2016). Comparing this to the iPhone7's technical specs; 1 hour charge time and 14 hour talk time. A 4.7-inch Retina HD display, and a memory storage of up to 256GB (Apple, 2016). These are just the specifications that they have in common. The iPhone7 offers a plethora of other features ranging from a 12mega pixel camera to standard Bluetooth headphone capabilities. Looking back at figure 3.1 further along the timeline closer to the present day, there is a shift for larger screens with better imagery, the mobile phones typical use is being changed by the introduction of new additions of technology. The mobile phone has shifted from an auditory device to a visual device its typical use is no longer to make a phone call, it is to check social media, email, schedules, send texts, video chats, and even to find new relationships, all of this because of the additions of a new technological aspect.

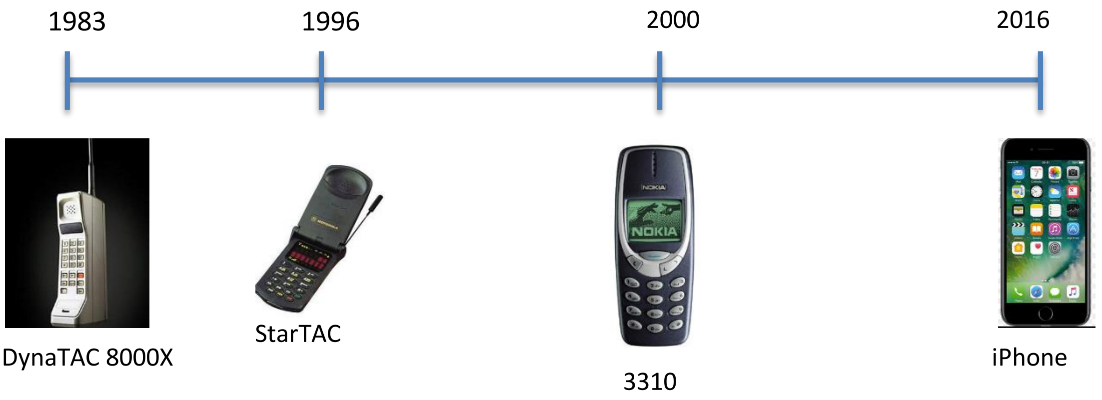


Figure 3.1 Timeline of mobile phones.

The scope of this criterion did not exceed any outside sources to aid in the redefining of uses. In other words, the augmented tool cannot receive additional support from outside sources other than those used by the standard tool. For example, if the standard tool utilized a physical star map to be read in conjunction with the standard tool, then the augmented tool may utilize that same star map.

3.5.4.5 Sustainability

The final criterion designed to quantify the successfulness of the case study presented within this research project addressed sustainability. This criterion speaks to the ability of the application to be a sustainable asset. As with the other criteria, the Oxford English Dictionary defines sustainability as 'the ability to be maintained at a certain rate or level.' Looking at a more industry specific definition, more specifically how the Software Sustainability Institute (and instituted founded with the purpose of supporting the UK's research software community) defines sustainability. "Software sustainability describes the practices, both technical and non-technical, that allow software to continue to operate as expected in the future" (Hettrick, 2016).

I am defining this criterion as the ability for the software to have a repeating presence of opportunities to be applied to other archaeological research projects. To further clarify the augmented reality application should demonstrate the ability to be applied to additional areas outside of the case study itself indicating a presence of need.

3.5.3 Task Design

The design of the individual tasks that were carried out by the participants during the case study is discussed in great detail in the Case Study Specific Quantification section within the case study chapter.

3.5.4 Observation Design

The observation that was carried out while the participants were working with the augmented reality applications was a critical step, even more so than some sections of the survey that followed the application. The observation of the participants allowed for the interpretation of their experience with the application without a break in presence, which is a quintessential aspect of the AR experience (Turner 2007). Immersion is a fundamental component of augmented reality; the feeling of being there is what drives this (Heeter 1992). By stopping and interacting with the participants during their use of the application, it would only detract from the immersion and skew the results of the study. To mitigate this, the solution of silent observation in conjunction with a video with sound recording was used as well as a screen recording of the devices uses. Privacy and anonymity are addressed later in the Criteria for Quantifying section.

The specifics of what is to be observed during the participants' usage of the AR applications included but was not limited to, their body language in terms of mood and self, interactions with surroundings, interactions with the device and software, and the pace in which they progress through their tasks.

The primary goal of the observation was to investigate not only how the user physically reacts to the AR application but also how it affects their movement and reactions to their surroundings. The other goal of the observation was to reinforce the responses to the survey being taken directly after the use of the application. Observing frustration or a lack of, reinforced the analysis of the participant's responses to the survey and ultimately the criteria set in place to quantify the case study.

3.5.5 Survey Design

The design of the surveys being conducted at the conclusion of the usage of the AR application was specifically designed to address multiple aspects of the quantifying criteria. First and foremost, of the survey design is the number of questions for each survey. Due to the amount of time that is set-aside for the participants to complete their tasks the survey will be relatively short. Each survey had between ten and fifteen questions. The specifics of the questions are addressed in the Case Study Specific Quantification section within the case study chapter. There were 21 participants in this survey, each of which was well educated within the field of archaeology but exhibit varying degrees of technical know-how.

The administration of the survey is of particular importance. In order to not skew or sway the results as best as possible, there are a few aspects that must be addressed. The first aspect I wish to address is one also related to the power dynamic, and that is the person who is asking the participants to participate. For example, if it were a professor asking students to take the survey the students may feel like it could impact their grade. This was not an issue, as the researcher (myself) had no official or non-official authority over any of the participants. The next aspect of the administration of the survey that needs to be addressed is the anonymity of the participants. The recordings were held on a secure encrypted device that was password protected off site. In addition to this at the start of each session, the participants were issued a number, unknown to them so as not to be shared amongst the participants, to be used instead of names; this was for transcription purposes, and names were removed from any written record.

The types of questions that were asked by the survey varied from Likert scale questions to short answer. As with the tasks and number of questions, the specifics of the types of questions are discussed within the Case Study Specific Quantification section within the case study chapter.

The analysis of the survey included a variety of methods from SPSS analysis to simple arithmetic allowing determination of percentages. As with previous aspects, the specifics of analysis and to which research goal they will be addressing is covered in the Case Study Specific Quantification section within the case study chapter.

3.5.6 Overall Analysis

The analysis of the surveys conducted during the case study each address the same five criteria (user-friendliness, streamlines a process, output > effort, redefines typical use, and sustainability). This was a conscious decision based on the work of Robert Yin (2006, 2008) and Robert Stake (1995), indicating that the deriving of a holistic view of the research is possible through the examination of similar aspects across multiple experiments. By keeping these five criteria the same across the three experiments and designing the survey and interview questions to address these in an unbiased way, a holistic view of the field can be taken from these results (Yin 2006,2008; Stake 1995). The specifics are outlined in the results sections of Chapter 8.

3.6 Addressing sustainability

Sustainability in terms of this research is defined as the ability to take on the attribute of usefulness in areas outside of the original design parameters. To put this simplistically, sustainability will be achieved if the augmentations can be useful for other projects and not just for the ones designed for the case study. The ability for technology to have multiple uses across the field is an important part of that technologies usefulness and lifespan within a discipline.

The research question proposed in the Aims and Objectives section of Chapter 1, more specifically "Does augmented reality provide a sustainable solution to the issues present in traditional tools and techniques for maritime archaeology interpretation?" was addressed by a comprehensive analysis of the case study by investigating criteria that have been developed to address this question. Specifically, whether or not the effort put into the creation is less than what the user receives and whether or not the applications have used with other subjects/sites.

In addition to the comparative analysis of the case study, a comprehensive investigation of other fields and their usage of augmented reality applications within their field also lent insight into this research question. By looking at other fields that have used augmented reality in similar ways to that in the case study and comparing their usage of AR over time through comparative theoretical analysis, the sustainability was derived across fields.

Chapter 4: Case Study: The Augmented Boat plan

4.1 Case study aims and background information

This case study addresses the potential of augmented reality to enhance maritime archaeological interpretation tools and techniques. The primary research aims are as follows:

- Does AR improve the tools and techniques of interpretation?
- Does AR complicate the tools and techniques of interpretation?
- Does the creation process of transferring the typical tool into an augmented tool, require a greater amount of effort than that of what is gained by the product?
- What effect does AR have directly on the typical boat plan?

In order to accomplish these research aims, I am adapting methods from the human computer Interaction (HCI) field because my research is directly related to how an archaeologist could use a computer interface to interact with their standard tools in new ways.

Maritime archaeologists employ a variety of detailed maps, diagrams, drawings, and plans as part of their research (Renfrew and Bahn, 2004). One of these is known as a boat recording. Boat recordings can be done either by hand or using scanning techniques, such as a laser scanner. The product of which can be seen in figure 4.1. A boat recording is a detailed depiction of a vessel and all of its parts. The process requires a large number of measurements and calculations in order to produce a useable boat plan.

The boat plan outlines size, shape, and location of all planks, frames, rigging, and any other component that has been found in association with the vessel, or vessel wreckage. Making a boat plan by hand allows the researcher to gain an intimate knowledge of every inch of the vessel. This has many obvious benefits to the archaeologist, including: finding and identifying abnormalities like graffiti, makers marks, or other small markings not directly associated with the vessel's seaworthy capabilities, or identifying various tool marks, or the order of the construction of the vessel (Green, 2004).

Boat plans are used for numerous applications, including but not limited to: experimental archaeology, replica building, understanding historical aspects such as vessel morphology changes over time, and figuring out how the vessel was built, why it was built, its seafaring capabilities, and cargo capacities, for when there is no direct access to the original site or vessel, and teaching purposes (Standard and Guidance of Nautical Archaeological Recording and Reconstruction, 2014).

4.2 Boat plan uses and problem areas

As with any archaeological find, there are procedures designed for the proper recording and mapping of the find, and boat recordings stay true to this as well (Renfrew and Bahn, 2004). Archaeologists conduct a boat recording survey as a standard procedure for a find. The typical boat plan would include a top view, side profile, and various cross-sections along the hull see figure 4.1. A ships line plan could also be included, see figure 4.2. The resulting boat plan would ultimately be included in the appendix of the archaeologist's report on the site. The purpose of a boat recording is a visualization for the accompanying text. However, there are problems with the standard boat plan (Standard and Guidance of Nautical Archaeological Recording and Reconstruction, 2014).

A fundamental problem with boat plans is that you only see what the creator has given you. The idea behind all archaeological illustration is accuracy but there is still objectivity, as with any illustration. However, each archaeologist or archaeological project will have different thresholds for what amount of detail makes it into the boat plan. According to Menna, Nocerino, and Scamardella, if the actual shape of the vessel is of utmost importance, the usual assumption that vessels are symmetrical cannot be applied to the survey, and the surveyor conducting the survey cannot record only half of the vessel. However, if the survey's purpose is to show distortion, alteration or damage, the product will not be corrected to show an approximation of the original design intentions but will be drawn to enhance the views of the irregularities (2012). The other fundamental problem that I will mention is significant but may not be applicable in every boat plan. Rafts, boats, and ships all have a humanistic element that is attached to them that cannot be seen on line drawings of the vessel but are just as important. Seeing crew stations, where and how they would sit, or perform their tasks will help the user of the boat plan better understand how the vessel was used. Which according to research conducted by Eve (2014) and work done by Rennell (2012) one of the goals of visibility study is "to engage with human scales" (Rennell, 2012, pg.513).

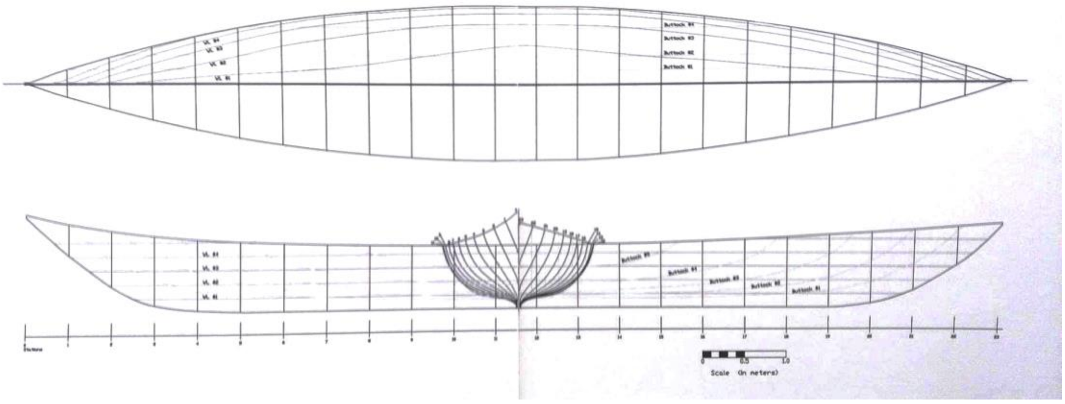


Figure 4.2 Ship Lines of the Eliza. Courtesy of Parkinson (2000).

4.3 Evidence of need

The boat recording is a crucial piece of equipment when conducting a reconstruction or even when it is a supporting document within a report, but as stated in the previous section it is not without its limitations. To reiterate the issues surrounding the boat plan, they are inherently subjective to the needs or mind of the surveyor. The second issue presented here is that they lack the human element.

The use of three-dimensional models could help mitigate these concerns. Here is a quote taken from The Dover Bronze Age Boat “the design of the boat required a three-dimensional visualisation of the intended shape as a linked structure” (Clark, 2004, pg.209-210). This was in reference to the Dover Boat. The reconstruction process was noted by having a failed launch in its early stages believed to be as a result of having been completed only hours prior to its first launch.

Another quote presented by Menna, Nocerino, and Scamardella “3D virtual models can permit to answer to scientists’ questions about historical advances in shipbuilding and test different hypotheses. They can help in comparing diverse strategies for the preservation or restoration of the surveyed object, allowing to prevent any potentially dangerous action” (2011, pg.247). This is arguing that the use of 3D models can only improve the scientific process and help answer research questions. To support this claim, Hocker states that 3D digital documentation of vessels increases the accuracy of the boat recording itself. By utilizing 3D modeling of ship timbers, the storage of geometrical information about the timbers can be stored in three dimensions (Hocker, 2003).

4.4 The augmented boat plan

My case study will address the issues stated above with the boat plan and possibly some other fundamental problem areas. To accomplish this task, I will be implementing augmented reality technologies to enhance the standard boat plan. By dividing the key areas of a boat plan and identifying what other types of information or data would be useful alongside it, the key problems mentioned previously can be mitigated.

A tablet and head-mounted display (HMD) will be used in this research instead of a smartphone due to the increased technical specifications of the tablet and HMD and the larger screen that will allow the user to see a larger area of the boat plan. By utilising these two pieces of equipment, a boat plan can be augmented in multiple ways. First and foremost, the main section could be augmented to display an interactive 3D model of the vessel. This model would have various virtual buttons that can be selected to alter this model. Depending upon which virtual button is selected the model can show either the order of construction, parts of the vessel such as frame, shell, rigging, etc., the final virtual button could display the vessel in use, showing the position of the crew. Other aspects of the augmentation could include three-dimensional models of common tools used on board and models of the rigging.

For this case study two AR applications were created for two separate vessels. The design of these applications was the product of need analysis combined with a technique called body storming due to the applications interactive nature. The process of body storming involves taking users and having act out the motions of use while an operator simulates the effects of their actions. The purpose of the exercise is to understand what movements and actions work better with different aspects of the application. The body storming phase showed a large desire for hands-free options and virtual button interactions.

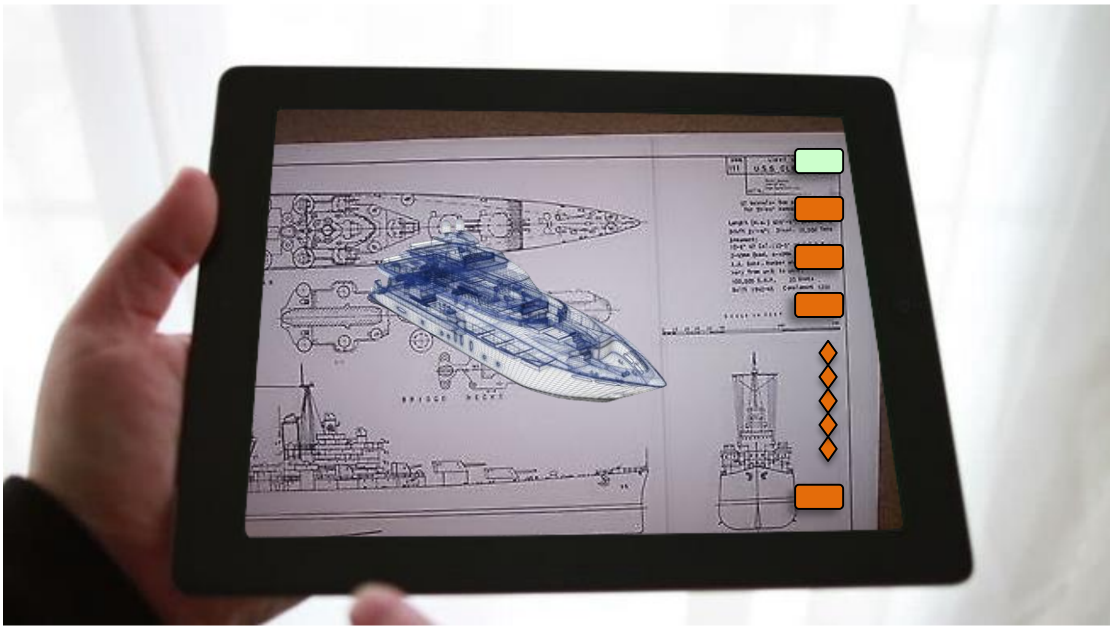


Figure 4.3 UI of augmented boat plan application. Image courtesy of author.

For this case study there were three vessels chosen, the first vessel is a small boat called the "flying Foam". This vessel was chosen based upon the clear and completeness of the boat plan itself. It offered a complete vessel with top view, side view, and three cross-sections. This simple but encompassing boat plan is ideal for experiment 1 which will be discussed in the case study design section of this chapter, as with experiments 2 and 3.

The second vessel chosen, for experiment 2, was the 1706 Warship Hazardous Prize. This vessel was chosen for experiment 2 because it offered a ready-made collection of 3D models, remote sensing scans, and surveyed measurements. The Hazardous Prize wreck represents a typical wrecked ship site making it ideal for the case study and giving a more holistic view of typical boat plans encountered in archaeology.

The choice vessel for experiment 3 will be the Elisa, an Azorean whaling boat. The exact age and origin of the vessel are unknown, but there are several clues that narrow this down. In work done by Tom Parkinson (2000), he outlines through correspondence letters around the time it was purchased by the Exeter Maritime Museum in Horta in March of 1981 the vessel was referred to as old. And again, in a fleet log the Eliza was registered as a whaleboat in 1949. Parkinson also references photographs, and the exhibit board, which says the boat was built in the 1940's but has determined that no correspondence can determine an exact build date and because of this he settled on a build date of between 1940 and 1949 (Parkinson, 2000).

The Azores whaleboat was a derivative of the New Bedford whaleboats from the 1860's. These were characterized by having batten seams, close frame spacing and thwart knees. The New Bedford whale boat also had a centerboard case. However, since the Azores whale-boat was launched from the beach, the centerboard box was removed due to the fact that it would pick up sand and rocks during launch and would jam. Also due to the beach launching, as opposed to its American counterpart that was launched from a ship, the Azorean model is longer allowing for seven crew members. In addition to these features, the hull is carvel built, due to noise in the water, and the hull is double ended to backwater quickly while harpooning (Parkinson, 2000).

