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Virtual Realities in Archaeology: Employing the Oculus Rift for Artifact Visualization and Education

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VIRTUAL REALITIES IN ARCHAEOLOGY: EMPLOYING THE OCULUS RIFT
FOR ARTIFACT VISUALIZATION AND EDUCATION

by

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Virtual reality (VR) is an emerging digital platform that can be utilized as an immersive
educational tool. This thesis uses the Oculus Rift virtual reality head-mounted display to create a
VR Museum, building upon research exploring video games in education. This VR Museum
leverages virtual reality and video game technology to educate players about archaeology.
Through virtual reality technology, players enter the digitally-constructed museum environment
as if they are inside the virtual world. This technology provides new avenues for engaging the
public in archaeological studies. This thesis also examines how digital copies of artifacts made
with photogrammetry can be utilized for education. The purpose of this thesis is to explore how a
functional model of a VR Museum can be created and serves as a foundation for further
development and research. This thesis also examines potential further developments.

The theme of this VR Museum is the archaeology of blacksmithing. The same concepts
for making a VR Museum can be applied to many other themes in archaeology, history, and
other subjects. The VR Museum went through four prototype stages of development, exploring
concepts on how to design a museum for VR. A fifth version of the VR Museum is the
completed computer program, which launched in the Western Michigan University VR Lab. The
VR Museum will receive continued development beyond this thesis, with ongoing player
feedback.

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CHAPTER 1

INTRODUCTION

In a museum exhibit hall—or perhaps in your own home, or in a library—you pick up a virtual reality head mounted display (VR HMD). It is similar to putting on goggles but has computer screens inside. As soon as you put it on, however, you forget you are looking at computer screens only an inch or two from your face. Instead, your mind is telling you that you have been transported to another environment.

Taking VR controllers into your hands, virtual hands appear in front of you. Moving a thumb-stick and pressing a button, you teleport yourself up to a reception desk in the VR Museum. Reaching out with your hand holding a motion-controller, you pick up a tablet from the reception desk. To do so, your hand squeezes a grip button on the controller. But your mind is telling you that you yourself are picking up the virtual tablet.

The tablet in your hand shows a directory. Reading it, you see different activities you can do and environments to visit in the virtual museum. One of those environments is a forest with reconstructed virtual buildings. You place the tablet back on the reception desk and continue your exploration of the VR Museum.

* * *

Virtual Reality (VR) is a technology that mimics a user's senses and places them within a digital environment (Blascovich and Bailenson 2011:37). Although some of the literature expands this definition to include all video game technology (and even novels and movies) (Blascovich and Bailenson 2011), I specifically use this term to refer to technology like that of

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the Oculus Rift head mounted display. Virtual reality technology has arrived, no longer constrained to science-fiction or experimental laboratories. The above passage describes an initial experience within the VR Museum created for the research described in this thesis. As described in the passage, virtual reality is a unique technology where the person using the VR device is wholly immersed within a virtual environment rendered by a computer. They are not an observer from the outside looking at a two-dimensional computer monitor but are themselves an active participant within the virtual world of the VR Museum.

Virtual reality is closely related to video games. The technology utilized for creating VR experiences was originally created for real-time rendering in video games. As video games have increased in popularity, so has research interested in their educational value (Gee 2003; Watrall 2014; Champion 2015; Chapman 2016; González-Tennant 2016; Mol et al. 2016; Champion 2017; Morgan 2017; Schwaderer 2017).

There has also been research pertaining to the potential benefits of digital models of artifacts for use in archaeological research and education (Douglass et al. 2015; Means 2015; Selden et al. 2014). These models are made by scanning a real-world artifact, and computers turn the artifact into a kind of 3-dimensional picture that can be viewed from any angle on a computer screen. However, there appears to be a lack in the literature about how to view and use these digital models after they have been made.

Virtual reality provides one solution for viewing digital models of artifacts and applying them for educational use. To investigate virtual reality as a means for archaeological education and the visualization of artifact models, a VR Museum was created for the Oculus Rift device. The VR Museum is a virtual environment that served as the experimental environment for the project. It was constructed with the intention of releasing it to the public for feedback. The VR

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Museum has been launched at the Western Michigan University (WMU) VR Lab. The WMU VR Lab was created in 2018 as a dedicated space in the university's library. Its purpose is to provide virtual reality technology as a resource for classes, student projects, and research.

Six further chapters make up this thesis. Chapter 2 is the literature review with three themes: Humans in Digital Realms, Digital Scanning Technologies in Archaeology, and Archaeology of Blacksmithing. The discussion in Chapter 2 includes why virtual reality is treated by human senses as a form of reality. Then anthropological literature is covered to examine how players interact and learn in video game environments. Chapter 2 also reviews various digital technologies, including those that turn artifacts into digital models. I argue that virtual reality provides a link between prior research on education with video games and what digital model artifacts can be utilized for. The chapter then examines virtual reality technology and some of its science-fiction origins to anticipate player expectations of VR experiences. Chapter 2 concludes with an examination of the literature on blacksmithing that has informed the content of the VR Museum.

Chapter 3 examines video games, including a discussion of the depiction of history and archaeology in video games. The video games discussed in this chapter are among those that inspired this project and have archaeological, historical, or educational components. There are two types of video games discussed. One type focuses on educating players. The second type of video game emphasizes entertainment, with a setting or theme heavily inspired by history or archaeology.

Chapter 4 describes prototype versions of the VR Museum. The foundational systems making up the VR Museum are also described. Chapter 5 then goes on to describe the final content of the VR Museum as a release version 1.0. These chapters also cover the thought

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process behind the VR Museum's construction and observations of the process of developing an interactive VR environment.

Chapter 6 describes some of the ideas for a future VR Museum that may be possible with a larger team and resources for development. The chapter is also concerned with early testing of the VR Museum and the feedback received from player testing of the prototype versions and the final VR Museum version. This feedback then informs a discussion of changes and additions that could be implemented into a version 2.0 of the VR Museum. Although the version 1.0 completed for this thesis was released for free, future versions (including version 2.0) could potentially be released commercially.

In the final chapter (7), I summarize the research and provide concluding remarks about the VR Museum and the value of VR in archaeology. This chapter includes how the VR Museum was released in the Western Michigan University VR Lab, and avenues for future release to the wider public.

CHAPTER 2

LITERATURE REVIEW

Before there can be a discussion of the literature, there needs to be some clarification of terms. Throughout the literature on digital technologies, various terms are used without consistency. Sometimes the same term is used with very different meanings from one source to another. First 'digital archaeology' and 'virtual archaeology' have been used in the literature synonymously, as well as the meaning of several distinct aspects of archaeology. Secondly, '3D' is used to refer to very different concepts. These terms are clarified, and alternatives presented below.

'Digital archaeology' has been used in the literature to sometimes refer to archaeologists restoring old computers, or to 'excavate' data from obsolete storage media. An alternative term for this type of archaeology is 'computer archaeology.' The computer and digital data are the subject of an archaeological study rather than the tool. As an example, I utilized digital archaeology for this thesis through the examination of past educational video games on Window 95 era computers. This is not to be confused with what could be termed 'computational archaeology' using computer statistical models to study and visualize patterns in archaeological data (Bocinsky 2018; Crema 2018).

Another dimension of digital archaeology is to examine the representation of archaeology in video games (Mol, et al. 2016). In some games, like the *Tomb Raider* franchise, the player is encouraged to act as an archaeologist in the game world. This examination then extends to an archaeological examination of the past represented in the video game as if the player is indeed an

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archaeologist within that game's fictional world (Reinhard 2016). Some games portray a fictional past with ruins of buildings or crypts the players can visit. These games may not have a narrative about the player being an archaeologist, but players can examine details of the ruins with an archaeologist's eye to learn more about the fictional past being represented. This form of digital archaeology could also be termed 'video game archaeology.' Another term that has been used is 'archaeogaming' (Reinhard 2016).

Video game archaeology also includes the use of video games to educate about archaeology, such as the VR Museum I made for this thesis. *Minecrafting Archaeology* is another case of a video game being used to teach archaeology. This is a modification (mod) of the popular video game *Minecraft* (Mojang and Microsoft Studios), intended to research how that game can be utilized to educate children about test units in archaeology and a reconstruction of a French fur-trade house (Schwaderer 2017).

Digital archaeology has also been used to describe the use of technology within the archaeological process. Computer tablets are used for a paper-less digital recording system during excavations (Sharp and Litschi 2014). In this sense digital technologies are a tool for archaeologists as part of the archaeological process. The term 'digital archaeology' makes sense to refer to this use of digital technology in archaeology.

Another form of digital technology, which could also be called 'virtual archaeology' is that of digital computer-based reconstructions of sites and artifacts (Forte and Siliotti 1996; Schwaderer 2017). 'Virtual' is being used to describe images constructed by computer graphics. Virtual archaeology includes the use of digital scanning technologies to create 3-d models of sites and artifacts viewed on the computer. Sites and artifacts can also be modeled directly in computer software as a method of illustration in a 3-d rendering. The VR Museum of this thesis

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would fall under virtual archaeology since it utilizes computers to render virtual environments players can walk through.

In virtual archaeology, there are several meanings of '3D' relevant to this thesis. '3D' has been used to describe 3-dimensional digital, or computer-made, models of objects and environments. Another term that can be used to describe 3-dimensional models is '3-d' with a lower-case 'd' and a hyphen to distinguish it from other '3D' meanings. Another meaning of '3D' is to refer to the type of stereoscopic images seen in movie theaters while wearing polarized 3D glasses. VR also utilizes stereoscopic '3D' imagery. It appears to be entrenched in current technology language to use a capital 'D' for stereoscopic '3D' so that is the convention followed here.

Three themes have been identified for this literature review: Humans in Digital Realms, which includes studies on virtual reality and video games in education; Digital Scanning Technologies in Archaeology, consisting of 3-d scanning technology; and Archaeology of Blacksmithing, discussing blacksmithing from an archaeological perspective.