This vessel was chosen primarily because of the amount of detail in the boat plan (Parkinson, 2000). The methodology set in place in the boat recording itself was very detailed. Tom Parkinson's methodology involved the rigorous measuring of every minute detail on the vessel using multiple anchored measuring arms with stationary datum's. This was done to ensure pinpoint measuring from exactly the same position. For a complete detailed report on the methods used see An Archaeological Study of Eliza and Azorean Whaleboat: Draft 4 (Parkinson, 2000) This attention to detail has lead to the creation of a high-quality boat plan, which makes for a good baseline to measure the success of the augmentation, which will be discussed later.

4.5 Case study design

Augmented reality increases the types of archaeological data available in the same amount of physical space and, therefore, produces a more streamlined process when procuring data from the augmented source. In order to test this hypothesis, the case study will have three experiments.

Experiment 1

This was the control experiment. They will be given an un-augmented boat plan. They will be given a series of tasks to complete using the traditional means of procuring data from a boat plan. They will be provided paper, pens, and measuring sticks. A copy of the tasks can be found in Appendix A. The session will be video recorded for observational purposes, as well as timed for completion. Once the participants complete the tasks, they will be given a brief questionnaire consisting of five Likert scale questions and four short answer questions (available in Appendix B).

Experiment 2

For experiment 2 the participants will be given handheld displays that will be used as a user interface to the augmented reality software. They will be given the same tools as experiment 1 in addition to the AR app. The key difference between experiment 2 and experiment 3 is the user interface. Since user immersion is a key concept for augmented reality investigating different means of usability will provide a more holistic view. As with experiment 1, experiment 2 will be given the similar tasks to complete (Appendix C), as well as five Likert scale and short answer questions to be answered upon completion of the set tasks. This session will also have the devices screen recorded for observational purposes as well as timed for completion.

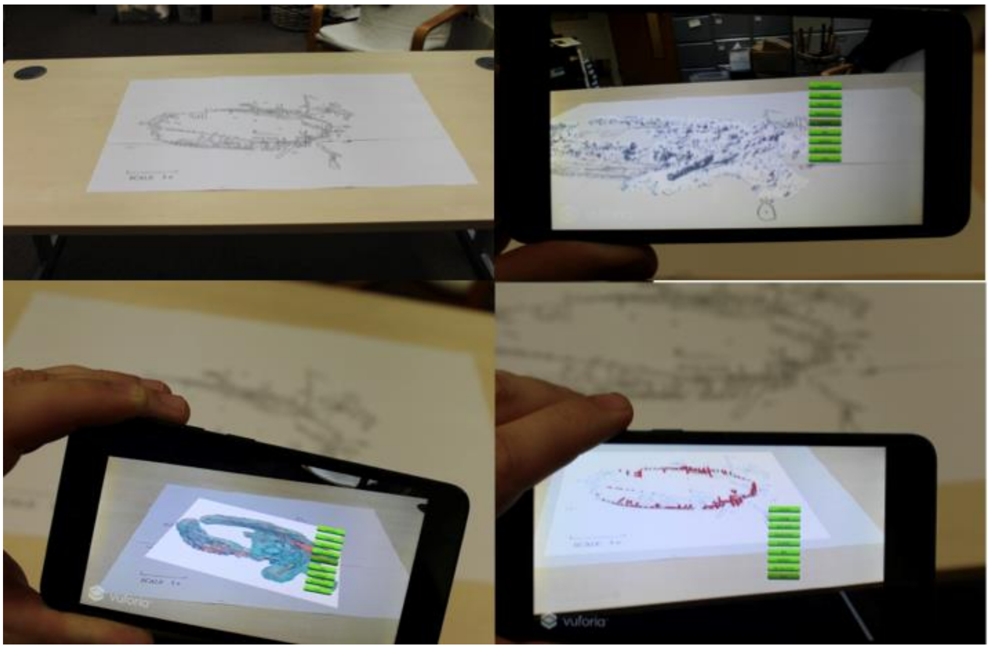


Figure 4.4 Hand-held device and AR application used with experiment 2. Image courtesy of author.

Experiment 3

For experiment 3 the participants will be given a head mounted display that will be used as a user interface to the augmented reality software. They will be given the similar tasks (Appendix D) to complete as experiment 1 and experiment 2. Experiment 3 will be given the same tools as the control group (paper, pens, and measuring sticks), in addition to the AR application. This session will have the devices screen recorded for observational purposes, as well as timed for completion. As with the other experiments, this experiment will also have five Likert scale and three short answer questions to answer once they finished their tasks (available in Appendix B).

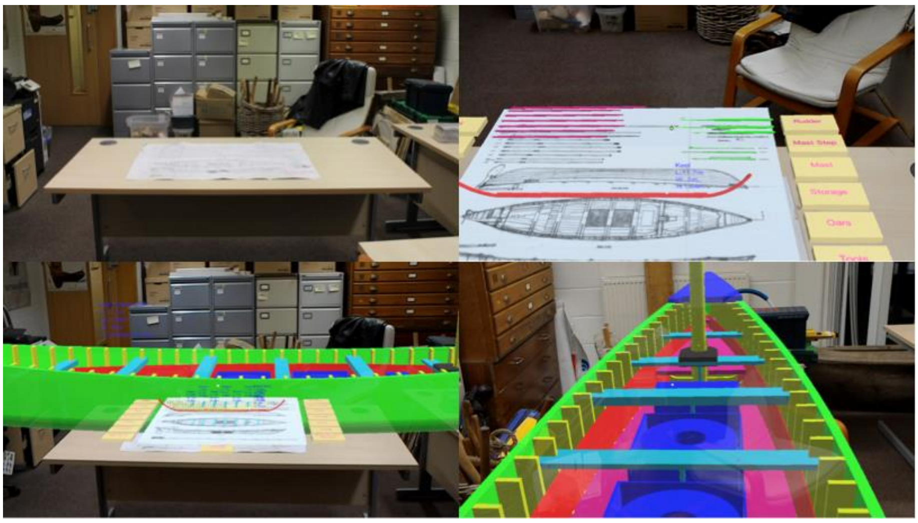


Figure 4.5 Example screens from AR application used in experiment 3. Image courtesy of author.

Before selecting participants, the ethical guidelines outlined by The University of Southampton will be observed, and the project will be approved by the ERGO committee. Before the selected participants can begin their tasks, they will be given a health and safety and knowledge base survey used to screen for health risks and to draw a baseline of their knowledge of the various tools and techniques used within the case studies three experiments (available in Appendix E). They conducted the experiments alone as an individual. I, being the case study administrator, will not to be part of any group instead I will act as an outside observer. The purpose of this is to observe the user immersion and retain the objectivity of my participants and myself.

The participants will be given two small projects to acclimatize them to the technologies that they will be using during the case study. The first acclimation project will involve a blueprint of a single room (appendix F). The participants will then be given tasks to complete that simulated the tasks that they would be performing during the case study. A copy of the tasks that will be

Figure 4.6 Head mounted display, Hololens, used throughout the case study. Image courtesy of author.

given during the acclimation phase of the case study can be found in Appendix G. The second acclimation project will involve a 3D environment of a single room (stills of the room can be found in Appendix H). The participants will then be given tasks to complete that simulated the tasks that they would be performing during the case study. A copy of the tasks that will be given during the acclimation phase of the case study can be found in Appendix I. At the end of the acclimation phase the participants will take the same survey that they will take at the end of the case study (Appendix B) to draw parallels amongst the participants, in order to mitigate the user ability bias.

To better understand this case study each phase will be broken down (table 4.1), and the rationale behind each choice will be explained. First and foremost, the participant health and knowledge base survey will allow each participant to have any health and safety concerns that could be affected by the AR equipment brought to light. Since I can't have each participant use no device, then a handheld device, and then a head mounted device to answer the same tasks three times for the same vessel, three different boat plans were used.

After the participants' health and safety and knowledge are assessed the study will progress to the first acclimation phase. The acclimation phases were designed to be similar to that of the experiments. An architectural blueprint works very similar to that of a boat plan in the sense that each is incredibly precise, have small and large details, and require measuring and analytical skill to draw out all of the available information pertained therein. The rational of the second acclimation phase is similar in the fact that the room they were in had large and small details, worked using digital measuring techniques, and analytical skills were also needed to investigate their surroundings. By giving the participants a period to acclimatize to the tools and skills needed for the experiments, it will allow them to relax and be more self-confident in their skill and knowledge of how to do what they are doing.

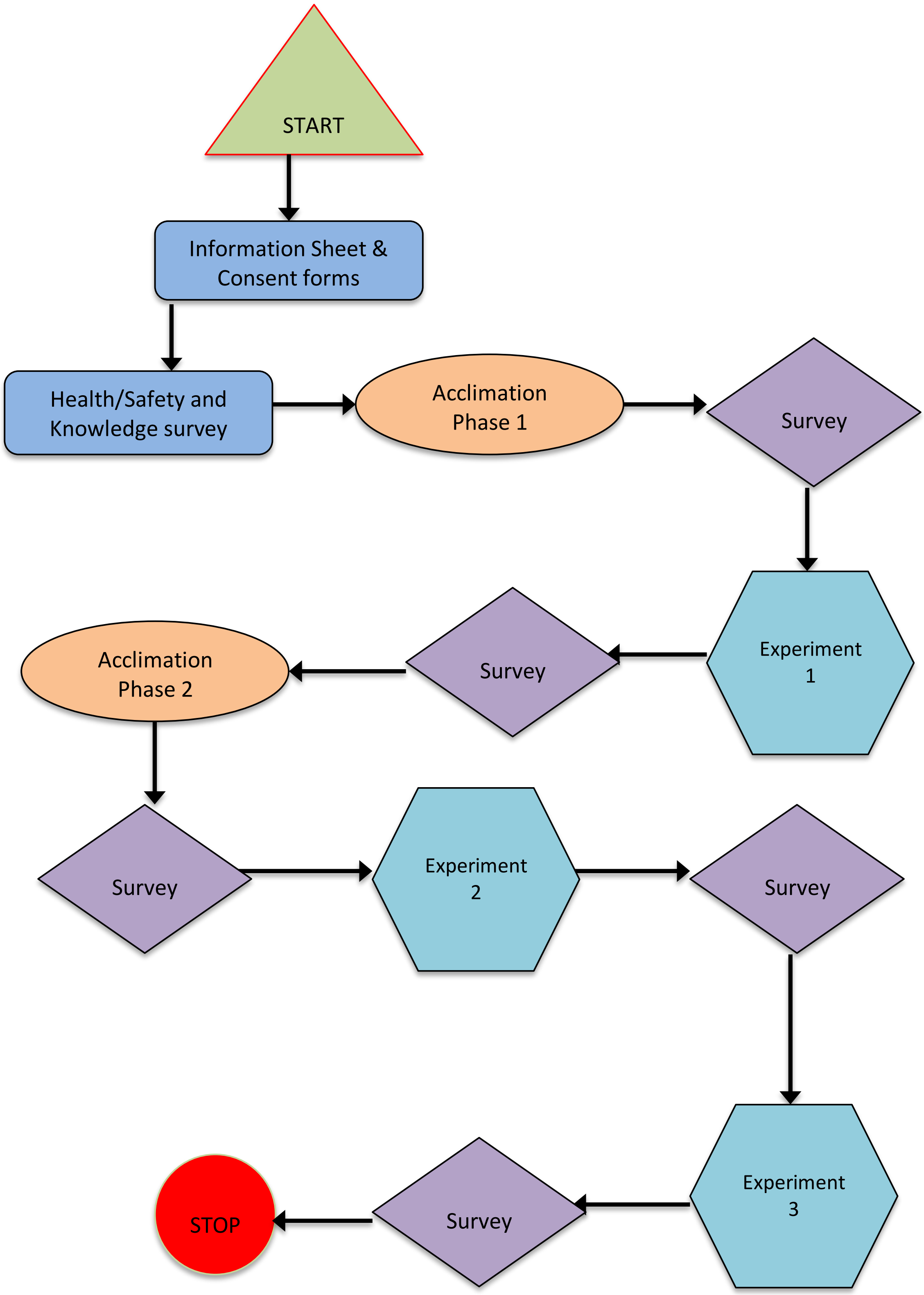


Table 4.1 Flow chart of activities for the case study

The acclimation phase will be proceeded by a questionnaire. This questionnaire follows Bloom's hierarchy of knowledge. It takes the participants from simple counting questions to questions about complex relationships. This questionnaire is the same one filled out by the participants throughout the case study. This will be done to draw relationships between the user's skills and not necessarily about the technology they used. For example, if a participant reveals a pattern of dislike for using tablets coupled with inexperience with that technology in the acclimation phase, and that dislike continues during the main phase then we attribute some of the negative feedback from an inherent dislike of the technology. Whereas if this initial questionnaire was not conducted and all that was given was the questionnaire after the main phase we may have confused a “lack of experience anger” with a “not a good software solution anger.” This is not to say that because one scores low in both, then it must be the user and not the application to be true.

From this point, the participants will move on to the first experiment of the case study where the participants work at completing tasks with an un-augmented boat plan using the traditional tools and techniques.

Once the participants have finished their tasks for experiment 1 they will answer the questionnaire a second time. Again, using the same questions to draw direct relationships. In order to make comparable results, I will adapt the methods used in HCI. Tests and questionnaires were analyzed from HCI studies (Lazar, Feng, and Hochheiser, 2010; Oxford Internet Institute, 2013) and were modified to serve my needs better.

From here the case study will move into the second acclimation phase. This works similar to the first acclimation phase whereas the participants are given a few tasks to complete to get them used to working with digital tools.

After the second acclimation phase is completed the participants fill out the same post task survey. As stated previously keeping the questions the same will allow for a better parallel to be drawn from the different experiments.

Continuing along the flow chart in table 4.1, the participants move into the second experiment, this involved utilizing the hand-held device to complete tasks on a wreck site boat plan.

This was followed by another session of surveying their experiences with the technology they just used to complete their tasks.

This survey leads into the final experiment on the flow chart which is the head mounted display experiment. Which is ultimately followed by the final survey of the case study.

Once finished with this final questionnaire the participants will have finished the study. During the entire process starting from the beginning of the acclimation phase to the end of the final survey there was no interaction between the participants and a figure of authority including stopping to ask questions either to or by the case study administer and/or giving directions to the participants. This was done to keep a certain level of immersion with the AR.

The equipment that will be used is a small representation of what is currently available. There are better interface devices available as well as worse devices available; the selection is based on what is readily available (a complete breakdown of the AR equipment can be found in appendix J). One of the key concepts to remember is that technology advances at an incredibly fast rate, it is constantly improving, and AR interface technology is no different. What is considered top of the line, high cost, expert rated specification today will be tomorrows everyday low-cost standard, as evidenced by the progression of mobile phone technology (Redorbit, 2016). What was being studied during this case study is not the technology being used but rather the interactions between the humans and the digital. The technological affordances of the augmented reality applications range to almost every field not just within archaeology. The applications have already been discussed in marketing, gaming, and tourism, to summarize, but within archaeology, the uses extend from funding pitches, on site, in the lab, and in the classroom. Using AR to create an interactive site map to pitch research ideas to potential investors is just one facet to the technological affordance to the AR spectrum. The other side of the spectrum is all of the hardware that can be used to implement AR software. From simple phones to completely interactive rooms the applications of AR are just beginning to peak (reference the Hype cycle in Chapter1, figure 1.2). The interactions used in the case study, at their core, transcend the current technology and can be applied at any stage of technological development and it is because of this that the actual technology being used shouldn't be based on what is cost effective or readily available. Which is the reasoning behind using differing technological devices ranging from Google Cardboard to the PlayStation VR to the HTC Vive, the technological and financial specifications can be found in appendix J.

4.6 Augmented reality software

In order to create the augmented boat plan (both applications used in experiment 1 and 2 will be made the same way but with different subjects), I will use a combination of programs. The first step will be creating a three-dimensional model of the vessel; this will be done with using a multi step process of AutoCAD modeling, and 3dsMax texturing. The resulting model will be used in conjunction with the software Unity to create a virtual interface for the user. The user will interact with the augmented element with a tablet or HMD via a downloadable application. By using Unity's camera tracking algorithms, the three-dimensional model can be viewed at any angle by moving the interface device. The built-in cameras of the tablet will be used to track the camera movement for the tracking algorithm. The application will be tested using the Windows and Android operating systems.

4.6.1 Coding and Implementation

The augmented reality applications used in experiment 2 and experiment 3 were built utilizing the same application development software, Unity, and visual studio, but was implemented on different devices. As previously mentioned the AR app in experiment 2 was implemented on a handheld device, and the AR app in experiment 3 was implemented on a head-mounted device, because of this the coding and creation of the two applications varied. In this section, we will discuss the creation and specifics of the implementation of the AR applications. It is important to note that other AR app developing software exists each with their methods to creating the app and many may differ from one program to the next., To explain the coding and implementation of the AR apps I will be referring to the steps I took using Unity, Vuforia, and Visual Studio.

The application used in experiment 2 was created using Unity with a Vuforia plugin specifics on these softwares can be found in Appendix J. When creating an AR application, the developer first creates the bridge between the virtual environment and the physical environment. This bridge took the form of an AR camera and target image. The AR camera will trigger the devices (tablet) camera and use it as a motion tracker; this will keep the user's position within the virtual environment as well as scanning for the target image. The target image acts as an activator for the virtual environment. When the AR camera sees the target image, it knows to load the associated virtual environment into the physical environment. The target image acts as an anchor between the digital and physical.

Once the bridge between the physical and digital has been created the developer can then build the virtual environment, this virtual environment will house all the digital data that the developer would like to be associated with the application. This would include any maps, drawings, scans, 3D models, or any other data. For the second experiment, the target image was a boat recording of the wreck site, from this image a virtual environment was created. The first step in developing the virtual environment involved importing in the various types of data that would be available to the user. For this app nine different data sets were embedded in the target image, the first three offered the users highlighted sections of the boat recording to identify the various parts. The next data set embedded was a series of site measurements, followed by various remote sensing scans and finally a photogrammetry model of the wreck.

Once all the data sets were imported and positioned in relation to the target image, each set was bound under the target image as a child. This step was done to have the imported data sets load when the AR camera sees the target image. It is at this point that the user interface was designed. For this application, a simple user interface was developed. A series of simple toggle activator buttons were selected and placed on the side of the viewing screen (figure 4.4), this was a conscious choice as a step towards user-friendliness. Each of the nine buttons was assigned and scripted to activate a separate data set; this works as a simple if loop. In the script, an algorithm was designed to say (simplistically) if pushed show X, if not pushed show nothing. At this point, the application was published and ready for use. For a further breakdown of the application and a step by step of how to use the application see Appendix L.

The second application developed for experiment 3 like the first application was built using Unity and Visual Studio. The key difference for this application as opposed to the first is the implementation of the application. This AR app was to be used on a Hololens and as such needed to have a special set of user interface tools used. As with the first application the virtual environment needed to be built with the physical world as its point of reference. For this application, a target image was not used. Instead, holograms were utilized. The interaction between the user and the holograms mimicked that of what the user would do if they had been on the physical plane instead of digital. It is this interaction that constitutes a true AR application. To further illustrate this if the user wished to push a virtual button, they simply needed to reach out and push the button, just as if it were a real button.

Once the data sets were imported, as with the first application, and positioned where they would be displayed when in use, the user interface could be created. The first step of this was to import the proper tools to develop a Hololens application. Instead of utilizing an AR camera from the Vuforia plugin like the first experiment, the hololens camera acted as the AR camera. Once the hololens camera tool was set into the scene, the interface buttons could be scripted. A special hologram toggle style button was created to activate the various data sets that were embedded in the application. There were fifteen buttons created for this application (figure 4.5). Eleven buttons that highlighted various parts of the vessel in the boat plan as well as displaying a 3D model of the part. There were two buttons that displayed 3D models of the tools and oars used aboard the vessel. One button the displayed a 1:1 hologram of the vessel, and one button that played a short video of the vessel in use. Once the buttons were created and scripted to their various data sets the user interface was complete, and the application was ready to be deployed to the device for use. For a further breakdown of the application and a step by step of how to use the application see Appendix M.

4.7 Rationale of the project

Referencing back to the key problem areas, of only seeing what is drawn and not seeing the human element, the augmented boat plan will address both of these problem areas and possibly more. By incorporating a high quality interactive three-dimensional model to the boat plan, the user will be able to see everything that can't normally be incorporated into a drawing such as the order of construction, or the vessel in use.

By adding a virtual button that can engage a working model of the vessel, including rigging and crew positions, the user will be able to visualize the human element. This can help with interpretations of usage and life on board as well as visualize the positioning of crew versus tools and supplies.

The purpose of this case study was to link other types of multimedia information to what is already a valuable piece of archaeological reporting data. The regular boat plan can only give a certain amount of data, given the fact that it exists in two dimensions. By adding the virtual element, such as a fully interactive 3D model of the vessel, we are effectively adding a whole new data set to the same data space. This can lead to better vessel analysis not just by the primary researcher but also by secondary researchers not present at the time of the creation of the boat plan. Which brings me to my next point, there are already many AR programs available to the general public to view heritage and archaeological products, as established in Chapter 2. The goal of this case study is to investigate the usfulness of AR for researchers as a tool for interpretation, so the target audience of these applications and the resulting data from the case study is for archaeological researchers, so it is their needs that are primarily addressed. Needs such as easy usablilty, resulting in a user-friendly streamlined product, as well as a sustainable method of investigation that is worth the effort needed to create it. Ultimately, this case study is investigating the effects that an augmented boat recording will have on archaeological reports and vessel interpretation.

4.8 Case study specific quantification

This section will discuss in detail the explanation of the specific methods used to quantify the data collected during the case study; this will include the tasks to be carried out by the participants' design, the number of questions, and what those questions were and why they were formulated. From there an examination of the various surveys design, they type of questions and how many of each used, what the questions where and why they were formulated, and how the survey data will be analyzed. The final method of quantification that will be explained in detail will be the interviews and group discussion design; this will include what the questions were and why those questions were asked.

4.8.1 Task design

The tasks that were carried out by the participants during the case study at various stages can be found as they were given to the participants in the appendices A, C, D, G, and I, but will be broken down in this section. The order in which the tasks will be discussed is in the order in which the participants conducted the tasks. Within each of the following paragraphs, the number of tasks and type of tasks will be explained, and a breakdown of each question and why this question was formulated will follow.

The acclimation phase 1 tasks were a series of 5 tasks ranging from counting objects and taking measurements to spatial analysis and deductive reasoning. All the tasks in this phase were designed to get the participants comfortable doing physical tasks as opposed to digital before jumping into the experiments. The first task was designed to get the participants used to reading a plan and counting simple objects (1. Count the number of doors in the room.). The second task was designed to have the participants get used to taking measurements with tape measures (2. Measure the square footage of the room). The third question was designed similar to the first but added a quality of formative reasoning, in which the participants needed to decide what constituted as furniture and what did not (3. How many pieces of furniture are in the room?). The next task was designed to have the participants get used to reading the plan as a whole and derive a conclusion from all the pieces of data available to them (4. Identify what kind of room this is.). The final task that was given to the participants in the first acclimation phase was designed to have the participants think critically and question what was given to them to be true (What is on the balcony?) there was no balcony.

The first experiment tasks were a series of 11 tasks ranging from counting objects and taking measurements to spatial analysis and deductive reasoning, just like with the acclimation phase. All the tasks were standard tasks that any archaeological research project could encounter when investigating any vessel and it should be stated that this was the baseline or control experiment. The second and third experiments were designed to be similar to this experiment. The first question similar to the first question in the acclimation phase involved counting objects, this was done because it is a staple in most research project, how many of “object”. It also was designed to determine if they could figure out what a thwart was if they did not know the term. (1. How many thwarts does the vessel have?). The second and third questions were similar in design, both involved taking measurements, again another standard practice in archaeological research (2. At its widest point, what is the width of the vessel? 3. What is the Length of the vessel from bow to stern?) The next question involved critical thinking and visual analysis skills. Another basic research practice is the identification of objects (4. Identify what this is?). The next question took the reasoning of the first and second set of questions and combined them. The participants needed to identify what, and which thwart was in question and then get a three-dimensional measurement of it, standard practice in archaeological research to have 3D measurements of objects (5 What are the dimensions of the middle thwart?). The sixth and seventh tasks were designed to trigger critical and deductive reasoning (6. Is the hull clinker or carvel built? 7. In what ways can the vessel be propelled?). The next four questions pushed what information could be pulled from the given materials and forced the participants to evaluate their knowledge and the outside materials. The eighth and ninth tasks involved having the participant critically investigate the given materials and assess different possibilities and interpret what they perceived to be the best answer (8. How many crewmembers did the vessel typically have and what was their role aboard the vessel? 9. Produce the order of construction of this vessel.). The final two questions were designed to be similar to that of the final task of the first acclimation phase, meaning, that they needed to assess what they were given and determine if they needed to collect more data to answer the given questions. This is a constant concept that is in every archaeological project (10. What is the purpose of this vessel? 11. By investigating the given materials, have any repairs been made to the vessel?)

The Acclimation phase 2 tasks was a series of 5 tasks ranging from counting objects and taking measurements to spatial analysis and deductive reasoning. Similar to that of the first acclimation phase tasks these were designed to prepare the participants for interacting with digital data physically. The tasks were designed to both get the participant thinking on how to solve basic tasks and also to get the participant accustomed to using the specialized equipment. The first task like its predecessors was designed to get the participants used to reading a plan and counting simple objects (1. Count the number of doors in the room.). The second task was designed to prepare the participants for physically manipulating digital objects (Move the jar from the desk to the shelf with the other jars.). The next task was designed with the same reasoning as its non-digital counterpart (3. Measure the square footage of the room.) The next task was designed to trigger the participants' deductive reasoning skills to identify things, an important aspect of any archaeological project (4. Identify what kind of room this is.). The final task was designed to engage the participants in the environment, (5. What is outside the double doors?) The only way to answer this is to move around in the digital world as you would in the physical world, triggering a sense of immersion.

The second experiment tasks were a series of 11 tasks ranging from counting objects and taking measurements to spatial analysis and deductive reasoning. These tasks like that of the third experiment were conducted using an AR application to augment a boat plan. The reasoning behind most if not all the tasks for both experiment 2 and experiment 3 will be the same for experiment 1. As mentioned in Chapter 3 and again previously in this chapter this was done to create a holistic view of the case study.

The first task in experiment 2 involved counting objects; this was done because it is a staple in most research project, how many of "object" (1. How many cannons does the wreck have?). As with experiment 1, The second and third tasks were similar in design, both involved taking measurements, again another standard practice in archaeological research (2. At its widest point, what is the width of the wreckage area? 3. What is the length of the wreckage area?). The next question involved critical thinking and visual analysis skills. Another basic research practice is the identification of objects (4. Identify what this is?). The next task involved having the participants read context from the dataset as a whole and use it to identify other individual parts to answer the actual question at hand (5. What is the length of the southernmost cannon?). Again, these next two questions, like the first experiment, involved having the participants critically assess the given materials to arrive at an answer (6. Has the wreck had any remote sensing conducted on it? 7. If so, what kind of surveys?). Similar to experiment 1 The eighth and ninth tasks involved having the participant critically investigate the given materials and assess different possibilities and interpret what they perceived to be the best answer (8. How many crewmembers did the vessel typically have and what was their role aboard the vessel? 9. Produce the order of construction of this vessel.). The final two questions were designed to be similar to that of the final task of the first acclimation phase, meaning, that they needed to assess what they were given and determine if they needed to collect more data to answer the given questions. This is a constant concept that is in every archaeological project (10. What is the purpose of this vessel? 11. By investigating the given materials, have any repairs been made to the vessel?)

The third experiment tasks were a series of 12 tasks ranging from counting objects and taking measurements to spatial analysis and deductive reasoning. These tasks like that of the third experiment were conducted using an AR application to augment a boat plan. As previously stated many of the underlying reasons behind the following tasks are similar to those of the previous experiments. In fact, the tasks laid out in experiment 1 and 3 are the same tasks, this was done to draw direct parallels between the two experiments. The exception is that experiment 3 had an additional question. The final task was designed to assess the critical thinking of the participants and their ability to take information from parts and put them together as a whole in their interpretation of the data given (12. What is the purpose for the bow and stern being the same shape?).

4.8.2 Survey design

The surveys that were carried out by the participants during the case study at various stages can be found as they were given to the participants in the appendices, B, and E but will be broken down in this section. The order in which the surveys will be discussed is in the order in which the participants took the surveys. Within each of the following paragraphs, the number of questions and type of question will be explained, and a breakdown of each question and why this question was formulated will follow. At the end of these individual question break, down will be an explanation of how the data collected will be analyzed.

The first survey filled out by the participants was the Health and Safety and Knowledgebase survey. This survey was designed as a pre-screening of the participants for those that cannot participate due to certain health risks that may be involved with the equipment, such as photosensitive epilepsy. In addition to this, this survey acted as a means of establishing a baseline for the individuals' skills and abilities to the technology in order to gauge the rest of their responses and actions. The first seven questions of this survey are health and safeties geared and have no bearing on quantifying the data. The following three sets of questions are Likert scale questions geared towards understanding the basic tools used in the case study, personal experience with computing technologies, advanced imaging technologies. The Likert scale questions were chosen because of three reasons. First, they are universally understood as a means to gauge a varying response type of answer. Secondly, they have a numerical value associated with the answer allowing for direct quantification, and finally, they are fast and as such the participants have many surveys to fill out and this was a means to mitigate fatigue during the case study.

For this survey, a breakdown of each question is not necessary as each pertains to a different tool but rather a breakdown of each set of questions will be more beneficial. The first set of questions were designed to get a baseline on how the individual would rate their skills at using technical reports, reading diagrams, charts, and other pictographic representations of data, and using measuring tools. As the participants will be using these during the case study getting a baseline on how comfortable/competent they are with using them will be beneficial when assessing their responses to later surveys. As previously mentioned, by getting this base reading on the participants skills and abilities, if the participant has a lack of experience with a particular tool or technique, and is later observed having difficulty with that aspect in the experiments, and in-turn marks that technology low we can make a judgement that user frustration due to lack of experience may be the culprit and not necessarily a fault of the tool or technique. The same reasoning can be said for the next two sets of questions. The next set of questions was designed to get a baseline on how the individual would rate their skills at using personal computing technologies. As there are a few skills that run amongst all computer programs that are needed throughout the case study such as recognizing input devices, working various software applications, and handling tablets and smartphones. The final set of questions was designed to get a baseline on how the individual would rate their skills at using advanced imaging technologies. The purpose behind this is that throughout the case study the participants will be using complex virtual environments with many different data sets embedded within each other.

The second survey that was filled out by the participants during the case study was the post-task questionnaire. This survey has been completed a total of five times per participant during the case study. This survey was completed after each acclimation phase and each experiment, this was done to draw direct parallels amongst each experiment. As with the Health and Safety and Knowledge Base survey this survey utilized a series of Likert scale questions. This choice was made for the same reasons as previously stated in the last survey.

The first portion of questions were Likert scale questions the first four questions were designed to gauge how the participant handled finding physical dimensions, specific features, identifying specific parts and categorizing objects, this was done because it is a standard practice found in all phases of the case study. These questions addressed the first two criteria established for quantifying the case study, user-friendliness and streamline a process. The fifth and final of the Likert scale questions were designed to gauge how the participant handled the usability of the technology itself. This question addressed the in part addressed all five criteria except the criterion of ‘redefines typical use’. The next set of questions was a series of 4 short answer questions; this was done to gain further insight into the participants’ immersion levels and overall attitude towards the various pieces of technology used throughout the case study. The first question was designed to assess what the participant viewed as the most important aspect of a piece of technology. The response to this question directly relate to the criteria of user-friendliness, streamlines a process, and sustainability. The next question was designed to directly get the participants thoughts on the technology they used during that phase of the case study; this is a very broad question that can lend insights into every aspect of the analysis process. The third and fourth questions were designed to get the participants to critically assess the technology they were using and apply it elsewhere (for the third question) and apply it to other archaeological projects (for the fourth and final question). This was done so that the technology can be assessed for sustainability, redefining typical use, and whether the information gained from the augmentations is worth the effort of creating the augmented tool.

The five post-task surveys in conjunction with their responses to the tasks, video recordings, and observations, will be used to gauge the various pieces of technology against the five criteria developed to quantify the case study data. The five criteria established in chapter 3 are User-friendliness, streamlines a process, redefines typical use, effort < gains, and sustainability. Due to the tasks in each experiment addressing their answers can draw the same topics across each other direct relationships, and physical responses observed during the case study, this combined with the analysis of the Likert scale questions will lead to results addressing the first three criteria. The short answer questions seen throughout each of the phases will address the last two criteria. A detailed breakdown of the numbers and statistics involved with the calculations and interpretations of the data collected during the case study will be discussed in detail in Chapter 5: Discussion of the Results.

Chapter 5: Results and Analysis of Case Study

5.1 Introduction

The following chapters will examine various data sets and review their results. The analysis of the case study data will be examined as well as the baseline technology of ArcGIS and how they relate to one another. Their relationship will also be assessed and how certain data trends and projections can be surmised from this relationship. We will also be looking at the results of the comparative analysis of various other fields and their use of AR technologies. Through these data sets, we can investigate the relationships between existing established technologies and project how immerging technologies may be received, used, and experienced by the discipline.

The following case study results section will be addressing the following areas. First, the case studies data will be reviewed and analyzed. This will look at the individuals' experiences without any augmentation, handheld augmentation, and head-mounted augmentations. This process will be explained in detail in section 5.1.3 Case study results/analysis. The following section will be the results of the comparative analysis of the three chosen fields that are currently utilizing augmented reality technology. This was done to gain insights into how the technology itself is being used and its lifespan within other fields. As with the previous section, the specifics will be explained in detail in section 5.2 Comparative Analysis Results. The final three sections of the chapter will each be dedicated to the three research questions of this thesis. Each section will have a detailed breakdown of how each piece of analyzed data from the previous sections and experiments relate to answering that sections' research question.

The aims established in Chapter 1 are too first, analyze the possible role of augmented reality technology in common maritime archaeological interpretative tools and techniques. This will be investigating if augmented reality can improve the typical tool and techniques of interpretation, if augmented reality complicates typical tools and techniques of interpretation, is the extra steps worth the effort, and what effect does augmented reality have on the typical boat plan? The second research aim is to investigate the potential ramifications of augmented reality on not just the tools and techniques but in the field of maritime archaeology as well. The final aim of this research is, does augmented reality offer a sustainable solution to the issues present in traditional tools and techniques for maritime interpretation? Each of these three research questions is addressed individually, in their own sections at the end of this chapter. However, the analysis of the data used to answer these three questions will be addressed prior to those sections. The data addressing research question 1 will be addressed in section 5.2 Case study results and analysis. Research question 2 will be addressed in section 5.3 Comparative analysis results and analysis. The final research question will be addressed by utilizing data from both sections 5.2's and 5.3's datasets.

The methodology used for this research involved a two-pronged process. The first involved a case study methodology and the other a comparative analysis methodology. The first prong (Case study) was outlined in great detail in Chapters 3 & 4; the second prong (comparative analysis) was outlined in great detail in Chapter 3. Each of these methodologies will lend extensive insights into how the data that is being analyzed in the subsequent sections will be utilized. The sections that follow will outline how each choice made for the methods used pertains to a specific research aim.

5.2 Case Study Results

This section will entail the presentation of data and results as well as the analysis of the case study conducted for this research. A brief reintroduction to the case study process will precede the analysis section in order to emphasize some of the finer points of the methods used. This will be followed by a brief explanation of the analytical framework used for this process.

The case study had many parts to it but consisted primarily of three experiments. The first experiment acted as the control for the case study. This experiment used traditional tools and techniques with no augmentations. The second experiment utilized an augmented plan that was interfaced with a handheld device. The third experiment utilized an augmented plan that was interfaced with a head-mounted device. The environment that the experiments took place in offered little to zero distractions, this was done to give the best chance for user immersion possible. The room was the same room for all participants across all three experiments.

The case study consisted of 19 archaeologists related to the maritime field. They all varied in experience with this technology as well as experience in the field itself. This experience ranged from students enrolled in a Master's of Maritime Archaeology program to professional maritime archaeological researchers. They were selected based off many factors discussed previously in Chapter 3 but primarily because of their experience with the field and boat recordings.

There was a smaller second set of participants included in the case study. This other set included two participants that were not archaeologists. Their background consisted of higher education in unrelated fields. This group was designed to look at how the archaeological data could be interpreted by those with zero knowledge of the subject and how using the augmented tools might affect those interactions. By using a small sample of those with no prior experience with archaeological datasets, we can look at how intuitive or complicated the data can become with the augmentations.

The data collected in the case study, as previously discussed in Chapter 4, take the form of questionnaires, observations, and video recordings of both the participants' screens and of themselves conducting the experiments. The participants used a questionnaire comprised of Likert scale questions and short answer questions. In conjunction with this questionnaire, observations were made on both the individual and the collective group of participants. The screens of the augmented experiments were recorded for observations due to the fact that observation of the screens during the experiment was not a possibility; this would have been very disruptive to the immersion of the AR applications. This data will be analyzed in the following section and can be found in Appendix O.

The analysis of the case study data will follow an established framework from the Human Computer Interface discipline (slightly modified to fit my purposes). This field involves as it says in the title how humans interact with computers through various interfaces. This can be any interface from toggle switches to motion capture and what effect these relationships have (Lazar, Feng, and Hochheiser, 2010). The particular methods will be discussed in detail in the following section (5.2.2), however, in brief, the process involves utilizing software to track user movements and interface times. Also, the statistical analysis of the questionnaires, individually and as a whole, is part of the HCI process of data analysis (Oxford Internet Institute, 2013).

5.2.1 Results analysis

The following is a detailed account of the data collected from the case study, how this data will be analyzed per HCI standards, and how the applications used in the case study compare to the predetermined list of criteria established in Chapter 3. First, the criteria will be re-introduced and then applied to the applications. Each application will be broken down and critically assessed with each individual criterion. Once this assessment is complete, we will examine the data from the case study and how it will be analyzed.

The five criteria used to evaluate the applications were: user-friendliness, streamlines a process, the output is greater than the effort to make, redefines the typical use, and sustainability. User-friendliness was defined, in Chapter 3, as having four attributes. The application must be simple and not have an overly excessive and busy user interface. The application must be intuitive and not need to be accompanied by a lengthy user manual. The application must have a solid workflow and be well organized. Finally, the application must be reliable and not crash or freeze excessively. The second criterion of streamlining a process is defined, as the application needs to eliminate actions, steps, or processes with their use that would be required in their absence. The third criterion is, too put it simply, is it worth the extra work? The next criterion of redefining uses is met if the augmented reality application can attribute additional application purposes for the tool or open up new avenues for interpretation, then the typical uses of that tool are redefined. The final criterion addresses sustainability; does the application have use outside of what it was immediately developed for. To further this, can the workflow, design, or concept built for the case study applications be used on other archaeological projects while still meeting the same rigors and standing as with this case study?