Humans in Digital Realms

Virtual reality (VR) in research and laboratory environments is not new. This prior research (Blascovich and Bailenson 2011) set the groundwork for the current generation of VR. Although VR as a term today appears to be almost exclusively used to describe technology like that of the Oculus Rift, early research expanded virtual reality to also describe the forms of reality presented in movies, social media, digital avatars, novels, and video games (Blascovich and Bailenson 2011:24-36). One of the many theories that comes out of this research is "psychological relativity" where perceptions among individuals is relative and determines what

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is considered reality for that individual (Blascovich and Bailenson 2011:15-18). For VR, this means that when a person is using a VR device that over-rides their senses, the virtual world temporarily becomes a form of reality for that person. The reality in VR is convincing enough for the brain to treat the environment as a real place the person is seeing. This makes VR uniquely suited to experiential leaning in virtual environments since it can be as effective as experiential learning in the real-world outside VR.

The other side of VR interactions and perceptions is social. Video games are curated experiences (Nardi 2010), which means the entire virtual world is constructed by deliberately placed objects and programmed gameplay systems. Yet, players can interact with the curated content in their own ways, sometimes in unexpected ways, that tailors their experiences to themselves. When players feel their experience is personal, they can more effectively take in content learned in the experience. This curation of the virtual world in the form of a VR Museum served as the experimental component of this thesis. Since VR as a consumer technology is still new, there are no sources on how to curate museum experiences in VR. There is, however, prior research into using video games for education to be built upon. There was a research project that sought to teach the history of ancient Egypt through the creation of a modification (mod) for *Civilization V* called *Red Land/ Black Land* (Watrall 2014). *Civilization* is a video game series that typically lets a player lead their chosen culture from a city-state into a vast empire spanning across the world map upon which the game is played, like the board-game *Risk*. Originally, the mod was to cover 3000 years of history from the Early Pre-dynastic period to the end of the New Kingdom. It was then realized the scope of the project would have been too great to simulate that entire span of time with the level of cultural and historical accuracy that was aimed for (Watrall 2014:42). This is a challenge all video game projects seem to face, especially where smaller

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teams are involved and do not have the resources of the large video game companies (Watrall 2014:48).

Although there are challenges in making educational video games, research has shown such games have benefits. These benefits include better attention to material being taught, greater engagement of students through interacting with video game worlds, and better retention of the material (Gee 2003; Dickey 2006; Blascovich and Bailenson 2011; Forte 2014; Watrall 2014; Champion 2015; Gabellone 2015; González-Tennant 2016; Mol, et al. 2016; Champion 2017; Morgan 2017; Hanes and Stone 2018). Non-educational video games are designed to teach players the game's mechanics in a fun way, so players do not realize they are learning. Sometimes video game stories convey deeper lessons, such as morals and consequences. Educators need to learn how to borrow the design principles the non-educational video game industry has mastered to more effectively teach students (Gee 2003). Employing video game technology, such as VR, is a step in that direction.

Since current VR is still new and there isn't enough information about its use in education and how to design interactive programs for VR, other sources were referenced. These include research projects with older generation VR hardware and other 3D solutions. Attempts have been made to use 3D TV and movie theater type glasses paired with special rooms with 4-wall projectors and simple motion controllers, such as the University of Michigan UM3D Lab's M.I.D.E.N. which also uses *Unreal Engine 4* (UM3D Lab), or 3D capable gaming-monitors in a wall set-up, among others. VR headsets provide better 3D than 3D monitors or the M.I.D.E.N., since they directly mimic human eyesight in a way traditional 3D cannot and convey a better sense of immersion and presence in a virtual world.

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VR hardware involves at least a headset people wear like goggles. The purpose of these headsets is to provide a stereoscopic view of an image rendered by the computer which envelops the user's line of sight. Headsets like the Oculus Rift also track the movement of the user's head in 3-dimensional space. This tricks the mind into believing the user is inside the virtual world they are seeing. Motion-controllers like the Oculus Touch controllers are combined with the headset to give users virtual hands. The controllers are tracked in 3-dimsional space like the headset and have buttons that can be programmed to do certain things in the VR program. The controllers include a grip button that is pressed when the controllers are squeezed in the hand, which can be programmed to replicate picking up an object with virtual hands in the VR program. This hardware combination contributes to the user feeling as if they are inside the VR program, not merely looking at a computer screen.

There are two main sorts of VR hardware based on the systems they are meant to run on: mobile and personal computer (PC). The focus for this project is on PC VR with the Oculus Rift. PCs are capable of much greater graphical fidelity than mobile VR. One of the downsides of the current PC VR headsets is the presence of a cable or 'tether' connecting the headset to the PC, limiting movement. Mobile VR devices like the Gear VR are completely self-contained, and therefore do not have a 'tether.' This comes at the cost of graphical fidelity since the computer is much less powerful. In the Gear VR the computer is a Samsung smartphone, which also acts as the display when plugged into a Gear VR headset. The Gear VR also has simpler sensors for tracking head movements and cannot track in 3-dimensional space like the Oculus Rift can.

Oculus sets minimum specifications of PC hardware to run VR programs with the Oculus Rift. This helps to ensure developers are targeting the same minimally required hardware. These specifications are important to keep in mind during the development of the virtual museum. It is

important to have a PC comparable in performance to the recommended specifications to minimize the infamous VR Sickness, or Simulation Sickness—which is like motion sickness (Oculus VR). On the Oculus DK2, programs had to run at 75 frames per second (the framerate), and the consumer Rift increased that to 90 frames per second (Oculus VR), which is not feasible on lower end computer systems. In the case of Gear VR, running on a phone, the graphical detail must be limited.

The VR devices themselves and even PC component companies have eliminated most of the hardware causes for simulation sickness. Maintaining the necessary framerate and the design of VR programs are the last two major hurdles to overcoming simulation sickness. Oculus provides literature to developers based on their own extensive research with suggestions for how to design programs to minimize this simulation sickness (Oculus VR).

Science-fiction novels that have described VR provide additional sources for how to design experiences in VR and establish what player expectations of VR may be. Blascovich and Bailenson (2011) mention the must-read science-fiction novels that describe VR: *Neuromancer* by William Gibson (1984), and *Snow Crash* by Neal Stephenson (1992). These are classics that have contributed to the terminology for virtual reality technology, such as 'avatar' and 'cyberspace.' Science-fiction novels like these also serve as a baseline for user expectations of VR. I have also found more recent publications such as the *Sword Art Online* Japanese light-novel series by Reki Kawahara to be useful in the design of the virtual museum experience, since they are a more modern outlook on VR with the benefit of being written in the internet age. It also takes place in VRMMORPGs (Virtual Reality Massively Multiplayer Online Role-Playing Games) that creatively addresses many of the concepts that are described in the academic literature on virtual reality including *Infinite Reality* (Blascovich and Bailenson 2011) and *My*

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*Life as a Night Elf Priest (*Nardi 2010). The illustrations included in the novels and the anime (Japanese animation) adaptation have been useful in concept ideas for a user interface system designed for VR. Another recent novel adapted into film by Steven Spielberg is *Ready Player One* by Ernest Cline (2011), where school is conducted entirely within VR. This has helped the project by providing ideas for ways in which multiple users could collaboratively learn within VR and take VR field-trips.

Digital Scanning Technologies in Archaeology

Recent years have shown an increase in research about how digital scanning technology can be utilized in archaeology to record site and artifact data. These technologies often fall into one of two types—laser scanning or photogrammetry. Both technologies are used to create 3-d models of landscapes, buildings, archaeological excavation test units, and individual artifacts. Laser scanning (also called lidar) involves a base-station shooting many lasers that measures distance between the points where lasers contact an object to generate a 3-d model of the object. Photogrammetry works similarly but relies on a normal digital camera to take photographs of an object from many angles with overlap between each photo. Computer software compares similarity in each photo to measure distance between each point of similarity. Recent research has examined the methodologies for using these technologies, the benefits or disadvantages of using one or the other, and the potential uses for the resulting 3-d models (Chase, et al. 2014; Galeazzi, et al. 2014; Magnani 2014; Selden, et al. 2014; Weber and Powis 2014; Wernke, et al. 2014; Douglass, et al. 2015; Means 2015; Verdiani 2015; Wrobel, et al. 2019).

The tomb of Tutankhamun has been laser scanned with high precision (Factum 2014). This was to make a full-scale 3-d printed real-world replica of the tomb as an alternative for

tourists to the Valley of the Kings. The replica tomb was placed near the entrance to the valley. The intention was to reduce the number of tourists entering the original tomb and thereby help its preservation. 3-d printing is a technology that takes 3-d computer models and prints out 3-dimensional physical copies layer by layer. Where traditional computer printers deposit ink on top of a single sheet of paper, 3-d printers deposit special plastics, metals, or even edible materials in many layers that gradually builds to the exact shape of the 3-d computer model. In projects like the reconstruction of Tutankhamun's tomb, a part of the process involved creating a 3-d computer model that could potentially be used for a wider range of digital applications. One of these uses could be to make a digital version of the reconstruction for use in education where students may not be able to personally travel to the Valley of the Kings.

Other archaeological projects utilizing laser-scanning has been described in the Society for American Archaeology's newest journal, *Advances in Archaeological Practice* (Galeazzi, et al. 2014; Magnani 2014; Powlesland 2014; Weber and Powis 2014; Gabellone 2015; Verdiani 2015; Porter, et al. 2016). In many of these cases, it was found that laser scanning provides greater detail in the models, but photogrammetry is often more economical and practical. Given constraints in available resources for this thesis, photogrammetry was used over laser scanning. 3-d objects made from photogrammetry were featured in one of the rooms in the VR Museum as described further in Chapter 5.

There are some methodologies described for using photogrammetry to scan artifacts, but these are often small, such as lithic tools (Porter, et al. 2016). These methodologies served as starting points for establishing a methodology for the photogrammetry used in this thesis. They could not be directly used due to differences in objects being scanned. For instance, the methodologies described included the use of a turntable upon which the artifact sat while the

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camera remained stationary. This was not possible for an approximately 200-pound anvil scanned for this thesis. There appears to be a preference among photogrammetry research in archaeology to use Agisoft's *Photoscan* software. Photogrammetry software like *Photoscan* processes digital photographs into 3-dimensional models. Photogrammetry directly regarding the VR Museum is discussed further in Chapter 4.

One problem with many of these articles is that they do not fully describe to what uses the 3-d models could be put to after they have been made. They are primarily concerned with methodologies, although one article notes of the 3-d model data, "the objects may be printed in 3D or studied on a computer screen" (Magnani 2014). There is another potential use for these 3-d models, which is for educating the public about history and archaeology through video games. In most of these articles, the methods for viewing these 3-d models consists of forcing 3-dimensional artifacts into a 2-dimensional viewing system—the standard computer monitor, or screen. VR offers an answer to how 3-dimensional models can be viewed in a more natural 3-dimensional way. These 3-dimensional models can be exhibited in a VR Museum, as demonstrated in this thesis using models of blacksmithing tools made with photogrammetry.

Archaeology of Blacksmithing

Blacksmithing is an ancient craft that involves the heating of ferrous (iron-based) metal in a forge, which makes the metal malleable and capable of being hammered into new shapes. The archaeology of blacksmithing focuses on various aspects of the blacksmithing craft, its materials, or the blacksmith's artifact remains in the form of tools and shops. Archaeologists can describe the identification of blacksmith shops in excavations and the internal layout of shops in various cultures around the world. The archaeology of blacksmithing can also provide

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information on the process of forging based on analyses of artifacts, and historical documentary sources. Experimental archaeology, where present-day blacksmiths reproduce artifacts, also provides a source of information about tool use and manufacturing processes. In recent years, there has been a trend to study the metallurgical properties of the metal alloys used in artifacts, their molecular or grain structures, and other metallurgical properties (Barnett, et al. 2008; Grazzi, et al. 2016; Stelzner, et al. 2016; Fedrigo, et al. 2017). This section seeks to identify the literature that was most helpful in creating the VR Museum and provide context for understanding the archaeology of blacksmithing as taught in the VR Museum. This literature was combined with personal knowledge of blacksmithing through experimental archaeology and involvement with the blacksmithing community over the past ten years.

Blacksmith shops in the 1700s and 1800s in North America have been excavated at several sites. One of these is a shop from Fort St. Joseph, Ontario, which has been an important case example in the archaeology literature of blacksmithing, cited as a source for shop layout in later literature (De Vore 1990; Stine 2000; Hyett 2002). This shop was used to describe a typical layout of a blacksmith shop with the identification of four spaces within and around the shop (Light 1984; Light and Unglick 1987). One space is the work area, where the blacksmith would do the forging. The work space includes the forge, bellows, anvil, and workbench. Another type of space was the storage space, which could include extra tools, metal stock waiting to be used, extra fuel, and broken forged items a blacksmith hopes to repair or reuse. A third type is domestic space, which can include a table for eating or to meet with the blacksmith's customers. The final type of space is the refuse area, which could include remnants cleaned out of a hearth or broken and unusable forged items. Refuse space outside the shop can include a larger pile of

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spent fuel, unusable metal, and remains of a blacksmith's meals. These spaces are illustrated in the reconstructed blacksmith shops in the VR Museum.

The Griswold Shop from Barton, Mississippi dating from 1851 to 1860 (McBride 1987) was the basis of one of the other blacksmith shops reconstructed in the VR Museum. This was a small shop, measuring 9 x 5 meters in size, with identified locations for the forge, bellows, doors, and several windows. There were some other articles describing historical blacksmith shops (Light 1986; De Vore 1990) but the Fort St. Joseph, Ontario shop and the Griswold Shop were among the better documented and were stand-alone shops (opposed to being adjoined to larger buildings).

To better understand the blacksmithing craft represented in the VR Museum, there are some tools unique to blacksmithing than need introducing. A forge is a hearth containing a high-heat fire in which metal can be heated. A bellows is a kind of lung made from leather and wood in the European tradition that feeds oxygen to the fire of the forge to make the forge's fuel burn hotter. In the 1700s and earlier, this fuel would have been predominantly charcoal and by the late 1800s coal and coke were introduced. An anvil can take many shapes and sizes but is fundamentally an iron or steel block that provides a hard work surface upon which metal being forged can be hammered.

The forge and bellows are significant features in a blacksmith shop due to their use in heating metal which is essential to the blacksmith craft. In comparison, most other tools are luxuries. Ferrous metal changes colors when heated. As the metal oxidizes in the fire it turns black, then starts to glow a dull red color around 1000 degrees Fahrenheit (F). Typically, forging is done around 2000° F when the metal is a bright-red or orange color, depending on the alloy. Between 2500° F and 2700° F, the metal can begin to burn, with the surface starting to turn

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liquid. It is in this range that two pieces can be welded together by a blacksmith in what is called forge-welding. At 2900° F, ferrous metal becomes a liquid.

The blacksmith community today has put out many sources documenting the process of blacksmithing, including newsletters for local blacksmithing groups or guilds (including newsletters I edited for the Western Reserve Artist Blacksmith Association from 2009 to 2015). These newsletters can often contain information presented at meetings of blacksmiths, or 'tips' articles written specifically for the newsletters. One of the most significant sources on blacksmithing is a book by the late master blacksmith Alex Bealer which explains what many blacksmithing tools are and the techniques for how to use them (Bealer 1969). This book has been used as a reference in identification and function of blacksmithing objects in archaeology (De Vore 1990) and has likewise been utilized for constructing the VR Museum. A more recent book called *A Blacksmith's Craft: The Legacy of Francis Whitaker: Volume I* (Dixon 2004) was also used as a source on identification and function of tools, as well as the design of some of the 3-d models of tools. This book, unlike Bealer's, features many images of tools and processes that aided in the construction of visual elements of the VR Museum, including 3-d models of tongs based on types illustrated (Dixon 2004:14-15).

Published catalogues of artifacts and reports are another useful source in creating 3-d models when photogrammetry is not available or is not necessary in the reconstruction of an artifact. One such catalogue utilized for this thesis is *The Mästermyr Find: A Viking Age Tool Chest from Gotland* (Arwidsson and Berg 1999). These tools once belonged to a Norse blacksmith dating from the Viking Age (CE 793-1066). Included among the artifacts documented is a hammer similar in form to modern cross-pein hammers. These hammers have a

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square, flat hammer face on one end, and a wedge shape on the other end which is the cross-pein. A 3-d reconstruction of a Norse hammer was made for the VR Museum.

A review of the entirety of literature pertaining to the three themes discussed in the literature review—Humans in Digital Realms, Digital Scanning Technologies in Archaeology, and Archaeology of Blacksmithing—could each fill a book of their own. This literature review sought to lay the foundation and describe the key research that directly influenced this thesis. One of the components that has not yet been thoroughly discussed here is prior work in video games. While some scholarly research has developed educational video games, the majority stem from the video game industry. There are also many popular video games that were not intended to be educational but have nevertheless influenced public exposure to history and archaeology. These popular video games portray historical settings and archaeologists in fun and engaging ways at the expense of accuracy. This thesis is in part a direct response to these video games. The next chapter therefore discusses some of these video games as an extension of the literature review.

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CHAPTER 3

ARCHAEOLOGY AND EDUCATION IN VIDEO GAMES

This thesis is partly a reaction to prior video games that sought to depict history and archaeology. These video games are generally either meant to educate or to entertain using stories or settings depicting historical events or archaeology. While video games can be both educational and entertaining, their design tends to focus on one over the other. This chapter discusses some video games from each category that helps to relate this thesis to prior video games. Throughout this chapter, and the next two chapters, are references to screenshots provided in Appendix A (they appear as A#).

In 1998, IBM released an educational video game called *Crayola 3D Castle Creator*. This video game focused on reconstructing medieval castles with interactive lessons on aspects of castle life and architectural features. The player could place pre-made models of buildings on a map or choose a map with a castle already made (A#1). One of the limitations of the game was that the map—the virtual landscape—had a very small area on which the castles could be built. This meant the reconstructions of castles were limited to a keep, some walls, and a few buildings. Castle towns could not be reconstructed, and the castle designs had to fit the small square map, narrowing the variations in castle design that could be demonstrated.

After a player made a castle to their liking from a bird's eye view, the player could explore the castle at ground-level in first-person view. Players could walk around the castle yard, and then enter each building. Inside the buildings there were a few characters representing different social roles who would speak to the player. Characters included a king, queen, jester,

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and stable-boy. The buildings that could be placed included stone keeps, wooden keeps, walls, stables, and storage houses. The game would explain through narration and text who the characters were and building function.

There was also an in-game book that described different types of castles and their architectural features. This book included line-drawings of castles and features in more detail than the real-time rendered 3-d graphics were capable of illustrating. The in-game book had sections providing biographical summaries of each fictional character, life in castles, and how castles were made.

There are many more instances of video games developed primarily for entertainment that depict history or archaeology. One such video game is *Age of Empires*, first released in 1997, around the same time as *Crayola Castle Creator. Age of Empires* was re-released in 2018 for current computers following the success of re-releases of later games in the franchise. The game is played from a birds-eye view with the player directing units, or people, to collect resources, construct buildings, or fight other units (A#2). Players can complete campaigns based on historical events or play against other players online. The first and second games in the franchise originally released in CD format with included booklets explaining the historical inspirations for every unit, building, and playable civilization portrayed in the game.

In the original game, there were no in-game resources for learning about the civilizations (later entries in the franchise did include such a feature), but each campaign mission included brief text about the historical context of the mission. Sometimes these texts directly stated theories that anthropologists or archaeologists had. Topics included the ages of technological development (Old Stone Age/ Paleolithic, New Stone Age/ Neolithic, Bronze Age, and Iron Age), or the development of agriculture in Egypt (A#3).