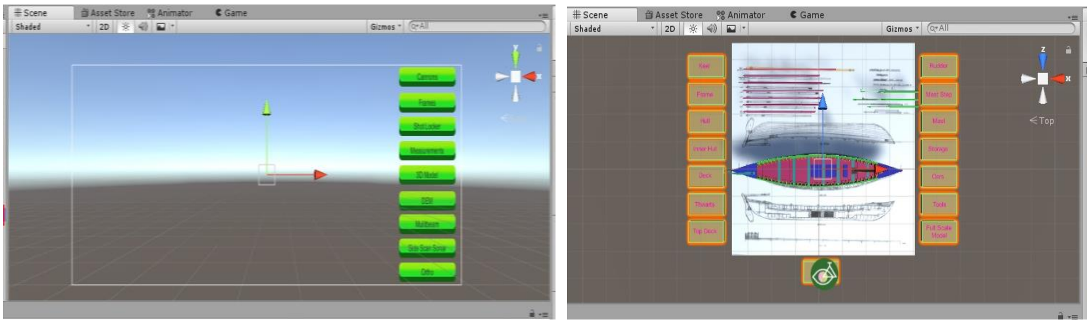


Figure 5.1 Left: UI for application used in experiment 2. Right: UI for application used in experiment 3

For the purposes of this section, the application used in experiment 2 of the case study will be referred to as application 2, and the application used in experiment 3 will be referred to as application 3. The criterion of user-friendliness, as just stated, has four attributes that must be met in order for an application to be classified as user-friendly. The first attribute, simple user interface, is met by both applications as seen in figure 5.1. The second attribute, intuitive, is met by both applications. During the case study, the participants were given no instructions on how to use application 2. The device was given to them with the application open with no indication of how the app worked. Application 3 was not explained either. However, there was a brief presentation given that covered Hololens basics. This included how to put input into the device the powerpoint can be found in Appendix N but did not include any specifics on application 3. With the participants given zero to minimal instruction on how the applications functioned all were able to use the applications without much difficulty. Related to this is the third attribute, organized; the application had a simple user interface that offered quick and simple workflows. The design of both applications offered that with each button there was a direct result. In other words, the user did not have to navigate through multiple windows or menus to find the output or function they were after. This attribute is met by both applications. The final attribute of reliability was met by both applications as well. During the course of the case study experiments, neither application crashed or froze. There was a single instance where the application needed to be restarted in order to better positioned for the participant within the room, but this was due to outside factors and not pertaining to the application itself. Both Application 2 and Application 3 have shown to possess all four attributes of user-friendliness as defined for this research (Chapter 3 section 3.5.2.1) and as such can be classified as meeting the first criteria of being user-friendly.

The next criterion to be applied to the applications is that of streamlining a process. For the applications to meet this criterion it must, as defined in Chapter 3 section 3.5.2.2, they need to reduce the number of processes with their use than that would be typically required if using the traditional means. Application 2 does reduce the number of processes as it adds layers of outside data to the drawing. For the observer to see these other layers (figure 5.2), they would need to visit other sources, thus adding additional steps to the process. By having the various embedded data into the drawing, these extra steps are eliminated. Application 2 meets this criterion. Application 3 mirrors this action as well. The boat plan is embedded with video of the vessel in

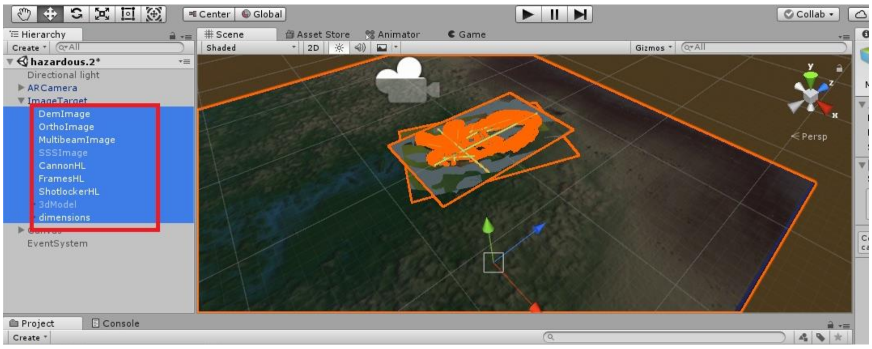


Figure 5.2 Experiment 2 multiple layers active.

use as well as three-dimensional models of the various parts that make up the vessel. As stated with application 2 if the viewer wanted to see the vessel in action or a 3D representation of that vessel they would need to seek outside sources. Since Application 3 has this additional information embedded within it, it eliminates the extra steps of having to seek out other sources to see the boat in use, among other aspects, and thus streamlines the process. Application 2 and Application 3 both meet this criterion.

The third criterion used to quantify the case study applications is the information gained Vs. effort of creation criterion. As previously discussed (Chapter 3 section 3.5.2.3) the applications must offer greater insight, more information, or some other form of greater knowledge that cannot be found with their un-augmented counterparts within a reasonable creation period. In other words, the information gained from having this augmentation must be more than something than that can just as easily be accomplished by a quick YouTube search. The creation process of making Applications 2 and 3 took about a week each. This time does not include the creation of the 3D models, the scans, measurements, surveys or any other data being embedded. This time just includes taking those sources and building them into the virtual environment and anchoring them to the physical world. This time must be less than that of what is gained; put simply is that week (minimum) of work even worth it. In order to answer this, we will look at three pieces of data collected during the case study; observations of the participants, the accuracy of their answers to the tasks they had to complete, and their testimony of the applications after their use. For Application 2 the users, in general, showed increasing enthusiasm as they explored further into the different layers presented in the application. This can be further backed up by a few select quotes from their responses. “It gives a good idea of 3D space, which can be used to provide plans with the 3rd dimension!” (participant 4), “absolutely amazing, the ability to overlay a data and manipulate it in playspace is highly useful” (participant 8), “yes, fun to play with and good educational tool” (participant 12), “I believe it’s a way to make lives easier an provide the same results with less work time” (participant 16). The final piece of data we will look at for this criterion is the participants’ accuracy of their responses to the tasks they had to complete using the applications. For experiment 2 the participants had an average of 1.8 incorrect answers out of 11. The most incorrect answers from a single participant was 5, adversely the least amount of incorrect answers from a single participant was 0, meaning that on average the accuracy of the participants’ information was 84%. Given the data represented here in conjunction with the observations and testimony, I would argue that Application 2 does meet this criterion. For Application 3 the users, again in general, were very excited about the prospect of using the Hololens. As with Application 2, the overall observation of the participants was enthusiastic. This can be further supported by the following quotes selected from the participants. “a great opportunity to show models in a 3D space, very good idea.” (participant 4), “The human element aids my understanding via emulating my natural vision.” (participant 8) “we don’t have to find paper drafts on our laptops. We can find the technology we need from using our mobiles.” (participant 15), “incredibly useful, easy to present to the public on, useful as well for the researcher.” (participant 16). As with Application 2, the average number of incorrect answers for experiment 3 was 3.9 out of 12. The most incorrect answers from a single participant were 8, adversely the least amount of incorrect answers from a single participant was 1, meaning that on average the accuracy of the participants’ information was 67.5%. This number unlike its counterpart in Application 2’s breakdown is low, and it is worth noting that this is in part due to the participants guessing at answers as opposed to putting unknown, this can be seen in Appendix O. Despite the low level of accuracy on the questions, the testimony combined with the observations made that include being able to view the human element to the vessel gives me the confidence that Application 3 also meets this criterion, but arguments can be made against this based solely on the inaccuracy of the answers.

The fourth criterion addresses whether the applications redefine the typical use of their traditional counterpart. To further define this the application will meet this criterion if the application can attribute additional functions and/or purposes of the tool or open new avenues for interpretation. By its very nature, an AR app meets this definition. They take additional functions or data and overlay them onto other physical objects or sources. So, in its basic sense, both applications automatically meet this criterion, but further analysis will be done. For both applications, they offer various aspects, but I will focus on the leading aspect for each that illustrates this criterion the best. For Application 2 the ability to see the various remote sensing surveys, photogrammetry, and other data in one place layered together showing each piece individually and as a whole, and this is the key concept, *in situ* is a big step towards redefining how the traditional tool is used. Similarly, can be said for Application 3. Application 3 utilizes a 1:1 scale model of the vessel depicted in the boat plan as well as a video of the vessel in use, both redefining how and what a boat plan can be used for. However, it is worth noting that the layers and additional information seen in Application 2 one can get the same results with an ArcGIS file, the main difference is that anyone with a smartphone or tablet can have access to the information as opposed to those with a computer, ArcGIS software, and the file/supporting files. The same could not be said for Application 3 as it is done with a head-mounted device as this gives a realistic sense of scale, something that is not obtainable with a display in front of you. Both applications meet this criterion.

The final criterion for the applications is that of sustainability. Can these applications be applied to outside projects? This could include any part of the application, design, framework, workflow, concepts, or implementation. The finer details of what these constitutes were discussed previously in Chapter 3 section 3.5.4.5. To answer this, the participants were asked directly if the application they just used (this was done as part of their post-task survey) had any outside uses other than what it was just used for. The exact question was “Does this technology have any outside use besides in answering the questions you were just presented?” Of the forty-two responses from both experiment 2 and experiment 3 (21 each), seven (4 from experiment 2 and 3 from experiment 3) of which were either; I don’t know, n/a, or some form of nondescript answer, indicating that there is indeed outside prospects for Applications 2 and 3. This can be further emphasized by the following quotes selected from the participants; “this can be used in teaching, entertainment, etc. just about everywhere.” (Participant 3, Application 2), “a useful tool to help non knowledgeable people understand the subject.” (Participant 19, Application 2), “very much so, including reconstruction, public engagement, access to inaccessible sites/resources. The ability to access by information is highly fun, engaging, and informative.” (Participant 8, Application 3). These statistics address the applications ability to adapt to outside projects. The participants were also asked about sustainability within archaeology as well. The exact question was “How useful do you think this technology is within the field of archaeology as a whole?” Of the forty-two responses from both experiment 2 and experiment 3 (21 each), of which 100% of the responses indicate that the applications are very useful within the field of archaeology itself.

Clarification of to what use and to further emphasize this sentiment can be seen in the following quotes of the participants; “really useful, from presenting results in museums and conference to help the archaeologist to understand better studying in the field.” (Participant 16, Application 2), “very it can allow archaeologist to visit/explore sites without having to physically travel there and interact with it in a state prior to excavation. (Participant 2, Application 3), “it would be fairly useful not only as an engagement project with the public to the past, but also in the accessibility of sites and information to researchers.” (Participant 3, Application 3). Both Application 2 and Application 3 meet the sustainability criterion.

Breaking down each application and comparing them to the established criteria laid out in Chapter 3 we can see that both applications meet all 5 criteria. From this point, we will move into looking at how the data collected in each case study will be analyzed in accordance with practices and standards established with HCI analysis. The first thing HCI looks at is the time. They look at how long certain tasks take as well as series of tasks (Oxford Internet Institute, 2013). To mirror this the times of each participant’s experiments were recorded. HCI, as previously stated, measure the time of each individual task. This is done to compare the times of one iteration of the interface to the next (Lazar, Feng, and Hochheiser, 2010). I selected not to do this as I will not be comparing one iteration of the same application to the next. Measuring the answering of one question is not quantifiable with its counterpart in the other experiments because each uses a different subject, and different interface. What is quantifiable however is that the questions established in each experiment are similar in design and number, each experiment makes the participants find the same type of answers, so the times of the experiment as a whole is quantifiable. HCI also utilizes Likert scale questions to gauge a number of things as outlined in work done on surveys conducted by the Oxford Internet Institute (2013). For the purposes of the case study, they were used to gauge skill levels with various types of technology and skillsets, as well as to gauge the usability of different aspects of each experiment. Each of these datasets, time and Likert scale questions, are both typically averaged and compared with previous iterations to show trends in the data (Oxford Internet Institute, 2013; Lazar, Feng, and Hochheiser, 2010). Since I will not be addressing previous iterations of the same applications but rather how they compare to augmented vs. non-augmented, the averages can be compared to each other to show trends in usability.

To summarize, the data from the case study was three-fold. First, some observational and video recordings were made to investigate the user immersion and over the usability of the applications. Secondly, the various Likert scale questions that cover a range of data; such as current levels of skill with various techniques and technologies to overall experiences with the technology that they used. The third piece of data was the short answer responses at the end of the post-task survey (Appendix B). Table 5.1 below outlines various data points collected during the analysis of the post-task surveys collected from the participants of both data groups, archaeologists, and non-archaeologists.

<u>Knowledge base survey (1not comfortable->5very comfortable)</u>

	Highest	Lowest	Average
1. Reading technical reports	5 / 4	3 / 3	4 / 3.5
2. Reading diagrams charts…	5 / 5	4 / 4	4 / 4.5
3. Using measuring tools	5 / 5	3 / 5	5 / 5
4. Do you work with boat plans	5 / 2	1 / 1	4 / 1.5
5. Using a computer	5 / 5	3 / 5	5 / 5
6. Navigate simple web apps	5 / 5	4 / 5	5 / 5
7. Using handheld devices	5 / 5	4 / 5	5 / 5
8. Using digital means to collect data	5 / 5	3 / 5	5 / 5
9. How often do you use a computer	5 / 5	5 / 5	5 / 5
10. Experienced with virtual environments	5 / 5	1 / 3	4 / 4
11. Wearing specialized technology.	5 / 5	3 / 4	4 / 4.5

<u>Experiment 1</u>				<u>Experiment 2</u>				<u>Experiment 3</u>			
	Fastest	Slowest	Average		Fastest	Slowest	Average		Fastest	Slowest	Average
Time	222/206	1114/502	517/457	Time	293/311	1023/503	504/659	Time	297/537	1317/600	637/869
	Highest	Lowest	Average		Highest	Lowest	Average		Highest	Lowest	Average
Incorrect answers	6 / 11	1 / 1	3.1/9.5	Incorrect answers	5 / 4	0 / 2	1.6/3	Incorrect answers	8 / 8	1 / 2	3.7/5

<u>Post task survey 1 (1not difficult->5 very difficult)</u>				<u>Post task survey 2</u>				<u>Post task survey 3</u>			
	Highest	Lowest	Average		Highest	Lowest	Average		Highest	Lowest	Average
1. Finding physical dimensions	4 / 3	1 / 1	2 / 2		5 / 1	1 / 1	2 / 1		5 / 1	1 / 1	2 / 1
2. Finding specific features	5 / 5	1 / 5	3 / 5		5 / 2	1 / 2	2 / 2		4 / 1	1 / 1	2 / 1
3. Identifying specific parts	5 / 5	2 / 4	3 / 4.5		4 / 4	1 / 2	2 / 3		2 / 2	1 / 1	1 / 1.5
4. Categorizing objects	5 / 4	1 / 4	3 / 4		3 / 4	1 / 3	2 / 3.5		4 / 1	1 / 1	1 / 1
5. Level of usability	4 / 4	1 / 4	3 / 4		5 / 4	1 / 3	2 / 3		4 / 2	1 / 1	2 / 1.5

Table 5.1 Table of data collected from the case study in chapter 4. Numbers to the left of the '/' indicate data from the archaeologist dataset while numbers on the right indicate data from the non-archaeologist dataset. Table courtesy of author.

Chapter 6: Results and Analysis of the Comparative Analysis and Baseline Technology

6.1 Introduction

By conducting a comparative analysis of other fields towards the field of archaeology, we can attempt to predict how augmented reality could impact the field. As stated in Chapter 3, augmented reality hasn't been used in the field of archaeology as long as other fields, at least not as a tool for research. If we re-examine the research aims, briefly as they were just restated, we can move into why such an analysis is necessary.

1. Analyse the possible role of AR technology in common maritime archaeological interpretation tools and techniques.
2. Investigate the potential ramifications of AR on not just the tools and techniques of interpretation but in the field of maritime archaeology as well.
3. Investigate the sustainability of AR technology as an archaeological tool (of research).

The second and third research question requires outside parallels to be made in order to answer these questions properly, the former even more so. To further elaborate on this, the key factors of investigation for the second research question are as follows; the uses of AR in other files Vs. how they are currently used and how they compare to the baseline technology, how did the baseline technology change the field once it was introduced, such as the trend in research topics, shifts in standard practices, and how is this comparing to AR's introduction so far. Other factors of investigation include augmented realities lifespan and usability (specialized or generalized) in other fields. As for the third research question, addressing sustainability, the use of a comparative analysis of its lifespan in other fields could show insights into the potential lifespan and sustainability of AR in archaeology. Simply put by looking at other fields uses of AR and comparing it to how the baseline technology is used trends and relationships can be drawn.

The baseline technology that is being discussed was defined in Chapter 3. The baseline technology is ArcGIS. To reiterate ArcGIS was selected as the baseline technology for 3 main reasons. First and foremost, technologically speaking they do very similar things. Augmented reality takes digital objects and overlays them on the physical plain. ArcGIS, in its basic sense, takes layers of other data (surveys, remote sensing, photographs, and other graphical data) and overlays them to maps and coordinate systems. Essentially, they both take data and layer them to localization. The second reason for choosing this technology is that they are both digital based, and the final reason is that it has an established presence in archaeology. ArcGIS was selected over other technologies such as side-scanning sonar, photogrammetry, and other techniques because of its similarity to augmented reality. This closeness will allow for a greater representation of potential ramifications for augmented reality.

This baseline technology will be compared to AR being used in other fields to draw parallels and trends between archaeology and the other fields. These other fields as established in Chapter 3 are Gaming, Marketing, and Tourism. The three fields were selected because of three contributing factors. First, the types of augmented reality applications they use, the technology they use to implement the applications, and how long they have used AR. The gaming industry was selected because of the high level of system registration and low latency that appears in the games (Clandestine: Anomaly, 2015; Invizimals: The Resistance, 2015). Both aspects are good for user immersion. The marketing field was chosen because of the low impact and user-friendliness of the applications (IKEA AR Catalogue, 2013; The Shiseido Makeup Mirror, 2010). This is good for a wide range of skill levels. The field of tourism was selected since the apps used for tourism are exceptional at displaying large amounts of data in various forms without being too distracting from the surroundings (Sekai Camera, 2008; Wikitude, 2008). This, as stated in Chapter 3 section 3.2.2.2, is good at face value.

The rest of this section will follow the analysis process of the comparative analysis of these fields. An in-depth examination of the baseline technology and its analysis will precede the detailed breakdown of each of the other fields. The specifics on how and what aspects that are being examined in each field will be discussed in their respective sections.

6.2 Baseline technology

The research into augmented reality as a tool for archaeological interpretation is two-fold. The first being a case study methodology and the second being a comparative analysis. The comparative analysis will analyze augmented reality being used in other fields and compare it to AR and a more established technological surrogate in Archaeology. This surrogate or baseline technology is Geographical Information Systems or GIS and by extension the software ArcGIS. As discussed in Chapter 3 a comparative analysis involves looking at multiple outside sources and comparing it to the source in question, in this case, AR in Archaeology, to derive an anticipated outcome (Perrow, 1967; Eltigani, 2000).

GIS has its roots in military and NASA technologies. Their work in surveillance and surveying paved the way for the creation of geographical information systems. This integration of accurate data superimposed onto maps is the core concept developed by early GIS systems. In the early 1970's GIS broke out of strictly federal and governmental use and into the commercial industry. During the next two decades, GIS would be developed by many different industries for more generalized purposes instead of for a specific project as it had been when first developed. It is at this point we find GIS's like ArcGIS becoming industry standards for surveyors and archaeologists alike (Wheatley and Gillings, 2002).

ArcGIS is proprietary software developed by Esri (Arcgis.com, 2018); it uses geographical information to work with maps and geographic information. According to the developers, Esri, a geographic information system "is a system for the management, analysis, and display of geographic information. Geographic information is represented by a series of geographic datasets that model geography using simple, generic data structures" (What is ArcGis, 2004). ArcGIS works by using three views of geographic information; Geodatabase view, Geovisualization view, and Geoprocessing View. Geodatabase view is a spatial database. This works by holding various datasets that represent geographic information such as features, rasters. Topologies, and networks. The Geovisualization view utilizes maps to show features and relationships of various features on the earth's surface. The Geoprocessing view is a set of GIS tools that can be used to derive new data from existing datasets (What is ArcGis, 2004).

6.2.1 How does GIS compare to AR

In its most basic sense, GIS's and ArcGIS is used to take maps of the physical world and overlay digital geographical data on to those maps as seen in various projects involving ArcGIS (Webber et al., 2018; Benkaci et al., 2018; Pucha-Cofrep et al., 2018). The same can be said about augmented reality, in its most basic sense. AR takes digital objects and overlays them on the physical world. The key difference is that one does it on a computer monitor and the other uses cameras and screens to do it *in situ*. To clarify the nomenclature of the subjects GIS is to Augmented reality as ArcGIS is to the HazardApp used in experiment 2 of the case study. GIS, as mentioned previously, is the encompassing term for all the systems be it ArcGIS, QGIS, or GRASS

GIS. While ArcGIS is a single GIS program; just like how augmented reality is an encompassing term, and the HazardApp is a single AR program.