Although *Age of Empires* can be educational, it took certain liberties for the sake of gameplay. One of these is how it portrayed different civilizations. All civilizations in the game share the same core elements of an *Age of Empires* game, regardless of historical accuracy for a civilization. In *Age of Empires*, players lead their chosen civilization through ages of technological development. This results in civilizations going through the Old Stone Age or New Stone Age even if the civilization historically did not go through such ages (such as Rome). Most civilizations also share the same basic units, sometimes given different appearances but functionally identical. In the second game, *Age of Empires II*, a blacksmith shop building type was added to the game. While not all civilizations historically had blacksmiths, this building served to upgrade a player's combat units with technology such as barbed arrows or chain-maille. While it makes sense for the game to maintain balance between each civilization in competitive play, it comes at the cost of educational value and historical accuracy.

Another game that opts for entertainment over historical accuracy is *Tomb Raider* ([A#4](#)). This is a long-running franchise of 3rd-person action-adventure games. The first game called *Tomb Raider* was released in 1996, with another game titled *Tomb Raider* rebooting the franchise in 2013. A twelfth game in the main series of games (as opposed to spin-offs) was released in 2018. The *Tomb Raider* games remain very much alive and depicts to millions of gamers an archaeologist ready to shoot enemies and destroy more archaeological sites than Indiana Jones.

The central character, Lara Croft, is portrayed as the daughter of a British archaeologist and nobleman who went missing searching for paranormal artifacts. Lara studied archaeology in university and later traveled the world in search of magical artifacts, pursuing her father's work. Along the way, she manages to find archaeological sites with complex puzzles that are a

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signature style of *Tomb Raider* games, and hordes of enemies she must fight through. While *Tomb Raider* games are very entertaining and cinematic, they offer little in educational value about who archaeologists really are and the history it depicts.

Similar to *Tomb Raider* games, but set primarily in the past, are *Assassin's Creed* games. The *Assassin's Creed* franchise began in 2007 and has eleven games in its main series as of 2018, growing to become one of the biggest franchises in video game history. Between 2007 and 2014 the *Assassin's Creed* franchise has sold 73 million copies (Futter 2014). Usually with each new game the setting is changed to a new historical time period and region. The original game was set in the Near-East of the Third Crusade, featuring reconstructions of the cities Jerusalem, Damascus, and Acre. Other games have been set in renaissance Italy, colonial New York, ancient Egypt, and most recently ancient Greece, among others. Most of the games incorporate a present-day storyline about an ongoing secret war between the Assassin Brotherhood and Knight Templars. The two sides continually fight for control of artifacts left behind by an ancient alien civilization that made humans.

Visually, the games can be very educational and depict simulations of large reconstructed cities. Each game includes an in-game database of historical facts regarding famous landmarks, people, or events. In one game (*Assassin's Creed: Liberation*) it was found that one of the churches reconstructed for the game's colonial New Orleans forgot to remove a present-day historic landmark plaque (A#5). *Assassin's Creed: Origins* includes a *Discovery Tour by Assassin's Creed: Ancient Egypt* that takes players on a virtual tour of the game's reconstructed ancient Egypt without the story and combat of the regular game (A#6). While the *Assassin's Creed* games delve very deeply into pseudo-scientific elements, some of its reconstructions contain educational value.

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One of the best video games for representing the historical past without ancient-aliens or magical artifacts is *Kingdom Come: Deliverance* (released 2018) ([A#7](#)). The game portrays a part of Bohemia (in present-day Czech Republic) of 1403 with a strong focus on historical accuracy. The main character is the son of a blacksmith and is the player's agent in witnessing pivotal historical moments. *Kingdom Come: Deliverance* follows a role-playing-game structure with the player leveling up certain skills such as sword combat or reading and taking on quests alongside the main story missions. Players have a wide range of options for clothing, armor, and weapons for their character.

Historical accuracy was sacrificed at times for the fictional story in the backdrop of real events, and in parts of the game's landscape. When development began on the game, there was a technological limitation on the game engine used where the world could be a maximum of 4 km x 4 km. This resulted in parts of the Bohemian landscape being condensed so more than one castle town could be reconstructed in the game. The game also took liberties in the narrative of the player's character starting as the son of a blacksmith and later becoming a knight in service to a nobleman, rising to become a great warrior and mayor of a village (if the player so chooses). The nature of the role-playing game lets the player act in large historical moments. There are many small stories the player can choose to take part in based on the culture of medieval Bohemia, such as investigating suspected witches for a local priest. It would be implausible for the son of a blacksmith to take part in all these events but is great for entertainment and involves the player in as much of medieval Bohemian life as possible.

Since the game features the son of a blacksmith for its main character—Henry—it was expected there would be emphasis on accurately depicting blacksmiths. I examined the portrayal of the blacksmith's craft and the reconstruction of blacksmith shops in *Kingdom Come:*

Deliverance. The game begins in a mining castle-town based on the real town of Silver Skalitz in CE 1403. The player is tasked with helping a blacksmith, Henry's father, collect some items from town to help finish a sword contracted by the castle's lord. The shop appears reasonably accurate and is of an open-air type. There are moments within the beginning of the game that show cinematics, which are movies that players must watch rather than control Henry directly. Some of the cinematics feature the father and Henry forging the sword, and assembling the handle and pummel (A#8). The cinematics may depict some of the most accurate representations of swordsmithing in a video game. It is shown how the wood grip of the handle is burned onto the tang, as is the practice of swordsmiths. Then the pummel is shown to be fitted onto the back of the handle and the tang is hammed over the pummel to hold the handle together.

Outside cinematics, the representation of blacksmiths becomes more typical of video games. All blacksmith characters depicted in the game, including the father, go through the exact same animations (A#9). They all pick a rectangular piece of metal out of a barrel, place it in the forge, and pull the bellows lever a few times. They remove the sword-blank metal out of the forge to hammer it a few times, sending dramatic sparks shooting off the metal. Then the smith dips the tip of the sword into a water quench bucket to cool the metal. They return it to the starting barrel full of rectangular metal. Then the whole animation repeats. Every blacksmith character observed, regardless of the reconstructed blacksmith shop they are in, uses the same animations and the same 3-d models. This is to be expected in large open-world video games such as this, where recycled models and animations are necessary due to resource and time constraints. Since the main character is the son of a blacksmith, however, it was hoped that greater attention would have been given to the portrayal of blacksmithing throughout the game.

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The reconstructions of blacksmith shops are a little more varied, with some unique reconstructions, and several types that are recycled in different locations. There are open-air shops (A#10), as well as enclosed stone-walled shops (A#11). It is not clear if archaeological excavations of blacksmith shops in the Czech Republic served as basis for these reconstructions, but they appear plausible. Some shops are depicted with dedicated areas for horse-shoeing. Sometimes they have more than one type of space associated with the blacksmith shop (work space, domestic space, storage space, and refuse space), but seldom depicts all of them in one shop. Most shops are sparse aside from the same models used for the recycled animations of the blacksmith working.

One feature not observed in other video games is a mini-game (activity within a game with its own set of rules) that has the player optionally sharpening their sword on a grinding wheel (A#12). The player picks what sword they want to sharpen and sits at a grinding wheel to sharpen chipped and dulled swords the player has been using. The player has control over the angle of the sword against the grinding wheel, place along the length of the blade, pressure against the grinding wheel, and speed of the grinding wheel. It takes some practice to have a sword obtain a 100% sharpness and carries a risk of harm to the blade if the player does it improperly. This is a detailed and reasonably accurate portrayal of how swords are sharpened.

There are many more video games that could be examined for their historical inspirations, enough to be a research topic of their own. Overall, most video games do not place a priority on historical accuracy for educational purposes. Their primary goal is to entertain. There are a few instances, such as *Kingdom Come: Deliverance*, where heavy emphasis was placed on historical accuracy in the simulation. It is possible to develop educational lessons utilizing these video games, but they were primarily designed for entertainment. This thesis

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evolved out of a desire to research how video game technology and VR could be utilized with

education in mind at the core of the design.

CHAPTER 4

EARLY VR MUSEUM PROTOTYPES AND GAMEPLAY SYSTEMS

This chapter describes early prototype versions of the VR Museum, the methods used to create the VR Museum, and the foundational gameplay systems making it interactive. The next chapter then describes the content of the release version of the VR Museum.

The VR Museum, in all its versions, used the *Unreal Engine 4* software package. *Unreal Engine 4* (*UE4*; Epic Games) was chosen because it is one of the leading game engines and has some of the requirements for VR built-in. There are a few other game engines available that meet the requirements for VR and real-time rendering. Ultimately, the choice of *Unreal Engine 4* was a personal one due to familiarity with the software prior to the VR Museum project.

Early Prototypes

The first few versions of the VR Museum were made to be used with the Oculus Rift Development Kit 2 (DK2). The DK2 was a prototype model VR headset released for developers to begin work on creating VR experiences before the final consumer model of the Oculus Rift was released. In these VR Museum versions, it was not possible to physically walk around a VR play area and pick up objects. The DK2 limited players to looking around and leaning with their body. The controls used a standard Xbox One controller. Some middle versions were made for the Samsung Gear VR. Later VR Museum versions were made for the consumer model Oculus Rift and Oculus Touch motion controllers.

The earliest prototype of the VR Museum (A#13) consisted of a large square building with two floors, a mountain and lake landscape outside windows, and some photogrammetry objects. The ground floor was divided into two wings by a large hallway in the center. These wings were meant to eventually house objects of different subjects. Initially, the outdoor environment primarily served as a backdrop view outside windows rather than a blank sky.

The next version of the VR Museum (A#14) expanded on the environment created in the first VR Museum. The original building was given an additional floor. It was envisioned that this new third floor, the top floor, would consist of small rooms to experiment with social systems in VR. This included what was to be classroom space, conference room space, and office space. These ideas were not developed further for the current VR Museum due to constraints in implementing network systems. These ideas are described further in Chapter 6.

Aside from the additional floor to the original building, a massive new building was added, adjoining the original building via enclosed walkways. There were several reasons for the expansion. First, the developing idea was to create a virtual museum with several wings and large open space. The location the player would enter the museum was moved to a room intended to only serve as the entrance room, rather than starting in the middle of highly detailed object models as in the first version. This room led to a large atrium made for dramatic scale in VR. This atrium then led to various sections of the museum. These sections included the original building, halls directly off the atrium, and a single gigantic room. This last section was to house oversize exhibits. One of these exhibits included a laser scanned gunboat from Smithsonian X 3D. This section was also to have contained reconstructions of archaeological architectural features.

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The second reason for the expansive museum building was the hypothesis that it would provide better frame-rate performance to spread the highly detailed objects throughout the museum rather than clumping them together in the same viewing space. This idea was modified to different rooms in a smaller museum space in later versions of the VR Museum.

In this second version the outside environment was also expanded. One reason for the larger exterior was to ensure a landscape could be seen from any window in the VR Museum. A small forest was added, with mountains ringing the map to block views of empty sky. Without a backdrop, it would appear as if the museum was floating in an empty sky, potentially breaking VR immersion. A second reason for expanded landscape was the formulation of ideas about placing reconstructed buildings in a forested environment. A doorway in the entrance hall of the museum led to the forest. This version also had a reconstruction of King Tutankhamun's tomb, made for a prior project, to experiment with adding large exhibit structures inside the museum building.

The next version of the VR Museum was a single room (A#15). The size of the second VR Museum was too large as a single map. The second version also contained a lot of unused space. The large interior spaces of the second version made lighting simulations work improperly and took too long to navigate from one section to another. So, this third version went the other direction with one initial room. This room consisted of a large central space and two smaller sides spaces. The only light source came through the large windows from simulated sunlight. There was a door that initially could not open, but suggested there could be other, separate, rooms in the VR Museum. The only object on display was a Mousehole Anvil made by photogrammetry.

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Where the first and second versions were meant to be used with the Oculus Rift DK2, this third version was meant for the Samsung/ Oculus Gear VR. This headset ran on a Samsung Galaxy S7 Edge smartphone. The museum was still compatible with the DK2, but compatibility with the Gear VR permitted a way to travel with a VR headset that allowed it to be demonstrated. It was much easier to carry a Gear VR headset and smartphone rather than a large and heavy personal computer used with the Oculus Rift. The single room of the third VR Museum remained, with some modification, in the fourth and fifth versions.

The fourth version (A#16) had several stages leading directly from one to another. It is where the remainder of the prototyping occurred. The fifth and final version of the VR Museum was built directly off the fourth version but is counted separately to distinguish between the prototype and final version.

The first stage of the fourth version was to create a new architectural digital model based on the basic design used in the third version's single room. This model was of the structure of the VR Museum, not the objects on display within it. The new model simplified the geometry that made up the third museum's structure. The earlier versions had used architectural pieces included with *Unreal Engine 4*. With the fourth version, custom architectural pieces were made. This new room model was expanded to include a hallway leading to an atrium.

This atrium was large. Like the atrium of the second VR Museum, the idea was to have a space that would appear with a grand scale in VR. To help make this space more practical, there was an elevated walkway leading directly to each of three doors. This atrium was to be a hub at the center of a museum with three sections. The concept of a hub with three sections of the VR Museum remained in the final version.

After the architecture of the fourth VR Museum was created in the modelling software *Blender*, the pieces were imported into *Unreal Engine 4* to test in VR. During testing it was found that the atrium was too large. Since the architecture was modelled to be modular—in separate pieces rather than one joined piece for the whole building—it was possible to continue refining the structure in *Unreal Engine 4* instead of remaking the whole model. As a result, many of the architectural pieces used in this first stage of the fourth version were still used for the final version.

In the next stage of the fourth VR Museum the atrium was reduced in size significantly. In length and width, this Hub space was reduced to the size it maintained through the final version. The Hub continued to receive modifications to is height and player entrance space throughout the fourth version.

At this stage, the concept of a Section 1, Section 2, and Section 3 off the Hub was cemented. Section 1 was expanded to five rooms connected by hallways. Section 1 Room 1 remained the most like the single-room concept from the third VR Museum and the earlier stages of the fourth version. Section 1 Room 1 had a door leading from the Hub. A second door led to Room 2. A third door led out of Room 5 so players could return to the Hub. The idea was for each room to be a separate streaming level in *Unreal Engine 4*, where only the current room the player was in would be loaded into the computer's memory and help with the frame-rate performance.

Each of the first four rooms in Section 1 was to showcase a different lesson on archaeology and blacksmithing. The fifth room was to be a reward room for the player completing lessons in the previous four rooms. Testing suggested Section 1 was too long, especially after expansion of Section 3. By later stages of the fourth version, Section 1 was

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reduced to three rooms and a hallway looping back to Section 1 Room 1. The concept of separate streaming levels for each room was also dropped. It was found to be an unnecessary complication to have streaming levels and some of the VR programming worked better without them.

Section 2 did not undergo very many changes. The concept for this room was to have the walls, floor, and ceiling covered in a meter-scale grid texture. The idea was to show an archaeological feature in a VR version of a plan map. Instead of drawn on a 2-dimensional paper grid, features would be shown in 3-dimesional space. The features depicted in this room were based on one of the reconstructed blacksmith shops in Section 3.

Section 3 underwent drastic changes by later stages of the fourth VR Museum. Initially, Section 3 was a room attached to the Hub like the rooms of the other Sections. Unlike the other rooms, Section 3 was intended to be a small outdoor space. It consisted of a grass floor, matte green walls, a few tees, and a small reconstruction of a blacksmith shop.

Unlike the early versions of the VR Museum, the fourth version did not have its own landscape backdrop outside the museum windows. In the early versions, it was possible to walk around outside the VR Museum. This was not possible in the fourth version. In early stages of the fourth version, the museum building appeared to be floating in empty sky. Some early tester feedback suggested this broke the illusion of being in a museum space. Gradually, more of a backdrop was added that depicted a city-scape outside the museum windows. From a bird's-view outside the museum, it would still appear to be floating in the sky, but from within would appear as the top of a tower in a modern city. The benefit of a free-floating museum building rather than placing it on top of a landscape was to more easily modify the museum structure and reduce the

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unused landscape space. The outdoor space in Section 3 was limited to only what was needed to house a reconstructed blacksmith shop.

Early tester feedback included comments about liking the outdoor concept of Section 3, but that the small enclosed space did not give enough sense of being outdoors. This feedback led to the creation of a forest environment with several reconstructed blacksmith shops. This forest was made as a separate map completely independent from the map containing the rest of the VR Museum. The forest map therefore did not share the size constraints that the initial Section 3 room had when attached to the museum building. By creating a separate map players could transport to the landscape did not have to match that of the main museum's map. Where the main museum appeared to be in the middle of the city, this forest environment appeared to be amidst mountains with no cities in sight. The player starting location was set in the middle of the map, and players were prevented from approaching the edges that would drop players into empty sky.

The fourth version of the VR Museum is where most of the prototyping of the VR implementation and other gameplay systems took place, as discussed later in this chapter. The fifth and final version of the VR Museum is described in the next chapter.

<div align="center">Photogrammetry Testing</div>

In the first few prototypes of the VR Museum, objects digitized by Smithsonian X 3D were used to experiment with introducing museum objects to the VR Museum. Although the choices of artifacts were limited, they were freely available to download at the time, were ready-made, and were digitized by photogrammetry and laser scanning. These objects included the Wright Flyer, the Pergolesi Side Chair, a reliquary from Jamestown, a mammoth, and a sculpture of President Lincoln's head. Another object included in these early versions was a Mousehole

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Forge anvil digitized specifically for this project using photogrammetry (A#17). These models served as tests for the methods of importing digitized objects into the VR Museum, and limitations of using the highly detailed models. The anvil also served as the test object for how to use photogrammetry software for creating new models for the project, and for testing different photogrammetry software options.

As discussed in the literature review, Agisoft *Photoscan* software has been used by archaeologists. At the start of this project a time-limited trial version of Agisoft *Photoscan* software was used. Later, Autodesk's *123D Catch* software was used. Unlike Agisoft *Photoscan*, *123D Catch* was free to use and the image processing was done on Autodesk servers rather than a local computer, greatly speeding up processing time from a couple of hours down to a few minutes. *123D Catch* has since been discontinued, replaced by Autodesk *ReCap* at a professional level. The software *3DF Zephyr Lite Steam Edition* was used as the photogrammetry software for the remainder of this project.

The choice of using *3DF Zephyr Lite* was a combination of price, features, and workflow. This software was available significantly cheaper than comparable software, including Agisoft *Photoscan* and Autodesk *ReCap*. The "Lite" version versus "Pro" version of 3DF Zephyr have the same features except for a few limitations that had no impact on its use for this project. *3DF Zephyr Lite* enabled a workflow that allowed almost all the work needed to prepare models for importing into the VR Museum to be completed directly within the *3DF Zephyr Lite* software.

In some cases, model preparation was also completed in the *Blender* modelling software before the final import into the VR Museum. This included changing the origin point of models to the center of the object's mass. Origin points serve as a kind of x=0, y=0, z=0 point coordinate location with the VR Museum as a large 3-dimensional graph. Control over the object's

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placement in the VR Museum is based on this origin point's location. For certain objects, it was necessary to ensure the origin point was at the center of an object rather than placed outside an object. The *Blender* software was also used to convert the scale of some objects, and clean some of the geometry from the photogrammetry process.

Prototyping Gameplay Systems

Prior to the finalization of the VR Museum content in the fifth version, several gameplay systems related to the VR implementation went through a series of prototyping phases in the fourth version of the VR Museum. *Unreal Engine 4* has several useful systems for VR built-in, which is one of the reasons why *Unreal Engine 4* was chosen for this project. These systems include support for the Oculus Rift VR headset. However, these systems only form a foundation upon which specific gameplay systems needed for the VR Museum were built. It was still necessary to prototype various VR Pawns, and ways for players to interact with the VR Museum environment.

The most important component of VR implementation is the VR Pawn. A pawn is what players directly control within the VR Museum. This pawn determines where the camera—and therefore the player's eyes—are located. The VR Pawn also includes systems for players to have virtual hands corresponding to the Oculus Touch controller inputs. Early versions of the VR Museum used very simple pawns. At the time, the Oculus Touch controllers were not yet released and a standard Xbox One controller was easily given basic functions in *Unreal Engine 4*. The Xbox One controller included inputs for walking around and buttons for exiting or resetting the VR Museum. The method of walking around in the early VR Museum versions was

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to move a thumbstick on the Xbox One controller to move the player pawn camera in the assigned axis. It was not possible to pick up objects with the Xbox One controller.