On examining the requirements needed for ArcGIS and the typical AR program they are either the same or one or two components different, depending on the AR interface. ArcGIS requires a computer and some datasets collected from outside means. AR, as discussed in Chapter 2, needs essentially a computer (processor, screens, and cameras) and the digital datasets being overlaid. For AR the computer is also the means in which the user views the augmented world, this can be a phone, tablet, Hololens or anything of the like. While currently ArcGIS is primarily utilized on computers and small but powerful handheld devices such as the Tremble® (What is ArcGis, 2004). Both user interfaces use a series of windows to display varying layers of data. Typically, AR applications only utilize a single window, whereas ArcGIS can have multiple viewports each with their own array of data layers. The final similarity between ArcGIS and augmented reality that should be brought to attention is the similarity of the tasks that can be accomplished. As established earlier both technologies involve layering datasets. ArcGIS is used to track changes, patterns, relationships and other forms of data that is bound by geographical location. Augmented reality can be used to do the same thing. In his work developing the concept of embodied GIS Eve's (2014) used AR to look at the same data seen in ArcGIS databases on location. This allowed for a more thorough and accurate phenomenological analysis of the site.

6.2.2 Early GIS in archaeology

Certain aspects of the Geographical Information System's concept were highly influenced by US Military and NASA's surveillance and mapping protocols, respectively (Wheatley and Gillings, 2002). However, the first modern GIS would be the Canadian Government's Regional Planning Information Systems Division's Canadian Geographic Information System or CGIS. This was built in Ontario, Canada and implemented in 1964 (Peuquet, 1977). This was in response to the exploitation of resources and the effects on the quality of life for the inhabitants of the surrounding areas (DeMers, 1997). Though the first GIS was built in the 1960's the majority of the development of GIS's took place in the 1970's and 1980's. This, in part, was due to until that time it was primarily government and federal agencies that were developing GIS's; however, during the 1970's there was an expansion of commercial developers creating Geographical Information Systems that not only changed how GIS's were made but also used. GIS was moving away from specific purposes and towards general use (Wheatley and Gillings, 2002; Conolly and Lake, 2006).

> From the 1970s onwards there was a gradual move towards the commercial sector. GIS underwent a gradual shift away from being systems designed and written for specific purposes, often by government agencies such as the Canadian Regional Planning Information Systems Division or the US Corps of Engineers, who wrote a raster-based GIS called the Geographic Resources Analysis System (GRASS). One of the earliest commercial companies involved in this was the California-based Environmental Systems Research Institute (ESRI), who began selling a vector-based GIS in the early 1970's. Throughout the 1970s and 1980s more and more commercially supported software products became available until today there are at least a dozen fully functional, commercial GIS systems running on all types of computer platform (Wheatley and Gillings, 2002, pg. 16).

Because of this shift some of GIS early uses were in the fields of Archaeology, business, Climatology, crime mapping, government, industry, Landscape architecture, National defence, natural resources, public health, real estate, regional and community planning, science, sustainable development, and transportation and logistics (Wheatley and Gillings, 2002; GIS Geography, 2018; Continuingeducation.bnpmedia.com, 2018).

Software similar to what we would consider GIS today was first seen in archaeology in the 1970's. The uses focused on the display of trends. Preliminary investigations done in Wheatley and Gillings' *Spatial Technology and Archaeology: The Archaeological Applications of GIS* (2002) show that these trends were the product of density mapping in the case of Feder's work (1979) or settlement distribution measurements shown in the work of Bove (1981) and digital elevation models or DEMs as seen with Arnold III (1979), Kvamme (1983), and Harris (1986). However, one of the earliest GIS works that integrated layers of data, something that we have established as important in comparing AR to GIS, was work conducted by Chadwick. Chadwick created maps that layered various datasets such as geomorphology and water supply to further their work on an early-mid Helladic settlement in Greece (1978). GIS's ability of predictive modeling (the Geoprocessing view discussed earlier with ArcGIS) is what first prompted archaeologists to its potential as a standard tool for cultural resource management, a big archaeological sector in the United States. Which, until the 1990's Geographical Information Systems in archaeology has primarily existed in the US. It wasn't until work conducted by Gaffney and Stancic (1991, 1992) showing Europe its capabilities as a regional interpretation tool, that archaeologists in European countries truly took an interest in GIS. This was shortly followed by a series of conferences specifically designed to show GIS work in Europe (Lock and Stancic, 1995). This demonstrated the large range of archaeological projects, research, and problems that GIS could be applied to. In addition to its applications to archaeology, it also increased predictive modeling accessibility. The resulting publications showed how GIS could and did revolutionize various fields of archaeological study and how GIS could create new fields of archaeological study (Ruggles et al. 1993; Wheatley, 1995a; Gillings, 1995, 1997; van Leusen, 1999; Wheatley and Gillings, 2000).

As with any new procedures or technology that is being introduced to any field there will always be criticism and pushback. The same is true for GIS and archaeology. Despite the perfect relationship between the spatial analysis programs and the inherent need for archaeological research to involve maps and spatial relationship investigations, GIS has received a moderate amount of criticism. During the early 1990's GIS had significant growth in the field of archaeology.

> "It is undoubtedly a positive sign that the spate of articles and edited volumes in the late 1980s and 199s combining the terms *archaeology* and *geographical information systems (GIS)* in their titles has slowed in recent years to a trickle. This is of course not a signal that archaeologists have become disillusioned with GIS, far from it; the absence of these titles signals that GIS has become such a standard tool among archaeologists that it no longer merits mentioning…" (Pluckhahn, 2007).

It became standard practice to have GIS used in any project involving a regional survey or spatial modelling, but this caused some areas of debate; primarily on the relationship between GIS archaeological analysis and encompassing archaeological theory, specifically theory on predictive modelling and environmental determinism (Zubrow, 1990b; Wheatley, 1993; Harris and Lock, 1995; Wise, 2000). To further clarify this, some argue and rightly so that if the use of GIS becomes too disassociated with the root techniques of archaeological practice and becomes a habit of making GIS maps because that is just part of what spatial analysis is now, that the resulting interpretations could be biased into overemphasising the impact of environmental factors as the key motivator for cultural activity as opposed to other equally relevant factors (Wheatley and Gillings, 2002).

Another factor in GIS's early struggle is the usability of the software to non-trained users. ArcGIS, for example, is a very complex system. There are immense workflows involved in the generation of usable spatial analysis datasets. Because of this, there is, naturally, an initial distaste for using such an overbearing piece of equipment, a sentiment that is made even further when the current methods archaeologists have been trained and taught in have been working just fine. Investigations into this were made by Harris and Lock in their publication "The diffusion of a new technology: a perspective on the adoption of geographic information systems within UK archaeology" published in *Interpreting space: GIS and archaeology* (Allen, Green, and Zubrow, 1990).

> "The second major drawback is in the training of technicians and users of GIS, again generally but especially in archaeology. It is difficult to avoid an element of pessimism judging by the precedent of the adoption of IT within university archaeology courses. A large proportion of qualified archaeologists in the UK have never used a database package in anger which is not encouraging when the complexity of GIS software is considered together with the underlying cartographic, statistical and spatial concepts. It is unlikely that universities will play a major role in the *general* training of GIS archaeological users in the short and medium term although they are likely to produce isolated exemplar research projects" (Allen, Green, and Zubrow, 1990, pg. 49).

This was an early problem, like with most emerging technologies being adopted by outside fields, where and when does training become part of the core curriculum? This was written in 1990 and still, over two decades later, GIS is often not taught as a core requirement but rather as optional or supplemental courses.

6.3 Analysis of augmented reality in the gaming field

The use of augmented reality systems has been present since the late 1990's and early 2000's. However, the first use of an augmented reality apparatus came nearly three and a half decades prior, in 1965. Where a scientist working at the University of Utah by the name of Ivan Sutherland created what he called "the ultimate display" (Sutherland, 1965). The HMD was a large device with a gyroscopic arm connected at the top (figure 6.1); its overall appearance gave it the nickname The Sword of Damocles. This early leap into cyberspace offered the ability for the user to look into virtual space relevant to their physical movements. To further clarify here is an excerpt from the devices user manual.

> "We can display objects which appear to be close to the user or which appear to be infinitely far away. We can display objects beside the user or behind him, which will become visible to him if he turns around. The user is able to move his head three feet off axis in any direction to get a better view of nearby objects. He can turn completely around and can tilt his head up or down thirty or forty degrees. The objects displayed appear to hang in the space all around the user. We have concluded that showing "opaque" objects with hidden fines removed is beyond our present capability. The three-dimensional objects shown by our equipment are transparent "wireframe" line drawings" (Sutherland, 1965).

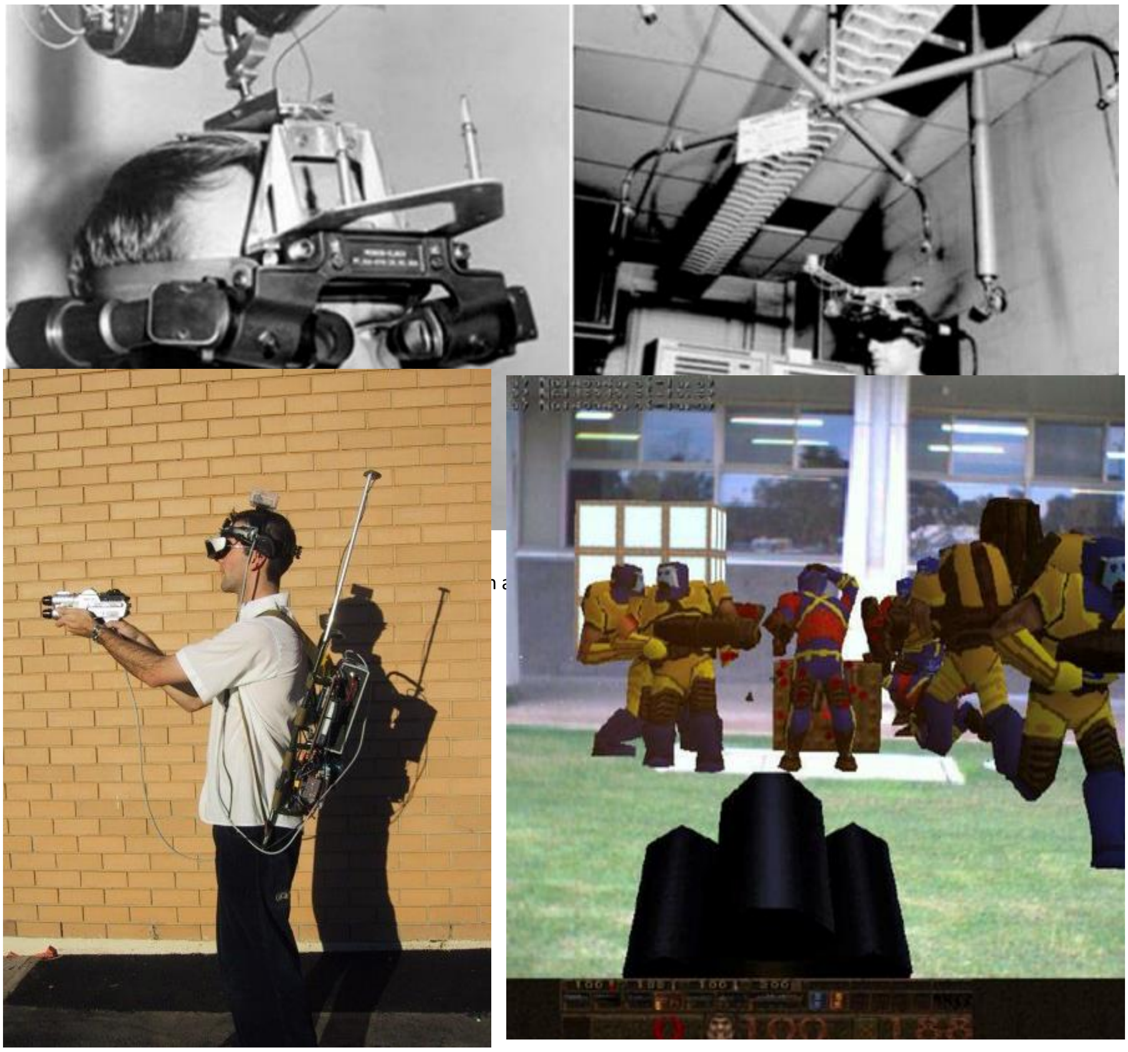


Figure 6.1 QuakeAR (Left) game rig. (Right) screenshot of gameplay. Image courtesy of Wayne Piekarski, Wearable Computer

Augmented Reality first crossed into video games in 2000 with AR Quake, a cumbersome augmented reality game that required the user to strap a laptop to their back, carry a cabled gun, and wear a contraption similar to the Sword of Damocles. This game, created by Bruce Thomas from Wearable Computer Lab (Das et al., 2017), which never made it out of development, was the forerunner for such games as Pokémon Go and even the Hololens. Despite this early interest, it wasn’t until 2010 that AR games really took off. It took off largely due to smartphone capabilities at this time, with several apps such as Zombies, Run! And DJ rivals becoming fast favorites (Das et al., 2017).

2016 represents a landmark year for AR games with the launch of Pokémon Go, which combined the anime Pokémon world and that of the real world. “The ground-breaking gaming experience, along with the popularity and nostalgia associated with the anime series, turned Pokémon Go into a worldwide phenomenon” (Das et al., 2017). Within the first 13 hours it had reached the top of the US App Store Overall and Games Chart, and to date, it has a total revenue of about $269 million, and Nintendo stock jumped $9 billion (Business of Apps, 2018).

Figure 6.2 Screenshot of Pokémon Go AR mobile game. Image courtesy of fraghero.com

Games and AR had an early start, but they also had a slow start. However, thanks to advances in technology, the gaming industry, and AR have boomed in recent years. There is little evidence of any stop in the foreseeable future, with more companies coming out with Augmented reality headsets, such as the Magic Leap One, and 2018 being touted as the biggest year yet (Armstrong, 2018).

6.4 Analysis of augmented reality in the marketing field

AR was introduced to Marketing quite early. In fact, marketing was the first commercial use of AR. In 2008, three German Automotive Magazines *Auto, Motor un Sport*, *Werben & Verkaufen*, and *Autobild*, ran an ad for the BMW Mini. When the magazine advertisement was held in front of a computer's camera, a 3D model of the car showed up. The model was then able to be viewed from different angles by manipulating the paper (Newstands, 2008). Since introducing AR advertising, BMW saw an increase in sales in Germany from 2007 (Bekker, 2011).

AR quickly became far more advanced and a popular advertising method, with many companies like National Geographic in 2011 utilizing the technology to show rare or extinct animal species walking through a shopping mall or Disney, also in 2011, showing cartoon characters on a large screen in Times Square interacting with people on the street (Harvard Business Review, 2016).

Figure 6.3 Left: 2008 BMW AR advertisement. Right: Advertisement augmentation. Images courtesy of

In addition to the BMW Mini Ad, other companies approached AR to allow consumers to "try on" items at home before buying. Such as the Apple in the early 2010's which, with the aid of a paper cut out, allowed users to see the Apple Watch on their arm before buying. However, these were often difficult to use, as they required the consumer to cut out a paper and size it appropriately (Harvard Business Review, 2016). Although AR started modestly enough with simple 3D models, it quickly surpassed that.

Currently, AR can be seen in multiple areas of marketing but is particularly present in the fashion industry, the automotive industry, and the home improvement industry. The fashion industry, with the Memory Mirror, created by MemoMi Labs in 2014. It allows customers to try on clothes, makeup, and eyewear and then control what's displayed on the mirror with simple hand gestures or a companion mobile app (FARM – Buffalo Strategic Marketing Communications, 2017). The Automotive industry hasn't been left behind either, as AR can be seen in the marketing of automobiles. BMW released an app that allows customers to not only view the cars in their own driveway but also to open the hood and "step inside" (Ft.com, 2017). The home improvement industry has, perhaps, been aided the most from the use of AR, as it allows customers to do something that no other advertising could do – see their project finished and in place before ever putting a nail to wood (Warc.com, 2018). Amanda Manna, Head/Narratives, and Partnerships at Lowe's innovation Labs reported that tools such as AR and VR could assist customers in gaining a clear picture of what their do-it-yourself plans would look like if implemented in practice,

> “One of the hardest things about home improvement is the ability to visualize what your project is going to look like at the end, or to be able to communicate to someone else who you’re working with what your vision is for that project…We’ve actually calculated that this is about a $70bn problem for Lowe’s every year – the people who never even start a project because they’re afraid of how it’s going to turn out, or they really just can’t get motivated to get off the couch and do something about it.” (Warc.com, 2018)

In addition to these three industries, AR is beginning to make its way into other industries as well, such as the candy industry, as Cadbury showed in Christmas 2017 with their Hero’s AR Advent Calendar, which allowed customers to add different filters to their photos, such as them with

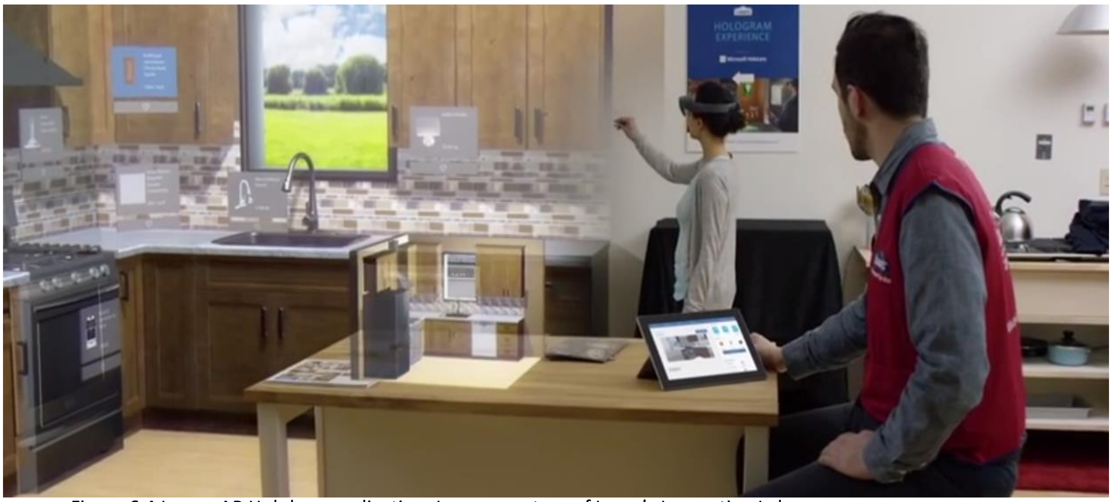


Figure 6.4 Lowes AR Hololens application. Image courtesy of Lowe’s Innovation Labs.

candy hats on, with antlers, or even wearing different sweaters (Blippar.com, 2017).

Beginning in 2008 with the BMW Mini ad, AR in Marketing quickly increased in number and, at the time of writing, is still growing. Although at the advent of AR in marketing, the programs were quite simple and often required a printout. However, currently in marking, AR apps have become very intricate, allowing interaction, creation, and they have all moved beyond needing any sort of print or cut out. Looking forward, the field of marketing has ambitious plans for AR. First, BMW is integrating the showroom and AR, allowing customers to both see the car in their real environment, save color options, and then order the car (ft.com, 2017) this is like the AUDI fully digital showroom that integrates with Apple (Forbes.com, 2018). But beyond that, Car Companies are also looking to integrate AR into their actual cars with HUD’s, such as Nvidia’s Drive AR, and glasses that eliminate blind spots with a special “x-ray” feature (International Business Times UK, 2018).