After the VR Museum changed to the consumer Oculus Rift and Oculus Touch controllers, the VR Pawn had to be completely re-worked. *Unreal Engine 4* includes a template VR Pawn with hands that can pick up objects. Instead of walking, this VR Pawn used a teleportation system. This lets a player aim at the floor to pick a destination and immediately teleport to that location. During testing, there were some issues with the teleportation system and other options for a VR Pawn were examined.

While it is possible to program a custom VR Pawn in *Unreal Engine 4*, I decided a pre-made VR Pawn from the Unreal Engine Marketplace would function as needed and allow development time to be spent elsewhere. The Unreal Engine Marketplace is a digital storefront that is part of *Unreal Engine 4*. It is where content can be purchased and added to *Unreal Engine 4* projects. The main benefit of using content from the Unreal Engine Marketplace is that it saves time from making every single component in a project and opens more time to be spent on overall design.

"VR Integrator Radial and Dockable Menus" by W3 Studios was used in later stages of the fourth VR Museum version, and the final VR Museum version. It was chosen because it has the hands and teleportation systems needed. It also provided a Dockable Menus system utilized for the signs in the VR Museum. This allowed custom content for the signs to be created, then placed within the 3-dimensional VR Museum space to be interactable with the player's VR Pawn. Although VR Integrator includes several types of VR hands, settings were modified to only allow one for simplicity. This hand type includes all the needed functions to pick up objects, teleport, and interact with the signs.

Besides the VR Pawn, some other systems underwent prototyping in the fourth VR Museum version. After Section 3 was expanded into a separate forest map, a teleporter system between maps had to be devised. One of the prototype ideas was for the player to simply move on top of a platform in the main museum to be automatically sent to the forest map. During testing, there appeared to be an issue where the programmed command to teleport to the forest map would be initiated as soon as the player entered the main museum's lobby without being near the teleporter platform. After VR Integrator was added to the project, the platform teleported idea was abandoned in favor of a Dockable Menu with custom teleport buttons.

It appears that some programming systems that work with non-VR pawns do not work as expected when VR Pawns are used. Besides the teleport platforms, there were doors until the final version of the VR Museum. These doors were meant to block the player view from seeing into the next room when streaming levels were being used. With streaming levels for each room, the rooms not currently occupied by the player would appear invisible. Since streaming levels were no longer used for the final version, and the doors did not always detect the VR Pawn correctly, the doors were removed from the VR Museum.

One door was to open and unlock progress to the next room when a correct object—a hammer—was placed on a certain table. Placing the hammer opened a door leading to Section 1 Room 2. There were also doorways leading to the Hub and from the hallway to Section 1 Room 3 by the final version. The hammer was able to be picked up, but had issues being detected to open the door. After the other doors in the museum were removed, it was decided the complexity of creating the doors for Room 1 were not worth the time taken from other improvements. Besides the door leading to Section 1 Room 2, there would have also needed to be a way to unlock the door from the hallway out of Section 1 Room 3.

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In the last stages of the fourth version of the VR Museum, the final design modifications were set. As the VR Museum approached the final version, there continued to be some late additions based on tester feedback. This included arrows and lines on the floor as a guideline throughout the VR Museum. The artwork from the Cleveland Museum of Art featured in the hallway leading from Section 1 Room 3 were also a late addition. The signs received another pass for editing their text. The fifth version of the VR Museum represents the final version, transitioning from the prototypes to a polished and completed program. This final version of the VR Museum is discussed in the next chapter, describing the final design and content of the VR Museum.

CHAPTER 5

VR MUSEUM RELEASE VERSION

The fifth version of the VR Museum is the completed release version. Where prior versions were given program version numbers '0.#.#' the final version was upgraded to the number '1.0.0' to reflect a release version of a computer program. The '1' reflects that this is a release version of the program. The next numbers reflect a '.major.minor' update designation in software. This chapter is broken down into sub-sections for each part of the VR Museum. The purpose and goals for each room are discussed. The contents of each room are described to help understand what the VR Museum is. The VR Museum is divided into a starting menu map, a main museum map, and a forest map. The main museum map is further divided into Sections 1 and 2.

Starting Menu

When the VR Museum program is first launched, it places the player in a small room with a main menu interface (A#18). This main menu sign has the title "VR Museum" and buttons for entering and exiting the VR Museum. To the left and right are signs showing the controls for the VR Museum on the Oculus Touch controllers.

The purpose of this room is to provide a minimal space to enter the VR Museum when it first launches. This has helped the VR Museum to launch faster than loading directly into the more complex main museum map. It also provides a space where the VR Museum can be reset for the next player. On teleport menus in Section 3 are buttons to reset to this space.

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Main Museum

The map containing the main museum consists of the museum building, its artifacts, lighting simulation, and city-scape backdrop. At the center is the Hub, which acts as the lobby and reception area for the museum. Leading out of the Hub are three Sections, or wings, of the museum. The Hub and each room of these Sections is described below.

Hub

The Hub of the museum is where the player enters after going through the starting menu map ([A#19](#)). To the left of the player's starting location is a copy of the sign showing the Oculus Touch controls. Behind the player are elevators and a stairway to suggest an entrance for the museum's floor. They help convey the illusion of entering a real museum space. The Hub has large windows around its ceiling space, with the tops of the surrounding skyscrapers visible amidst the sky. The VR Museum appears as the top floor of a skyscraper in a city.

Ahead of the player is a reception desk. To the right, leading from the player's starting location up to the reception desk are glass-backed signs. These signs are for the titles of the museum and serve the purpose of leading the player to the reception desk. The reception desk has the primary purpose of containing tablet-sized signs showing the directory for the museum. The directory contains short descriptions of what can be found in each of the museum's sections. The middle of the reception desk contains text suggesting the player go to Section 1 for their first activity. The reception desk also has text prompting players to try picking up the decorative objects around the desk. This includes a laptop, notebook, pens, and smartphones. This helps to fill in the otherwise empty space in the middle of the Hub and lets players begin to learn how to interact with objects in the VR Museum space.

The doorways to each Section are labeled as Section 1, Section 2, and Section 3. Throughout the VR Museum, door-frames are colored bright-red against mostly white walls. An exception is in the Hub where the entire wall with the doorway to Section 1 is bright-red. Next to the doorway to Section 1 is a sign that tells the player to follow lines on the floor, and that exit signs indicate the way back to the Hub. A short hallway connects the Hub to the first room of Section 1.

Section 1

Section 1 contains three rooms featuring blacksmithing tools, and a hallway exhibiting artwork from the Cleveland Museum of Art. The three rooms are designated as Section 1 Room 1, Section 1 Room 2, and Section 1 Room 3. These rooms were designed to introduce players to interactions in the VR Museum. They also serve as an introduction to blacksmithing tools. Section 1 Room 3 exhibits models of tools made with photogrammetry.

Section 1 Room 1 consists of only a single table of objects on display (A#20). The room is meant to ease players into picking up objects—hammers in this room—and reading signs that talk about the objects. Text on the floor beside the table tells the player how to pick up and drop the objects. The three hammers in this room were modelled in *Blender* specifically for this project. Two are based on the dimensions of modern hammers, the third is based on a Norse artifact from the Mästermyr Find (Ardwidsson and Berg 1999). The exercise for the player is to examine these hammers and guess which one the Norse hammer is. Then they go to the backside of the sign and read about the Norse hammer. Other signs talk about the preservation of wood handles and other organic materials in archaeological contexts. The full text of the signs in the VR Museum are supplied in Appendix B.

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Within a room, players are meant to follow blue lines on the floor from sign to sign. Then they can follow an orange line on the floor to the next room. There are also a series of arrows along the lines to indicate the intended direction. These guide the player if they get turned around in the VR Museum or are unsure of where to go next.

Section 1 Room 2 is meant to educate about basic tools in blacksmithing. These objects include a forge, anvils, tongs, hammers, and wooden mallets. The assumption is that most players of the VR Museum do not have prior knowledge about blacksmithing. By explaining the tools in this room, context of their use can aid player understanding of other exhibits in the VR Museum. Many of the blacksmithing tools in this room were from Unreal Engine Marketplace content packs. It was decided these models serve illustrative purposes well enough that time was better spent elsewhere. There are five different tongs, on the left side of a table dedicated to tongs, that were specifically modelled in *Blender* for this project (A#21). These tongs are directly referenced in the sign about tongs as illustrating the varieties of jaw shapes made to hold different shapes of metal. Where a particular point was being made, it was seen as beneficial to make custom models. Otherwise, content packs from the Unreal Engine Marketplace gave the benefit of adding more models to the VR Museum than otherwise possible for this project and making the museum appear fuller in content. All the hand tools can be picked up, examined, and dropped by players with the virtual hands controlled by the Oculus Touch controllers. A list of the Unreal Engine Marketplace content packs utilized throughout the VR Museum, alongside what software was employed, is provided in Appendix C.

Besides hand tools, this room also depicts a sword and a sword blank—a rectangular bar with a tang in the rough shape of a sword. An accompanying sign explains some of the processes involved in producing a sword. The sword serves as an example of the process a blacksmith

follows to make a sword with the tools depicted. The processes described include forging, grinding, and tempering of the blade.

This room begins to add variety to the sign types. Where Section 1 Room 1 had signs with plain text, Section 1 Room 2 has two of its signs that have a scrollbar. This scrollbar can be used by the player to reveal more text on that sign. These signs introduce interactive signs ahead of another interactive sign type in the next room.