6.5 Analysis of augmented reality in the tourism field

Augmented Reality and tourism first came together in 2010 when Voglio Vivere Cosi, a tourism campaign for a region of Tuscany, released Tuscany+. Tuscany+ is an AR App that acted as a tour guide through Tuscany, wherein users could download the app and, by pointing their phone's camera at various sites, get extra information in both English and French regarding accommodation, dining, nightlife, and sightseeing (Staff and Archer, 2017; Kounavis, Kasimati, and Zamani, 2012). Although this is not the first appearance of this type of AR, which could be attributed to Wikitude in 2008 – a browser that allows extra information to be laid across physical landmarks via AR (en.wikipedia.org, 2018), it is the first app designed specifically for tourism (Staff and Archer, 2017; Kounavis, Kasimati, and Zamani, 2012). While Wikitude used user input, Tuscany+ had the information pre-programmed and was designed with an increase of tourism in mind (Staff and Archer, 2017; Kounavis, Kasimati, and Zamani, 2012).

Since the implementation of Tuscany+ there has been a dramatic increase in AR Applications for tourism. In fact, there are now four subcategories that fall under tourism, all with incredible AR app examples: accommodation, transport, catering, and tourist attractions. In accommodation, there is a wide range from the basic 3D room tours, to intricate interactive hotels with AR murals in every hotel room. Transport AR apps also have a range, from simple directions or translations to animating the subway map in New York with the app Tunnel Vision. Catering offers restaurant menus with an interactive 360-degree view of each dish, correct portion size, and ingredients, and navigation (thinkmobiles, 2018). Finally, tourist attractions, which get at the heart of tourism AR apps, also vary greatly. While there are still apps such as Tuscany+ which give general information about the city, there are also more intricate apps. Such as the Skin and Bones app, which allows users to see full life interpretations of extinct animals in the museum by pointing a phone or tablet towards the skeleton (Thinkmobiles, 2018), or the Then and Now and Street Museum apps, with the Then and Now app based in Paris and the Street Museum App located in London, both offer the ability to see parts of the city at various points in history (Chen, 2014; Kounavis, Kasimati, and Zamani, 2012).

As a whole, the AR apps in Tourism have increased in both intricacy and number. From the simple information available in English and Italian to real-time translations, interactive room selection, easy access to information, reliable navigation, and interactive dining and entertainment (Augment News, 2018). The current trend in tourism, especially within museums, is a push towards digitally enhanced exhibits. The ability to overlay more information without taking up more physical space is ideal for museums. This exact notion was one of the key factors leading towards the Hololens applications at the Preston Car Museum (Hills-Duty, 2018; YouTube, 2018). With the increase in personal devices capable of running the ever-expanding pool of AR applications, it is expected that the various areas of tourism will continue to employ the use of augmented reality.

6.6 Summary of comparative analysis

The comparative analysis of augmented reality in other fields was, as discussed previously, to draw certain conclusions on how augmented reality may fair in the field of archaeology. Address this the three fields were chosen based on certain attributes that mimic the desired attributes of AR in archaeology. Gaming offered high levels of registration and low levels of latency, Marketing offered low impact and easy to use applications, and Tourism offered apps that were able to display multiple datasets in an intelligible and efficient way. In addition to this, the field of archaeology's baseline technology was selected based on its similarity to augmented reality. GIS and specifically ArcGIS is designed to layer data over other datasets just like AR as well as the many other reasons discussed previously in section 5.3.2.

The similarities between the baseline technology and augmented reality technologies offer, to a certain degree, a glimpse into what can be expected by the introduction and integration of augmented reality as a primary tool for archaeological data interpretation. Given that the baseline technology was introduced in the 1970's but didn't take off in the field until the 1990's (Wheatley and Gillings, 2002), it took GIS a decade plus or minus five years to become standard practice in the field of archaeology. However, GIS has remained a standard practice and shows no evidence of this stance changing. This introduction did receive a few delays to its inevitable mainstream tool status. It's complicated nature and the possibility for researchers using it to become reliant on it and tend to jump to conclusions based on an environment without looking at other non-environmental factors (Zubrow, 1990b; Wheatley, 1993; Harris and Lock, 1995; Wise, 2000). The same can be said for augmented reality. It requires specialized software and a dedicated skill set in order to create even the most basic of AR apps, let alone a highly detailed and accurate representation of archaeological data that would be required for the application to have any valid archaeological data produced from it. The other challenge experienced by GIS with being easily complacent with its face value data can also be said for augmented reality. The determination of what is 'real' and 'fake' is dependent upon the user and does have the ability to differ from user experience to user experience.

Each of the three fields offered a different perspective and use of AR technology, but all seem to have the same result, Augmented reality is growing exponentially and is showing no evidence of slowing down. Within the gaming field, augmented reality was introduced in the early 1990's but didn't really take off until 2010. This in part was due to the need for large clunky gaming apparatuses and the cost of the technology needed to implement the games. However, by 2016 AR has exploded in the gaming field producing the largest grossing mobile game in history, generating a total of $269million dollars (Business of Apps, 2018). This has sparked a change in mobile technology and pushed for other developers to take on similar projects. Like the Gaming field, Marketing also had a slow start with AR. Introduced in 2008 and not taking off until four years later in 2012 augmented reality had a premature start but as with the gaming field, with mobile technology changing AR advertisements could become easier to get to the consumers. With the new technologies being used augmented reality has pushed for new innovations in many different industries as seen with the automotive innovations done by BMW (Ft.com, 2017). Again, similarly, with marketing, AR tourism was introduced in 2008 but didn't take off until 2012. With AR becoming more mainstream it caused a division in the tourism apps (thinkmobiles, 2018). Breaking mobile application into four different categories: accommodation, transport, catering, and tourist attractions. Each of these has sparked a plethora of AR apps, and there are no signs of this slowing down. Using this data in conjunction with data from the case study in the sections to follow I will be addressing how these relationships with other fields can answer directly the research questions posed at the beginning of this thesis.

Chapter 7: Addressing the Research Aims

7.1 Addressing Research Question 1

This and the previous chapter have detailed the various methods used to investigate the research questions proposed at the start of this thesis. The rest of this chapter will be dedicated to directly answering these questions. First and the primary concern of this research project was to analyze the possible role of augmented reality technology in common maritime archaeological interpretation tools and techniques. This research goal is a substantial one, to address this accurately and thoroughly it was broken down into four direct questions: (A)Does augmented reality improve common maritime archaeological interpretation tools and techniques? (B) Does augmented reality complicate common maritime archaeological interpretation tools and techniques? (C)Is it worth the effort to create the augmented tools? (D)What effects does augmented reality have on boat plans? To answer this and its sub-questions a case study methodology was developed (Chapter 4). Through the investigations carried out during the case study, presented in Chapter 5 section 1, there were various factors that we will be using to answer this research question; time, accuracy, added insight, the human element, sense of scale, participant interaction, and emerging elements because of the augmentation.

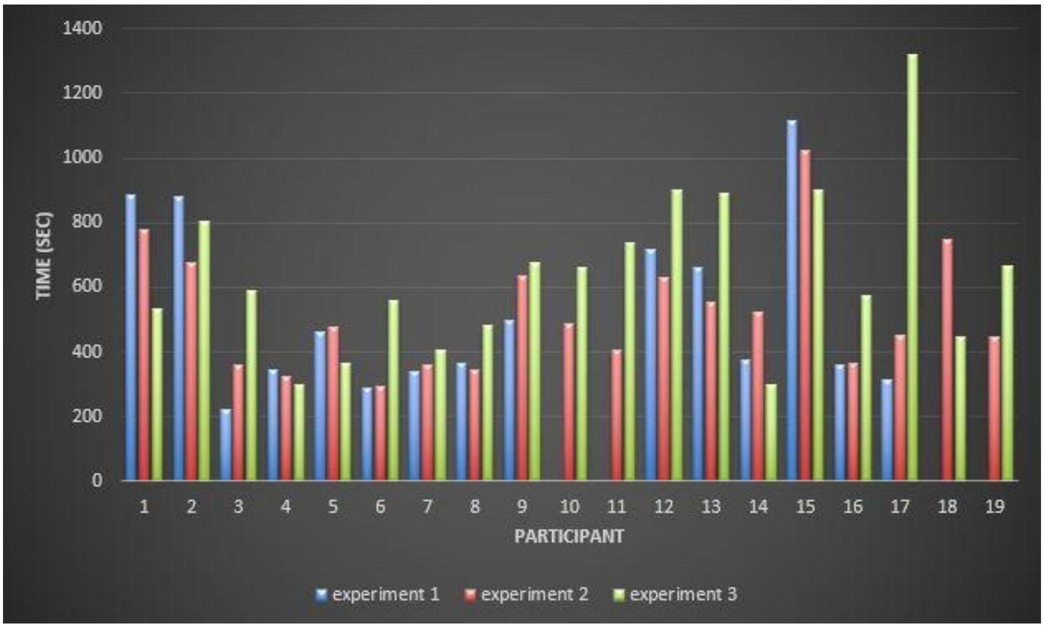


Table 7.1 Graph showing each participants time of completion for each experiment

Does augmented reality improve common maritime archaeological interpretation tools and techniques or does it complicate them? To answer this the results of the case study will be addressed for the participant's completion time, the accuracy of the answers given by the participants, application usability, and if there was any added insight given by the augmentations. The time spent to complete the control experiment with zero added augmentations using traditional boat plan reading tools and techniques had the fastest time of 222 seconds and the longest time for completion of 1,114 seconds, and the average is 517 seconds. The second and third experiments involving augmented tools and techniques had, respectively, the fastest times of 293 and 297, and the longest times of 1,023 and 1,1317, and the average times of completion of 504 and 637. The amount of time to complete the tasks given to the participants for the first augmented experiment was 2.6% faster or less time to complete than the control experiment. However, the amount of time to complete the tasks given to the participants for the second augmented experiment was 23.2% slower or more time to complete than the control experiment. A full graph of individuals times over the three experiments can be seen in table 7.1. Time is not enough to gauge the practicality of the augmented tools; we must also look at the accuracy of the results of the tasks. The greatest number of mistakes made by participants for the control group was 6, the fewest being 1, and the average being 3.1 mistakes or incorrect answers given. The second and third experiments involving augmented tools and techniques had, respectively, the most mistakes of 5 and 8, the fewest being 0 and 1, and the average 1.6 and 3.7 mistakes or incorrect answers were given during experiments two and three. In other words, for experiment 1 28% of the answers given were incorrect, for experiment 2 14.5% of the answers given were incorrect, and for experiment 3 31% of the answers given were incorrect. It is worth noting that answers of I don’t know, unknown, blank, or similar answers were included in these figures, but will be examined on their own next. For experiment 1, of the 209 questions answered (11 questions/tasks X 19 participants = 209) 19 were left blank, about 9%. For experiment 2, of the 209 questions answered 8 were left blank, about 4%. For experiment 3, of the 228 questions answered 25 were left blank, about 11%. The final factor that I will be using to determine if AR improves or complicates tools and techniques of maritime interpretation is the usability of the tools. After each experiment, the participants took a survey, and one of the questions directly asks about the usability of the tools. The question gauged their answers using a Likert Scale, for this scale 1 indicated very easy to use and a high level of usability where a 5 indicated that the tool was very difficult to use and a low level of usability. The control groups, the traditional groups, the highest score was a 4 moderately difficult, the lowest score was a 1 very easy to use, and the average score given among all 19 participants was a 3 indicating that the tool is not easy, but it is not difficult either. The second experiments highest score was 5 very difficult, the lowest score was a 1, very easy to use, and the average score given was a 2 indicating that it is moderately easy to use. The third experiments highest score was a 4 indicating that it is moderately difficult to use, the lowest score was a 1 indicating that it was very easy to use, and the average score given was a 2 indicating that it is moderately easy to use.

The data examined is showing a trend that an augmented tool (handheld device) is improving the tools and techniques used for archaeological interpretation, however, when introduced with a more sophisticated piece of hardware to augment the tool, i.e., the Hololens, things become complicated and are causing longer times to complete tasks without increasing the accuracy. Even though the Hololens scored a better usability than the traditional tool, it is evident that without proper training and a better understanding of how to utilize the Hololens, the tech gets in its own way. To directly answer the first question, does augmented reality improve common maritime archaeological interpretation tools and techniques? Yes, it is clear that simple AR tools can be utilized without specialized training to improve common maritime interpretations of archaeological datasets. Does augmented reality complicate common maritime archaeological interpretation tools and techniques? Also, yes, with more sophisticated tools things are more complicated and specialized training could mitigate these hurdles but without it, it does complicate the average archaeologists use of the tools.

The next sub-question that will be addressed is whether the effort needed to create the application is worth the insight gained by the app. To determine this, we will be looking at three different factors time, accuracy and the added insight of the augmentations. As with the first and second sub-question, we will look at the time it took to complete the tasks of each experiment. The amount of time to complete the tasks given to the participants for the first augmented experiment was 2.6% faster or less time to complete than the control experiment. However, the amount of time to complete the tasks given to the participants for the second augmented experiment was 23.2% slower or more time to complete than the control experiment. As stated previously, a full graph of individuals times over the three experiments can be seen above in table 7.1. Again, as with the first two questions, accuracy must be taken into account. For experiment 1 28% of the answers given were incorrect, for experiment 2 14.5% of the answers given were incorrect, and for experiment 3 31% of the answers given were incorrect. As stated previously this figure includes blank answers, which to answer this question we must look at how much more the participants are able to answer with the new tools versus the traditional tools. For experiment 1, 9% of the questions were left blank. For experiment 2, 4% of the questions were left blank. For experiment 3, 11% of the questions were left blank. As seen with experiment 2, the augmentations sped up the process and offered a 50% decrease in the number of unanswered questions as well as an increase in the accuracy of the answers themselves. However, with experiment 3 there is an increase in time, errors, and blank answers given.

The data given addresses two important aspects, first there is added benefit to creating the AR application, but there is a point in which the tools can be too complicated to work without prior training. It is evident that given the applications quantification criteria, which were met, and the data collected and presented here that it is, in fact, worth the effort. There is, in at least one case, a substantial increase in the data accuracy with the augmented tool. It should be worth noting that each of the participants were asked about outside applications and further applications of the tools used and 100% of the responses were in favor of the technology being useful outside of the direct questions be answered. So just because the application may have limited use in the present does not constitute that the same will be true for the future.

The final sub-question being address is what effects AR has on the typical boat plan. This research question gave interesting results. First and foremost was the added grandeur of seeing things in a 1:1 scale. As archaeologists the majority of what we deal with are physical objects, all the stuff left behind by past cultures. Being able to see this ‘stuff’ in person is key to accurate interpretations. However, the destructive nature that is the archaeological process doesn’t always allow for this to be possible, which is why we rely heavily on proper recording techniques. In many cases, paper records are all that is left of some cultural remains. Embedding a 1:1 model of the artifact, in this case a boat, to the paper record combined with the ability to add multimedia of the object in use added that extra insight into the interpretation, as evident by the participants’ testimony “absolutely amazing, the ability to overlay a data and manipulate it in playspace is highly useful. The human element aids my understanding via emulating my natural vision” (participant 8). Investigations into the results of the Likert Scale questions given to the participants after the experiments (Table 5.1) show that every aspect of the technology scored low indicating that it had a high level of usability. To directly answer what the effects AR has on boat plans, simply it adds a sense of scale and added insights into the human aspects of the objects. It allows the researcher to put themselves in close relation to the object and ultimately the culture that object belonged too.

7.2 Addressing Research Question 2

This section will be dedicated to answering the second research question posed by this research, what are the potential ramifications of augmented reality on not just the tools and techniques, as with the first research question, but in the field of maritime archaeology as well? To address this question, a comparative analysis was conducted using a well-established technology in archaeology as a baseline (GIS) and investigating the uses of augmented reality in three other fields (gaming, marketing, and tourism). The data presented in sections 6.3, 6.4, and 6.5 will be used to address this question. There are multiple factors that will be investigated to answer this question, and they are as follows: the uses of AR in other fields Vs. how it is used now in archaeology and how that compares to the baseline technology, how did the baseline technology change the field once introduced, and AR's lifespan and usability in other fields and how that relates to its current life cycle in archaeology.

As seen in their respective sections (6.3, 6.4, and 6.5) augmented reality has been used in multiple ways from the simple to the highly intricate. In the gaming field, it started out as a clunky apparatus with low-resolution graphics and is currently supporting high definition graphics on devices that fit in your pocket (Das et al., 2017). For marketing augmented, reality started as a simple point and view advertisement and is currently working on a fully integrated interactive automobile (Newstands, 2008; ft.com, 2017). For tourism, AR started with simple GPS based local hot spots and points of interest and now involved multimedia touring experiences (Staff and Archer, 2017; Kounavis, Kasimati, and Zamani, 2012). As with gaming early experiments with augmented reality in archaeology involved large clunky devices and offered low to standard definition on graphics (Allen et al., 2004; Benko et al., 2004). So, it is possible to see that with progression the implementation and product/result is becoming better. The same can be said for its archaeological counterpart. Some of the more current archaeological experiments in AR are becoming more streamlined and offer better graphics on smaller devices. If we mock this trend over its archaeological equivalent (GIS), it had a slow start as well. Large computers were needed for the processing power required to generate the GIS maps and data; now GIS can be done on the move (Wheatley and Gillings, 2002).

As discussed previously in section 6.2 the baseline technology shares many attributes with augmented reality, and as such parallels and projections can be drawn and established. If we look at early GIS in archaeology, it was slow to spread to all areas of archaeology. Starting primarily in the USA and eventually making its way to Europe roughly a decade later, speaking in terms of being mainstream. There were complications at first, such as lack of training and a concern for archaeologists to be complacent with interpretations without looking at other sources. The same can be said for augmented reality. Creating an AR application does require specialized training, and equipment, and a very long philosophical debate could be made on what constitutes real and not real and how that impacts data. Though with its slow start we saw that after a two decades GIS had become standard practice in archaeological surveying projects, especially those that are landscape based (Wheatley and Gillings, 2002; Pluckhahn, 2007). This same trend is starting to emerge for augmented reality in archaeology. It had a slow start with only a handful of projects targeting archaeological research such as the ARCHEOGUIDE in Pompeii that utilized augmented reality and other virtual aspects to augment the current landscape to depict scenes of the past (Vlahakis et al., 2001); and the VITA Project that allowed a user to remote access an archaeological site by building a digital version of it around the user. This was done by the use of a HMD and models created by laser scanning or photogrammetry (Allen et al., 2004; Benko et al., 2004). Looking back on Chapter 2 section 2.5 the discussion of these projecst showed a growing trend in the development of this technology to increase the users ability to interact with and understand the data it portrayed. Not unlike the development of GIS over its lifetime (Wheatley and Gillings, 2002; Pluckhahn, 2007).

Looking at augmented reality's lifespan so far in other fields we can get an idea of how AR could act in archaeology. The fields were chosen based on off criteria that linked it to how it is being used for archaeological purposes, giving a valid relationship between the fields. The gaming field had its earliest introduction to the technology (early 1990's), but it took the technology a decade before it took off in the field, as the baseline technology. This was in part due to the lack of easy to implement user interfaces and hardware. The other two fields had a much later introduction to augmented reality, about 18 years later, so the technology to develop and implement easier to use AR experiences was quicker to come about. For both the field of marketing and tourism, from the introduction to the technology sparking innovations and becoming mainstream in the field, it took about four years.

By looking at the clear data presented in their individual sections and here, augmented reality is following a similar path as GIS. They both exhibited a slow start, both require specialized training to utilize to their full potential, and both show no signs of the technology leaving. In the outside fields, the lifespan of augmented reality is demonstrating similar trends as those shown by GIS and current uses of AR in archaeology. To answer the research question directly some to the ramifications of AR on the field would include a short period of technological resistance from the field of about one to two decades of which we are approaching the end of. This also correlates with the Hypecycle presented in Chapter 1 and trends in HCI discussed in Chapter 2. HCI is developing towards natural body language and gesture commands for greater user immersion (Rautaray and Agrawal, 2012). User immersion is the goal here, just as with augmented reality, user immersion is key. We saw this with the studies conducted on mental health therapy and with the Augmented Mirror project. So, taking the discussion on the Hypecycle in Chapter 1 and the HCI and AR discussions in Chapter 2 it is projected that after this period of resistance to adapt a new technique and technology, and given the correct technological advancements take place for more access to inexpensive AR technologies, the development of projects concentrated on AR will increase exponentially, and ultimately become standard practice or be replaced by a different technology, as AR is showing no signs of slowing down in terms of applications and development.

7.3 Addressing Research Question 3

The final section of this chapter will address the final research question. This research question is an important question that must be asked about any technology that is being used, and that is its sustainability. What is the sustainability of augmented reality technology as an archaeological tool? To address this, there are many factors that will be investigated. These include the participant's responses to the post-task survey presented in the case study, the lifespan of augmented reality as seen in the other fields of the comparative analysis, and the worth the effort analysis was done in the analysis of the case study data. To answer this question, I will be utilizing data from both the case study and the comparative analysis.

During the case study after each experiment, the participants were asked to complete a survey (Appendix B). The final three questions of this survey directly addressed the sustainability of this technology. They are as follows: What are your thoughts on using this technology? Does this technology have any outside use besides in answering the questions you were just presented? How useful do you think this technology is within the field of archaeology? another aspect that should be included with sustainability is usability. As with sustainability, the participants were also asked about the technologies usability in the form of a Likert Scale question, 1 being very useful and 5 being very difficult. In 100% of the answered questions each participant agreed that this technology could be used, in outside projects, and in other areas of archaeology. in addition to this the average response to usability for each augmented tool was 2 indicated that the tool had moderately easy usability. A complete account of each participants' response can be found in Appendix O.

The second factor that I am using to address sustainability is the AR lifespan in other fields addressed in the comparative analysis sections. As previously mentioned the gaming field had its earliest introduction to the technology in the early 1990's, and it took ten years before it became popular in the field. For both the field of marketing and tourism, from the introduction to the technology sparking innovations and becoming mainstream in the field, it took about four years. Since their popularity in their field, each has shown zero indication of the technology stopping or slowing down for that matter. Given the similarity between how each of these fields utilizes AR technology, it is safe to compare the lifespan of AR in these fields to that of AR in Archaeology, which as it currently stands is starting to become a popular tool for research and not just heritage tourism.

The third and final factor was addressed previously as well. Is the application worth the effort to make it? As concluded previously, it is apparent that given that it is worth the effort. It has demonstrated a substantial increase in the accuracy of answers with the augmented tool. In addition to this, each of the 19 participants was asked about outside applications and further applications of the tools used and 100% of the responses given were in favor of the technology being useful outside of the direct questions be answered. So, to reiterate, just because the application may have limited use in the present does not constitute that the same will be true for the future.

Given the three factors that I have used to evaluate the sustainability of augmented reality as an archaeological tool, there is sufficient evidence to support the technologies sustainability. The direct responses of users of the technology unanimously agree that it has sustainability. Comparative analysis of outside fields yielded a relationship between themselves and archaeology, in terms of usage, and they each show no evidence of AR going anywhere, but also show advancements in their fields because of using AR. Combine this with the studies and reviews of the current trends of HCI and user immersion discussed in Chapter 2 sections 2.4 and 2.5 and a clear trend towards the use of AR is going to increase in the years to come. And finally, effort analysis of the case study data has deemed that it can be worth the extra effort to create an AR app, but it is also worth mentioning that not every instance of archaeological interpretation requires an advanced mixed reality counterpart. Sometimes a pot is just a pot.

Chapter 8: Conclusion

The following chapter will be covering several topics. First and foremost a reintroduction of the central concepts, themes, and processes used throughout the research project. This will include a brief but detailed summary of how the project was conducted and what choices were made and why. The second topic of this chapter will be the conclusions I have derived from the various data sets that have been collected. This will also include a summary of how the data was collected, processed and analyzed. The third topic of discussion in this chapter, and possibly one of the more important topics of this chapter, is why this research is important. In this section, we will revisit some of the earlier themes discussed at the beginning of this thesis. This section directs the topic of discussion towards recommendations for future research and recommendations for practitioners. Based off the experiences and research conducted by myself I will offer my insights into where I believe the research should be directed to and recommendations based on the experience of how practitioners should approach augmented reality as an archaeological tool. The final section will be devoted to a few final remarks on the data and topic of augmented reality as a tool for data interpretation.

8.1Summary of Research Project

This research project consisted of several stages (refer back to table 3.1 in Chapter 3), initial investigations into the current state of the technology in both the field of archaeology and as the technology itself, investigations into related concepts and themes of augmented reality, investigations into projects that utilized augmented reality within archaeology and other related heritage fields, investigations into research gaps with AR and general IT in the field of archaeology, methodology design, case study design, conducting the case study, analyzing the case study results, comparative analysis design, conducting the comparative analysis, analyzing the comparative analysis results, addressing the research questions with the data sets collected, and finally writing up. To address these in a coherent fashion this section will be comprised of several subsections, one for each of the previously mentioned stages of research. Within each of these subsections, a brief explanation of the actions that took place during that stage of research will be given as well as the rationale for any choices that were made for that stage.

1. Before it all began
   Before any of the reading, before any of the interview, and well before any of the sophisticated tools used during this research project, it all started with simple question. “Wouldn’t it be cool if…”. It is often discouraged in academia to go down this route, and it

is true that it is a slippery slope, but it it's my recommendation to not let this mind-set deter you but rather use to reign you in a bit. For fields to progress researchers must find and identify gaps, and then determine 1, why is there a gap, and 2, how do we fill that gap? Finding this gaps can be as simple as "wouldn't it be cool if" because that sentence implies that something is missing, but what you do with that and how you present your findings is the difference between legitimate research and wild armchair speculation. After my awe-inspiring wouldn't it be cool question, a series of preliminary inquiries were made to academics and professionals in the field of Maritime archaeology and boat building. This revealed many avenues for research and adaption for my idea. The original system of delivery for the "enhanced boatplan" (the original name for the project) was a virtual reality system. However, a quick internet search revealed that the field was flooded with this type of system. It also revealed that VR is not a viable tool for the field. VR systems are cumbersome and require a dedicated space to be utilized properly. However, this search also introduced augmented reality as a potential alternative, and AR has the potential to be a worthwhile field tool.

2. <u>Initial investigations into the current state of the technology</u>

   The next stage of this research project consisted primarily of looking at how the technology, augmented reality, was currently being used. Investigations took place in the field of archaeology as well as in many different fields including, the gaming, medical, entertainment, marketing, automotive, military and defence, as well as construction and home integration technology. It was from this point I could focus my attention on how AR works.

3. <u>Investigations into related concepts and themes of augmented reality</u>

   This stage was completed devoted to understanding all the concepts related to how AR works, and how AR came to be. First, research was directed at understanding what AR is and is not. What constitutes what on the mixed reality spectrum. From here I could focus on components are needed to create an AR application, such as sensors, cameras, models, etc. With the hardware firmly understood I directed my research towards understanding the concepts related to augmented reality. These concepts include dimensionality, how AR is perceived by the user, and how AR came to be. What pieces of technology came together and what advancements were needed to push technology towards AR.

4. <u>Investigations into current projects</u>

   During this stage, I revisited previously researched projects from stage one that was in the field of Archaeology specifically. This stage of the research project consisted of analyzing the current and not so current uses of AR in archaeology and archaeological tourism.

Looking at projects such as the ARCube and the Vita Project gave significant insights into the potential of uses for AR in archaeology, this in turn, illuminated where potential gaps in the research could be.

5. <u>Investigations into research gaps with AR and general IT in the field of archaeology</u>
   At this stage in the research, I had gained a significant understanding of how augmented reality was designed, built, and worked. I also had investigated where AR had come from and how it was currently being used, which naturally would lead research towards where it could possibly go and what gaps were there that needed to be investigated. It was during this stage of the research project that directed me towards the gap between lab data and field data (discussed in Chapter 1). This sparked investigation into work done by Stuart Eve and others that were utilizing IT, be it AR, VR, computer simulation, etc., as an archaeological tool and not just to display archaeological data. Which lead me to the conclusion that there is a significant gap in the research about the impact that the various forms of IT have on the field itself. This realization helped reshape my research questions and direction of research into its current state. It was from this point that the research would focus on how augmented reality could impact the field of archaeology as a tool for archaeological data interpretation.
6. <u>Application design</u>
   The Methodology (7 in this list) and applications used in Archaeomented Reality were developed closely together. The application design had many steps. As with any program coding project a pseudocode needs to be developed. This outlined many aspects of the application that I wanted to incorporate within it. Once I was happy with my pseudocode my attention turned towards the design and interface of the application, due to the nature of an augmented reality application the interface is important and needed to be thought about early in the development process. Which ultimately lead to a unique research aspect of the project, bodystorming.
   Bodystorming is the act of idea and thought developing by use of physical motions and miming out commands and actions. The bodystorming session involved taking participants and having act out using the AR apps. This will reveal how the body *will* and *want* to react with the applications. By using the feedback from the participants of the bodystorming session a more immersive and user-friendly experience with the applications was achieved.
   After the bodystorming the actual design of the applications took place, this involved the creation of a prototype application and field testing with various users. They would detect bugs or glitches in the application as well as report on usability and capabilities. In turn, revisions to the applications would be made and the field testing process would be

repeated. This continued for several iterations of the applications until the final build would be published on the open market and be ready for use in the case study.

7. Methodology Design

   Once the research direction was finalized a methodology could be designed. This stage of the research consisted of examining my aims and objects and determining the best route possible for answering and reaching those goals. Through research of other projects and viewing the design and success rate of those projects, a two-pronged methodology was designed. The first would be a case study and the second would be a comparative analysis. These were chosen based on the successful uses of other similar projects.

8. Case study design

   The design of the case study was a crucial stage. It was ultimately decided that a single case study with the focus on how the participants interpreted the subjects (boats) using three different methods would be the best approach to understanding the impact augmented reality would have on the interpretation process. The design process utilized HCI techniques adapted for my purposes.

9. Conducting the case study

   The case study involved 3 different experiments where the participants needed to work through various tasks and then answer a short questionnaire on the experiences with the technology. The participants were also observed for various verbal and non-verbal cues to denote how the AR experience was being perceived by the participant. Time and accuracy were also recorded for analysis purposes. There was also a second set of participants that consisted of non-archaeologists. This was done to investigate the inherent abilities of AR as a tool without specialized training.

10. Analyzing the case study results

    During this stage, the data collected from the case study was analyzed using tested HCI methods that were adapted to this project.

11. Comparative analysis design

    The design of the comparative analysis was crucial. This was done to draw parallels with well-established AR fields to see how AR could impact archaeology. the fields were chosen based on characteristics of how they utilize augmented reality. The field of gaming focuses on low latency and high registration, the field of marketing focuses on easy to use interfaces and programs, and the field of tourism focuses on the best way to display data.

12. Conducting the comparative analysis

    During this stage of the research, project investigations were made into 3 different fields to see how AR had to be used, how it impacted the field, and what AR's lifespan looked like in that field. There were also investigations done in the field of archaeology for an already well established technological advancement that could be used as a baseline technology to compare augmented reality with. This was done to see how AR could potentially impact the field of Archaeology as well as get an insight in the lifespan it could have within the field.

13. Analyzing the comparative analysis results
    This stage, like its case study counterpart, consisted of analyzing the data collected during the comparative analysis investigations.
14. Addressing the research questions with the data sets collected
    This stage of the research project was devoted to looking at each data set and applying them towards the research questions developed at the beginning of this project. Each of the research questions was broken down to their core parts and answered using the various methods designed specifically for each question.
15. Writing up
    The final stage of the research project involved writing up all my findings and experiences throughout the research process. This was done in a manner to offer others insight into my investigations and the ability to replicate my experiments and findings.

8.2 Research Conclusions

This research project yielded many conclusions at its finish, the following section will reiterate everything that I have drawn from my own research and from the investigations into other related fields and projects. This will be done by first looking at the case study, followed by the comparative analysis and finally the research questions.

The case study had multiple stages and processes during its conduction but consisted primarily of three experiments. The first experiment, the control, used traditional tools and techniques with no augmentations. The second experiment used a handheld device to act as a user interface for the augmentations. The third experiment used a head-mounted device to act as a user interface for the augmentations. Though necessary to address different ways of interacting with the AR interface this case study could have, in my opinion, and in hindsight, could have excluded the handheld device and focused more on the head-mounted device. The Microsoft Hololens was a superior interface and experience for the users (participants). By focusing on just the head-mounted and the control experiments, I may have been able to create a better blend of physical and digital data. All this being said, the use of two different interface methods does offer its own benefits. First and foremost, it allows for a more holistic view on interfacing, and secondly, it gave a definitive answer to interface preference and AR experience quality between the two options. Both of these outcomes were reason enough to keep the experiment in the case study.

My conclusion on the case study results are as follows; the applications designed both met all five of the criteria (user-friendliness, streamlines a process, the output is greater than the effort to make, redefines the typical use, and sustainability) I developed for the evaluation of the applications. This made the applications a valid tool to investigate my research questions. The data collected from the participants followed well established and successful practices from the field of HCI. Again, this made the process a valid tool to investigate my research questions. The results from the case study were both accurate and valid in formulating the conclusions discussed in the sections that address each research question.

In addition to the group of participants that are archaeologists, I had a secondary group that consisted of non-archaeologists. This was done to see if there were any added benefits not related to having an archaeological background. Does AR make finding the correct data easier? This group only consisted of two members to reflect on the data accordingly, this is not a proper sample size but rather a glimpse into something that could be. Both participants showed an increase in the number of tasks and questions that they completed or answered correctly for both augmented experiments versus the control experiment, in other words, they were able to answer questions about the vessels that they normally would not be able to.

The comparative analysis portion of the research, as with the case study, had multiple avenues of research involved within it. The comparative analysis involved investigating various archaeological tools and techniques to find a viable baseline technology in which to compare augmented reality with, and the investigation of three different fields and how augmented reality has been introduced, utilized, and is fairing in those fields.

One of the key things I would have done differently if not for geography, financial, and temporal constraints, would have been to personally use and experience each of the tools investigated within each field. This could have given a better understanding of the technology and its uses. As well as interviews with professionals within each field to address the day to day life of AR within their respective fields.

The data collected during the comparative analysis was thorough and consisted of several aspects that were researched in each field to offer the same results throughout, a technique used to ensure a direct correlation could be used between the three fields themselves as well as with the field of maritime archaeology and its baseline technology.

The research questions posed at the beginning of this research project and then answered in the previous chapter offered valuable insight into the role augmented reality could play as a primary tool for data interpretation. Throughout the research process I kept any biased thinking on what AR could do for archaeological data interpretation off my mind, now that the results have been calculated my personal thoughts on the role AR could take are as follows:

Analyzing the possible role of augmented reality technology in common maritime archaeological interpretation tools and techniques, I have found that there are inherent complications with the introduction of a new step in the research process or in this case a new step with additional tools and processes and equipment, however, there are many benefits that outweigh this. The ability to interact with digital content in a more 'humanistic' and natural way opens the door to new ways to interpret data. Being able to see objects in a 1:1 scale allows archaeologists to view data in new ways, not to mention data accessibility increases drastically as well. These were the first two conclusions that I derived from the results, but something that I would also like to note is the invaluable method of refining the process that we have been using for interpretation (taking 3D objects, translating them into 2D records, then later trying to interpret them back into 3D) into being able to keep things in three dimensions throughout.

The potential ramifications of augmented reality on the tools and techniques, and in the field of maritime archaeology as well are vast and unknowing for certain, however, given its similarity to ArcGIS, I am comfortable after conducting my investigations, that AR would follow a similar path. There will be resistance to learning to not only use AR tools but to develop the AR tools themselves. There will be a new wave of Digital Archaeologist in the upcoming years as the technology becomes more commonplace. There will be, as with GIS, an increase in AR research topics in the different fields within archaeology, as well as its healthy fill of criticism as a viable and valid source of data, just like with ArcGIS and other GIS programs.

To address the sustainability of augmented reality as a tool for archaeological data interpretation I would like to first point out that with every project there is the proper tool to get the job done and it's not always going to be an augmented reality application. That being said, the limit on what AR can be applied to is quickly diminishing as technology gets more advanced. As with my own investigations into what AR could be utilized with and according to 100% of my participants (including those in the non-archaeologist group) the sustainability of augmented reality within the field of archaeology is clear and promising.

8.2.1 Why this research is important

The current trends in technology are pushing towards interactive virtual environments. This is reflected in the Hype cycle presented in Chapter 2. Approaching the 'slope of enlightenment' is virtual reality and augmented reality. This means within the next 4 to 5 years both technologies will be integrated into most areas of life. This trend is already emerging in the three fields used in the comparative analysis and is reinforced by the trends present in HCI. The growing movement of computer devices that interact with non-verbal ques from its uses is pushing for user immersion through gesturing commands and other means (Rautaray and Agrawal, 2012). We see specific integration of the new AR applications that use similar functionalities as the applications used within this research project as with those from the ARET system in the Mental Health field (Wrzesien et al. 2011) as well as with the Augmented Mirror project (Vera et al. 2011) and the Ubi Finger system (Tsukada et al., 2001). The field of archaeology already utilizes virtual environments for a multitude of simulations (Renfrew, 1997; Gillings, 1999; Barceló et al., 2000; Ryan, 2001; Zhukovsky, 2001; Gillings, 2005; Bruno et al., 2010). The next step in this procedure is moving from virtual reality to augmented reality.

As mentioned in Chapter 1 and Discussed in Chapter 2, there is a detachment between field data and lab data. This gap is discussed by Huggett (2000), Lock and Brown (2000), Banning (2000), and Eve (2014). The basis behind the choice of augmented reality over that of other related technologies to bridge this gap is based on three simple facts. First, it is the next step in reality perception that is already being used in archaeology. VR is already used abundantly in archaeology, and the next step in the mixed reality spectrum is AR. Also, the choice of AR over VR, as mentioned in Chapter 1, archaeology already has a large quantity of projects, and data concerning VR's use (Renfrew, 1997; Gillings, 1999; Barceló et al., 2000; Ryan, 2001; Zhukovsky, 2001; Gillings, 2005; Bruno et al., 2010). Augmented reality's purpose is to overlay the digital on the physical which is in direct relation to the detachemnt between the field and the lab, taking lab data (digital) and overlaying it directily into the field (physical) could be a direct soltution to this disassociation. The second fact is that some of the preliminary work for its usefulness with archaeological data has already been done (Barceló, 2000; Vlahakis et al., 2002; Allen et al., 2004a; El-hakim et al., 2004; Caarls et al., 2009; Garagnani and Manferdini, 2011; Wang et al., 2011; Niedermair and Ferschin, 2012; Eve, 2014). The final reasoning for the choice of AR is that of its projected growth as a mainstream technology.

The final point I would like to reiterate in relation to the necessity of this research is the lack of data for AR as a tool. The vast majority of publications within Archaeology pertaining to augmented reality is belonging to the category of look what we can do with it, the same can be said for IT in general (Lock and Brown, 2000; Eve, 2014). There is a missing data on the effects of IT more specifically AR on the field of Maritime Archaeology. It is because of these three factors, technological advancement trends, disassociation of lab and field data, and lack of data on the effects of AR on the field, that makes the research conducted for this research project, relevant, important, and needed.

8.3 Recommendations and Final Remarks

As mentioned and the end of Chapter 1 in section 1.5 Concluding remarks, I stated that, “the ultimate goal of this research is to provide a stepping stone, an origin point to branch out and study the effects of augmented reality and to begin to utilize AR as primary tool for archaeological data acquisition…”, and after concluding the research done in this thesis I strongly feel that AR will play a pivotal role in archaeological research.