Section 1 Room 3 exhibits models made with photogrammetry (A#22). These models were made specifically for this project to experiment with the photogrammetry process and the display of the resulting models in VR. These models include a modern cross pein hammer, a ball pein hammer from the early to mid-20th century, modern hand-forged tongs, and a Mousehole Forge anvil. The Mousehole Forge anvil was forged circa 1840 in England. There are larger-than-life-size versions of the hammers and tongs in addition to the life-size versions. Models in VR are not limited to real-world scale. The larger versions can show detail not as easily seen in the smaller life-size versions or the original real-world objects. Each photogrammetry model was given several levels of detail (LOD) in *Unreal Engine 4*. This reduces the amount of detail when the object takes up less screen percentage—as the player gets further from the object. High detail cannot be seen well from a distance and can have a performance impact. The life-size versions of the hammers and tongs can be picked up by the player in the same manner as all the other hand tools displayed in the museum.

The sign for the Mousehole Anvil is a unique type in the museum. The different sign types are intended to maintain player interest by providing different interactive elements. The Mousehole Anvil sign is double in width from standard signs in the museum. The left half has buttons which control the text displayed on the right half. When a button is clicked, the text on

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the right half changes. The topics include what parts of the anvil do, the anvil's history, the

hundredweight system of measure marked on the anvil, and how photogrammetry was used to

make the model. Players can lean toward or walk around the anvil to see the parts described by

the sign.

When players are finished looking at the photogrammetry objects, they can leave Section

1 Room 3 and return to Section 1 Room 1 and then back to the Hub. While there are hallways

between each of the rooms in the museum, the hallway from Room 3 to Room 1 is different.

Besides being longer than others, in order to bypass Room 2, this hallway is decorated with

artwork (A#23). The artwork depicted is from the Cleveland Museum of Art's Open Access

collection. Open Access permits use of the images and metadata of artwork for commercial, non-

commercial, and scholarly use. The artwork displayed in the hallway depict blacksmiths of the

18th and 19th centuries. They are shown in the VR Museum in larger-than-life sizes to show the

detail of the images. Metadata information appears beside each artwork as a small sign.

Displaying artwork of this type in the VR Museum demonstrates the variety of objects that can

be put on exhibit in a VR Museum. A list of artworks used from the Cleveland Museum of Art is

supplied as part of Appendix C.

Section 2

Section 2 consists of a single small room outlining some of the features of a blacksmith

shop before players continue to Section 3 which shows fully reconstructed blacksmith shops.

This Section is accessed directly from the Hub. The floor, walls, and ceiling of this room are

covered in grid patterns scaled to 1-meter squares. In the center of the room is the outline of

features in a blacksmith shop (A#24). For instance, the location of the forge is represented by

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blue cubes where stone blocks of the forge could be found. The features of this shop correspond exactly to the locations of the features in a fully reconstructed shop in Section 3. This shop and the one in Section 3 are based on a shop from an archaeological excavation (McBride 1987).

The blue shapes are intended to be a suggestion of the features they represent rather than full reconstructions so that players can better see spatial relationships between features rather than focusing on the features themselves. The outlining of features on a grid illustrates a 3-dimensional VR version of a plan map of an excavation of the shop. Accompanying signs explain the grids, and the identification of shop features in archaeology.

Section 3

Section 3 is a forest environment with three reconstructed blacksmith shops. While the main museum consists of Sections 1 and 2, the forest of Section 3 is its own part of the museum. To get to Section 3, the player first returns to the Hub. Through the door labeled Section 3 is a single room with nothing but a sign. This sign has buttons to teleport the player. One button sends the player to the starting menu. Another button sends the player back to the starting location in the lobby and resets the placement of all objects to where they began. A third button exits the VR Museum program. A fourth button teleports the player to a new map. This map has the appearance of a forest with mountains in the distance. The forest map is separate from the main museum map with no trace of the main museum or its city-scape.

The player enters the forest on a path amidst rocks (A#25). This helps limit the player's view as objects continue to load and leads up to the first sign. Wooden walls block the way up the path behind the player to indicate which way to go in a way that blends into the environment.

Following the path, the player comes to a clearing in the forest with three reconstructed blacksmith shops (A#26).

The player can only explore the area immediately around the blacksmith shops. The limitation keeps players from getting lost in the woods and focuses the experience. The map is much larger than just the area around the shops. The shop area was adapted from a nature content pack from the Unreal Engine Marketplace. It was deemed sufficient for the purposes of this project to start with a premade forest environment and adapt it to the needs of the project rather than spending time making an entirely new environment resulting in something that would have looked similar.

The shops themselves were made from pieces in content packs from the Unreal Engine Marketplace. A piece of a wall, a segment of a roof, and a door are all separate pieces that could be combined in different ways to create new buildings. This allowed a greater focus on the overall design of the reconstructions rather than details in the models. It also made it possible to recreate more than one shop since it was not necessary to make a new custom architecture model for each one.

When the player enters the clearing with the shops, an open-air shop is on the left and a small enclosed shop is on the right. A larger stone-walled shop is further back. The open-air shop is not based on any specific shop found archaeologically but demonstrates how some shops have nothing more than a roof. The small enclosed shop is the one used for the illustration of features in Section 2 of the main museum map. This small enclosed shop is based on the Griswold Shop (McBride 1987). The dirt floor, dimensions, window locations, and the locations of the forge, bellows, anvil, and workbench are all based on the Griswold Shop. The height of the walls to the support beams of the roof was estimated based on what felt natural during testing in VR. One of

the benefits of employing VR in the creation process is that it can be used to obtain a sense of scale. When in VR, personal experiences can be recalled for comparison to the building being reconstructed in a way not possible when looking at a typical computer monitor.

The third shop, the larger stone-walled one, is loosely based on the shop from Fort St. Joseph, Ontario (Light 1984). The layout is similar, but the dimensions of the reconstructed shop were enlarged. This was done so that several types of spaces within a blacksmith shop could be illustrated (A#27) and to increase the available space players could teleport to. The teleport system requires open floor, and a smaller shop with many objects would limit the player's ability to teleport around the virtual space. The lessons on spaces of a blacksmith shop were based on the spaces identified for the Fort St. Joseph shop (Light 1984).

While all the hand tools can be picked up by the player, they are not the focus of Section 3. Section 1 had signs teaching about the tools; Section 3 places those tools in context of blacksmith shops. The signs in Section 3 are primarily about the identification of blacksmith shops in archaeology and the use of spaces by the blacksmith.

When the player has finished exploring the reconstructed blacksmith shops, they enter a fenced-in area beside the third shop (A#28). This area has a teleporter sign like the one in the Section 3 room of the main museum map. This version of the sign has buttons to reset at the beginning of the forest map, or to return to the Hub of the main museum map, alongside the buttons to reset to the starting menu or to exit the VR Museum program. With the player's completion of Section 3, the player's journey through the VR Museum is finished.

The fenced-in teleporter area also has a sign showing the address to a personal website (jrnau.weebly.com) that players can visit to complete a survey about their VR Museum experience or to find more information about this project. The survey was made in

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SurveyMonkey and embedded on a page of the personal website. The purpose of this survey is to gather informal feedback on the VR Museum after it launches and will be available beyond the completion of this thesis. Copies of this sign also appear in the Hub of the main museum map, and the Section 3 teleporter room in the main museum map. Proximity to the teleporter signs were chosen since they each have buttons to exit the VR Museum program, and the sign about a survey would be one of the last things players see. Since it is possible to exit any VR experience through an Oculus menu, placement near exit buttons inside the VR Museum do not guarantee the signs will be seen. Therefore, the website sign was also placed in the Hub. Placement of the sign in the Hub was chosen as one of the rooms in the VR Museum players are required to visit, whereas visiting each Section is optional.

CHAPTER 6

REFLECTION ON THE VR MUSEUM AND FUTURE DEVELOPMENTS

There were many changes and additions to the VR Museum based on early tester feedback. Although the VR Museum has transformed and expanded in ways not planned when the project was first begun—mostly for the better—there were some features that could not be completed as originally envisioned. These features could be subjects of further research. They are described here to discuss the potential of VR programs when more resources are available and as VR technology matures.

Firstly, the concept of the VR Museum does not have to be about the archaeology of blacksmithing. Almost any object, painting, or archaeological site could be presented in a VR museum. Indeed, early ideas for the VR Museum envisioned several sections of a museum building that could be added to later versions of the VR Museum, like how real-world museums construct new exhibits over time. VR museums have the advantage over real-world museums in that VR is not constrained by physics, space, and money in the same way exhibits in the real-world would be. While there are still costs to VR development, it is possible to reconstruct an entire city in VR, as an example. Reconstructing a whole city in the real-world would not be feasible.

Imagine, a player enters the Hub of a VR Museum. This Hub can have many teleporters to different exhibits. One teleporter can send the player to a 3-d scan of an archaeological site—say, the city of Pompeii. After the player has finished seeing what the city looks like today and has learned about the process of archaeology at the site, the player could teleport into the past.

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This past shows the player what the city may have looked like when its inhabitants still lived. The player could take up the character role of a Roman living in Pompeii, following a narrative teaching the player about daily life in the Roman city and about Roman culture. Then, as part of the simulated narrative, Mount Vesuvius erupts, and the player learns about the tumult that results from such a powerful force of nature that ends with the city's inhabitants—and the player—frozen in time through molds of ash. Time could then fast forward to give the player glimpses of the re-discoveries of Pompeii throughout the centuries to its first archaeological excavations.

While such an expansive project was not feasible for this thesis, it is within the capability of today's technology. It would be much less expensive to reconstruct Pompeii in VR than to build a whole reconstructed city in the real-world with a living history cast portraying the Roman inhabitants. VR would allow a simulation of the eruption of Mount Vesuvius that visually looks realistic, where it would simply be impossible to have a volcanic eruption and deposition of ash in a living history museum-city. Further, if a part of a city is reconstructed in the real-world the process of design today would likely involve 3-d models in planning what the reconstruction would look like before it is built. The same 3-d models could be adapted to VR and be used as the basis to expand a virtual reconstruction of the rest of the city.