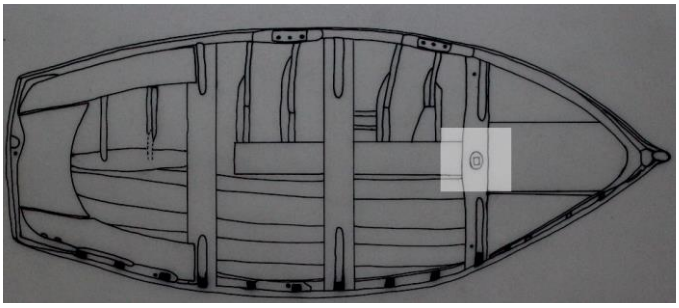
One of the case studies originally designed for this thesis involved an interactive finds database, I called it a walkthrough database. To put it simply and in as much detail as I can it involved taking all of the finds from a site with all of the individual piece’s metadata and mapping them in physical relation to each other based on where they were found. As we know archaeology is a destructive process, once we dig a site it is gone forever, the only remnants are the artifacts and the paper records. By taking digital 3D models of the artifacts, features, and structures of the site and plotting them in XYZ positions we can recreate the physical space destroyed by the excavation process. Then by utilizing AR technology we can walk around the site and interact with each artifact *in situ*, with all of its metadata associated with its 3D model. I believe this is where AR can be of most use in archaeology. It allows the researcher all of the benefits of lab data on site and having a detailed finds database at your fingertips, displayed in a 1:1 ratio across the physical plane. This is the direction I would take with augmented reality as a tool for archaeological data interpretations.

Recommendations for future researchers carrying out research projects pertaining to AR in archaeology, I would recommend looking at the phenomenological work done by Stuart Eve (2014). This was a great stepping stone for my work it showed the benefits of utilizing AR in the field in a clear way. I would also take the research carried out within this research project as a means of utilizing HCI methods and adapting them to archaeological practices. One product that was produced by the Archaeomented Reality project that should garner acknowledgment is the methodology. The methodology used within this project has the ability to be directly reused for other augmented reality projects within the field of Maritime Archaeology as well as Terrestrial Archaeology. As mentioned, this project was designed to be a starting place, to be used to expand on the uses of AR as a tool for research. I would also warn practitioners to pay close attention to what constitutes a true AR application, there needs to be an interaction between the human and digital as if they existed in the same plane; and as an academic do not be afraid to say “wouldn’t it be cool if” and just see where it goes.

Appendices

Appendix A Tasks to Be Completed by Participants for Experiment 1

1. How many thwarts does the vessel have?
2. At its widest point, what is the width of the vessel?
3. What is the Length of the Vessel from bow to stern?
4. Identify what this is?



5. What are the dimensions of the middle thwart?
6. Is the hull clinker or carvel built?
7. In what ways can the vessel be propelled?
8. How many crewmembers did the vessel typically have and what was their role aboard the vessel?
9. Produce the order of construction for this vessel.
10. What is the purpose of this vessel?
11. By investigating the given materials, have any repairs been made to the vessel?

Appendix B Questionnaire to be Completed by Participants After They Have Completed Their Set Tasks for Case Study 1: The Augmented Boat plan.

This is a brief survey that will be used to gauge your experiences with the technology that you used during the exercise. If a question does not seem applicable to your experience circle N/A.

1. On a scale of 1 to 5 with one being not difficult at all and 5 being very difficult, please identify your difficulty level with finding physical dimensions?

   Not difficult 1 2 3 4 5 Very difficult N/A

2. On a scale of 1 to 5 with one being not difficult at all and 5 being very difficult, please identify your difficulty level with finding specific features?

   Not difficult 1 2 3 4 5 Very difficult N/A

3. On a scale of 1 to 5 with one being not difficult at all and 5 being very difficult, please identify your difficulty level with finding with identifying specific parts?

   Not difficult 1 2 3 4 5 Very difficult N/A

4. On a scale of 1 to 5 with one being not difficult at all and 5 being very difficult, please identify your difficulty level with categorizing objects?

   Not difficult 1 2 3 4 5 Very difficult N/A

5. On a scale of 1 to 5 with one being not difficult at all and 5 being very difficult, please identify your difficulty level with usability?

   Not difficult 1 2 3 4 5 Very difficult N/A

1. What is the most important aspect for a program to have? (user-friendly interface, advanced capabilities, fast results) and why? N/A

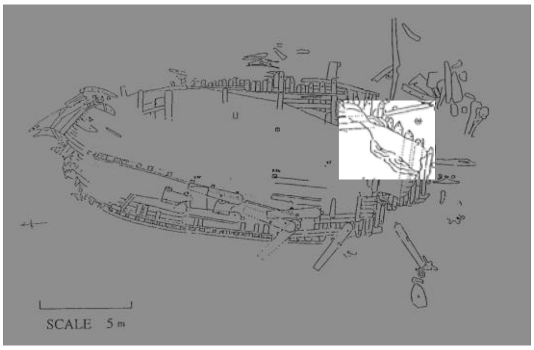
2. What are your thoughts on using this technology? N/A

3. Does this technology have any outside use besides in answering the questions you were just presented? N/A

4. How useful do you think this technology is within the field of archaeology as a whole? N/

Appendix C Tasks to be Completed by Participants for Experiment 2.

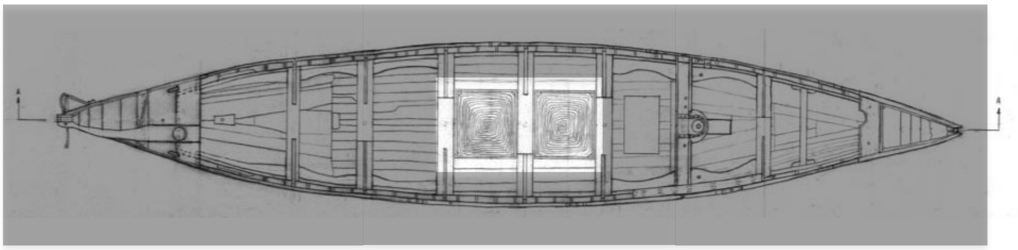
1. How many cannons does the wreck have?
2. At its widest point, what is the width of the wreckage area?
3. What is the Length of the wreckage area?
4. Identify what this is?



5. What are the length of the southern most cannon?
6. Has the wreck had any remote sensing conducted on it?
7. If so what kind of surveys?
8. How many crewmembers did the vessel typically have and what was their role aboard the vessel?
9. Produce the order of construction for this vessel.
10. What is the purpose of this vessel?
11. Identify what parts, tools, or equipment remain of the ship.

Appendix D Tasks to be Completed by Participants for Experiment 3

1. How many thwarts does the vessel have?
2. At its widest point, what is the width of the vessel?
3. What is the Length of the Vessel from bow to stern?
4. Identify what this is?



5. What are the dimensions of the middle thwart?
6. Is the hull clinker or carvel built?
7. In what ways can the vessel be propelled?
8. How many crewmembers did the vessel typically have and what was their role aboard the vessel?
9. Produce the order of construction for this vessel.
10. What is the purpose of this vessel?
11. By investigating the given materials, have any repairs been made to the vessel?
12. What is the purpose for the bow and stern being the same shape?

Appendix E Health and Safety and Knowledge Questionnaire

The first set of questions will be used to assess your personal well-being for this exercise.

A. Do you suffer from any health factors that my affect your balance or vision?
Yes No

B. Do you have a history of vertigo or any other predispositions to ailments that my affect your coordination?
Yes No

C. Do you need glasses, contacts, or other vision corrective devices to see up to 5 feet in distance?
Yes No

D. Do you need glasses, contacts, or other vision corrective devices to read either paper or computer screen?
Yes No

E. Do you or any family members suffer from light or video induced epilepsy?
Yes No

F. Do you or have you in the past suffered from seizures?
Yes No

G. Do you suffer from light induced migraines?
Yes No

This set of questions will be used to get an understanding of how versed you are with the basic tools and understandings that will be used during the exercise.

1. On a scale of 1 to 5 with one being not comfortable at all and 5 being very comfortable, how comfortable are you with reading technical reports?

   Not comfortable 1 2 3 4 5 Very comfortable

2. On a scale of 1 to 5 with one being not comfortable at all and 5 being very comfortable, how comfortable are you with reading diagrams, charts, and other pictographic representations of data?

   Not comfortable 1 2 3 4 5 Very comfortable

3. On a scale of 1 to 5 with one being not comfortable at all and 5 being very comfortable, how comfortable are you with using measuring tools, such as tape measures and rulers?

   Not comfortable 1 2 3 4 5 Very comfortable

4. On a scale of 1 to 5 with one being not often at all and 5 being very often, how often do you work with, see, or interact with boat plans?

   Not often 1 2 3 4 5 Very often

The following set of questions will be directed at your personal experiences with computing technologies.

5. On a scale of 1 to 5 with one being not comfortable at all and 5 being very comfortable, how comfortable are you with using a computer?

   Not comfortable 1 2 3 4 5 Very comfortable

6. On a scale of 1 to 5 with one being not comfortable at all and 5 being very comfortable, how well can you navigate simple web applications such as social networking sites and email accounts?

   Not comfortable 1 2 3 4 5 Very comfortable

7. On a scale of 1 to 5 with one being not comfortable at all and 5 being very comfortable, how comfortable are you with using handheld devices such as mobile phones, tablets, and eReaders?

   Not comfortable 1 2 3 4 5 Very comfortable

8. On a scale of 1 to 5 with one being not comfortable at all and 5 being very comfortable, how comfortable are you with using digital means to collect data?

   Not comfortable 1 2 3 4 5 Very comfortable

9. On a scale from 1 to 5 with one being not often at all and 5 being very often, how often do you use a computer?

   Not often 1 2 3 4 5 Very often

The final set of questions will be geared towards advanced imaging technologies that will be used during the exercises and how your past experiences may relate to the tasks being conducted

10. On a scale of 1 to 5 with one being not very experienced and 5 being very experienced, do you have any experience with virtual environments such as video games, 3D models, virtual reality, augmented reality?

    Not experienced 1 2 3 4 5 Very experienced

11. On a scale of 1 to 5 with one being not comfortable at all and 5 being very comfortable, how comfortable are you with wearing specialized technology that can impede your vision?

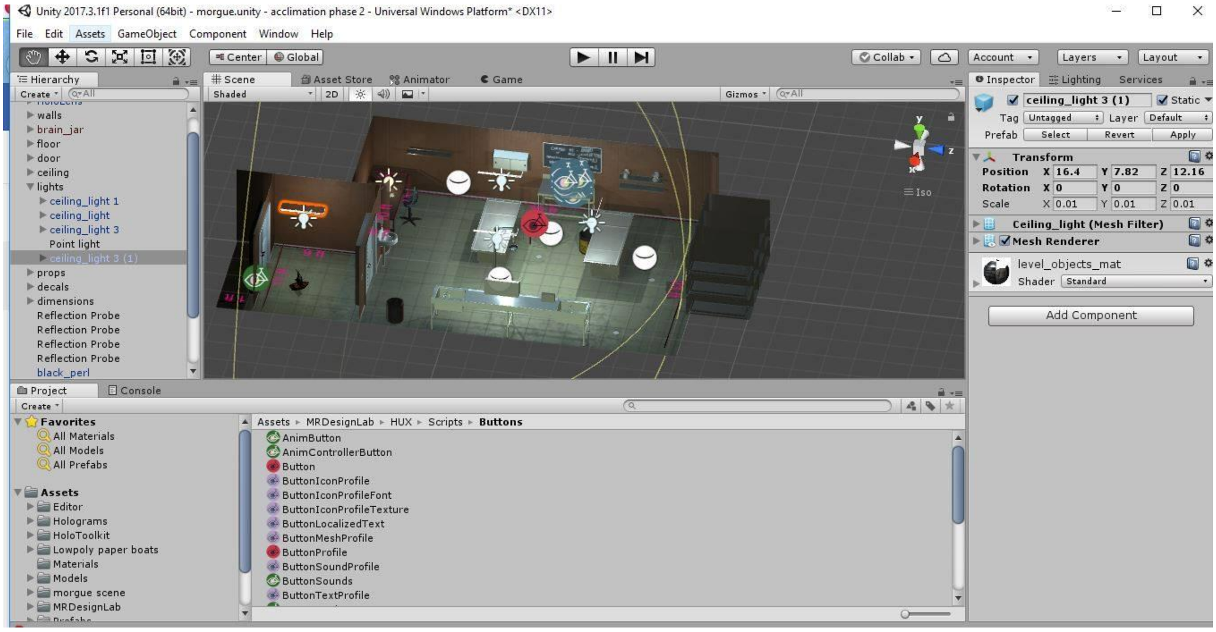
    Not comfortable 1 2 3 4 5 Very comfortable

Appendix F Acclimation Phase 1 Blueprint

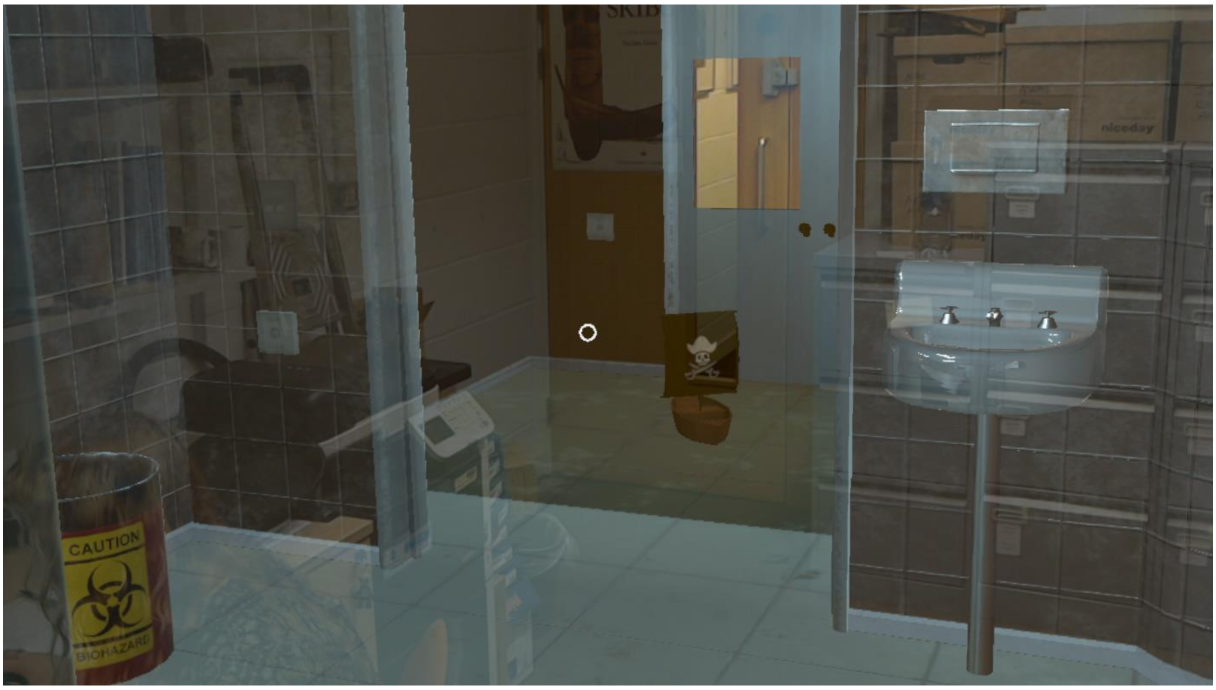
Appendix G Tasks to be Completed by Participants During the First Acclimation Phase

1. Count the number of doors in the room.
2. Measure the square footage of the room.
3. How many pieces of furniture are in the room?
4. Identify what kind of room this is.
5. What is on the balcony?

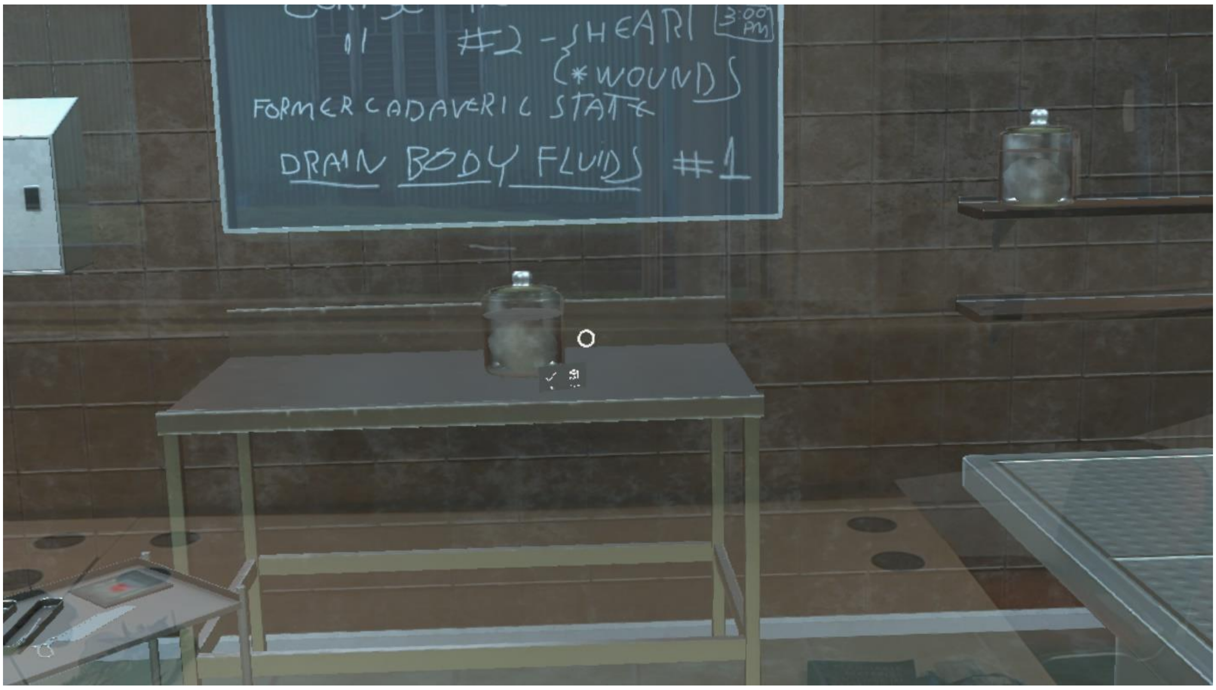
Appendix H Images of Virtual Environment Involved with the Second Acclimation Phase



Appendix H


CAUTION
BIOHAZARD

Appendix H


#2 - {HEART 3:00 PM
{*WOUNDS
FORMER CADAVERIC STATE
DRAIN BODY FLUIDS #1


9:00 AM
BRAIN
HEART 3:00 PM
{*WOUNDS
STATE
FLUIDS #1

Appendix I Tasks to be Completed by Participants During the Second Acclimation Phase

1. Count the number of doors in the room.
2. Move the jar from the desk to the shelf with the other jars.
3. Measure the square footage of the room.
4. Identify what kind of room this is.
5. What is outside the double doors?

Appendix J Table of Hardware/Software Specifications

Hardware/Software	Developer	Platform	Cost	Description
AutoCAD	Autodesk	Windows PC	$1,575.00	Standard drafting and digital modelling software
3DS Max	Autodesk	Windows PC	$1,505.00	Standard drafting and digital modelling software
Unity	Unity Technologies	Windows PC, Android smartphone Windows device	No Cost	Virtual environment creating software, game engine
Vuforia	Vuforia	Windows PC	No cost	Augmented Reality SDK plugin for Unity, and other development software
Samsung Galaxy Smartphone	Samsung Electronics	Smartphone Android	$129.99	Standard sized smartphone
Microsoft Hololens	Microsoft	Windows 10	$5,000.00	An advanced mixed reality computing system, head mounted display with sound and gesture, interfacing.

Capture Recorder	Private application	Android device	No cost	Standard screen recording software.

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