A project that utilizes 3-d scanning as part of the documentation process in archaeology could use VR for research in addition to education. In the example of the Pompeii project above, 3-d scans of the city as it appears today could be taken. The same scans could be viewed by archaeologists in VR with a better sense of scale and spatial relationships than could be achieved on a desktop monitor. Archaeologists could walk around the site or go to a bird's-eye view above the city. This could potentially open archaeological sites to more researchers who cannot

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personally travel to a site regularly, if at all. The same concept applies to individual artifacts as it does to archaeological sites. Museums could digitize their collections, and researchers—or anyone interested—could enter VR and see the 3-d models of artifacts. The artifacts could be picked up in VR to be seen from different angles. This could be useful if the original artifact is highly valuable or delicate and cannot be handled by just anyone. In VR, it is also possible to make artifacts appear larger than life-size to see fine detail better, as was demonstrated with the photogrammetry objects in the VR Museum of this thesis.

Another component of VR museums that could be expanded upon in future projects is the addition of multiplayer. In video games the term multiplayer means more than one player can be playing the same video game and appear together in the virtual world. Players see each other in the form of avatars—virtual representations of a body, usually with the appearance of humans. Multiplayer was not implemented in the VR Museum for this thesis due to complexities of networking and server requirements. However, other VR experiences are available that do support multiplayer, usually for entertainment or social purposes.

In VR, other players in the same virtual space have a sense of presence—of that other player sharing the same space—which feels more like sharing a space in the real world with other people than any other technology currently available. In the Oculus Rift, with the Oculus Touch controllers, it is possible to convey certain basic gestures. The controllers can detect when a player is gesturing with thumbs-up or pointing at an object with an index finger. People can wave to each other, or hand each other 3-d models of objects. Sometimes in VR only the heads and hands of other people are visible (torsos too) since those are the only body parts directly tracked by the Oculus Rift headset and Oculus Touch controllers in 3-dimensional space. This is still enough to know whether a player is facing towards another player while one is speaking to

the other, or to tell if one of those players is looking in other directions and not paying close attention to the speaking player. The nuances of communicating to other players in a shared VR space can truly feel as if the players are in the same space together in a way phone calls or video chats cannot convey. It does not matter if the two (or more) players live in distant parts of the world from each other. The internet, and VR, connects them.

This kind of multiplayer could impact VR museums in several ways. One is that players may co-operatively work through lessons in a VR museum. This would make the lessons more engaging just by sharing the experience with someone else. Another potential use of multiplayer in a VR museum would be to have an instructor—a real human rather than an artificial character, or bot—guide players through the VR museum. Rather than making players read signs, an instructor could teach within VR. Instructors could pick up objects they are talking about, then hand them to the visiting player. The instructor could point at details in the virtual environment as they are being discussed. An instructor sharing a virtual space with visiting players could answer questions in real-time. Generally, it would be like having an instructor guiding students through any real-world museum. Except, the instructor could be in one part of the world and the students could be at home or school in different countries.

While there are current technological limitations to how many players could share a virtual space at once, it would be possible for a class of thirty students to be in a virtual space together. Some non-VR video games have achieved one hundred players sharing the same virtual world. Massively Multiplayer Role-Playing Games (MMORPGs) can have millions of players together by breaking the virtual world (sometimes the size of continents) into small pieces with fewer players. That a whole class can be in a VR space means VR has wide applicability in altering distance-learning. It would be possible to teach entire courses in VR. One of the early

prototypes for the VR Museum even had rooms constructed that were intended to eventually house classrooms. Students were to have a class in the space, and then have a field-trip to other sections of the VR Museum. The classroom would have served as a sort of homeroom for the students. The wider implication is that students do not need a classroom in a VR museum environment. Their classroom could have the appearance of any environment and they could have field-trips to several independent VR museum projects.

An addition that was explored for the VR Museum in this thesis, but not implemented, is characters. Instead of other players controlling these characters in multiplayer, they would be controlled by the simulation. These characters can be designed during the creation of the museum to animate with pre-set motions or have some degree of artificial intelligence (AI) letting the character react autonomously. These AI characters, or bots, could be blacksmith characters appearing to be working in the reconstructed blacksmith shops. They could talk to players, explaining their shop and work instead of having players read signs. There was also a concept model of a robotic docent for the VR Museum that was created but not used. It was realized the software necessary to animate the characters and to create the sound files of narration were beyond the resources of this thesis (the software is often priced with professional studios and businesses in mind and can cost over $1000 for a single piece of software). Ultimately, it was decided time and resources would be better spent improving other aspects of the VR Museum than to implement animated characters in the current version. Nevertheless, it would improve the immersion and educational content of the VR Museum to include characters that could talk to players.

Besides characters, it would be possible to add more interactions between the player and the environment. This could include small details like the ability for players to pull a lever on a

bellows to see larger flames in the forge-fire. While it was decided to eliminate exercises players would have had to complete to progress to new rooms in the current VR Museum, future versions of the VR Museum could re-introduce such systems. In an early prototype version of the VR Museum players had to place a correct hammer in a specified location to unlock the door to the next room. In future versions, there could be other types of interactions to unlock doors. Correctly answering a multiple-choice question based on content learned in the room could unlock a door. Players could swing a sword at a target to trigger the unlocking of a door. These interactions could make the learning more engaging and add an element of motivation for learning content with the reward of a newly unlocked room to explore. A disadvantage of having doors unlock with correct answers is that it prevents the player from freely exploring the VR Museum. This is one of the reasons why doors were removed in the current version of the VR Museum. For the purposes of letting players explore the VR Museum concept as they wish without constraints, unlocking doors were eliminated in the current VR Museum.

Player feedback has already suggested some other areas for future VR museums to build on. While the scope of this thesis did not include a formal public test of the VR Museum with many test players, it did include limited testing. As ways to make the VR Museum accessible to the public are explored after the completion of this thesis, wider public feedback may become available. The completion of this thesis included a release of the VR Museum in the Western Michigan University VR Lab, which is one avenue of continued player feedback.

Some players who have tested the VR Museum so far do not like the teleportation system used to move players around the VR Museum environment. Teleportation from point to point is a common method in current VR experiences and is the default solution in *Unreal Engine 4*. It is intended to reduce the feeling of nausea some players experience when camera control is taken

from the player. Teleportation maintains a player's control over the camera—and therefore what they see in VR—by teleporting them directly to a desired location with a moment of a black screen during the transition. However, some test players have expressed an interest in the choice of horizontal movement of the camera based on the Oculus Touch's thumb-stick control, like many non-VR video games. This would let players freely move around within a virtual environment and is more seamless than teleportation. Early prototypes of the VR Museum did use this method of movement, but teleportation was deemed the safer option for most players. Future versions would make the movement method—teleportation or free-movement—a choice of the player.

Some feedback expressed unclarity of instructions in the VR Museum. Players familiar with VR understood how to teleport and pick up objects since the controls are similar to other VR experiences. Some players unfamiliar with VR and video games expressed unclarity in how the teleportation destination is based on aiming at the floor with the Oculus Touch controller. Others did not understand the need to press the grip button on the Oculus Touch controllers to pick up or drop objects. Players unfamiliar with VR also often forgot they could look around with their own head as they normally would outside VR. They would remain facing forward unless verbally prompted to look around during testing sessions. While there are signs explaining the controllers and how to use them in the Starting Menu and the Hub, as well as reminder text throughout the VR Museum, it appears a dedicated tutorial on how to use VR may be necessary. When a person sets up their Oculus Rift for the first time, they are immediately placed within an Oculus tutorial environment. This is not immediately started when the Oculus Rift has been set up for many users in a testing or a library setting. Some VR experiences include their own tutorials, lengthy experiences of their own, independent from the core content of that VR

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experience. The challenge for future VR museums will be how to implement a more effective tutorial system integrated into the VR museum experience that gets players exploring as soon as possible.

Future VR museums will have to decide what audience to target. This thesis was a generalized exploration of a VR Museum environment. It was released in a library VR lab setting, with the intention to release it on wider distribution platforms such as the Oculus Store (which is like an app store for VR experiences on the Oculus Rift). For use in a library or museum, where people may be more likely to try a VR experience in short bursts of time to allow others to try the VR experience, this VR Museum would take too long to fully experience all the content. In such library or museum settings it may therefore be better to concentrate on one lesson. There could be several stations set up dedicated to different lessons. So, one station could show players one of the Section 1 rooms in the VR Museum explaining blacksmithing tools, and not let players explore further. Then another station could be dedicated to the forest map of Section 3.

On the other hand, a release on the Oculus Store might have an audience expecting longer experiences, played from the comfort of their own homes. Since any wider release of the current VR Museum will be free, this is less of an issue presently. If the VR Museum were to require purchase, however, there would probably not be enough content in the current VR Museum for players to feel a price more than $5 is justified. There is subjectivity in how much content players may feel they need to justify varying prices, which also must be balanced with development costs. As previously stated, the current VR Museum would be free, but pricing based on content is a consideration future VR museum projects will need to make if they wish to go the commercial route.

VR is still in its early years. As the technology continues to develop there may be new ideas for what experiences VR museums could provide to players. This thesis sought to lay a foundation for how VR can be utilized for VR museum experiences. This chapter sought to illustrate future possibilities for VR museums. There are developments that could be implemented into a version 2.0 VR Museum, expanding on the version 1.0 of this thesis. Larger ideas, or new ideas can be taken up by completely new VR museum projects produced by museums, education companies, and other researchers.

CHAPTER 7

CONCLUSION

Archaeologists are increasingly using 3-d scanning technology to document and preserve archaeological sites and artifacts. Video games have also been researched and utilized for applicability in educating the public about history and archaeology. Virtual reality (VR) is a technology that can be leveraged to combine those two areas of archaeology into immersive educational or research experiences. Players in VR are not merely playing a video game, they are inside the virtual world of video games. Professional archaeologists can also use VR as a tool for viewing the 3-d data captured in scans, or to collaborate across vast distances with other researchers in a shared space. VR is unique in how it transports players inside virtual environments and provides a sense of presence of being in that environment.

The VR Museum created for this thesis was built from the ground-up in *Unreal Engine 4*—a popular real-time rendering engine used in the video game industry—to explore VR in archaeology. The theme of the VR Museum was blacksmithing in archaeology for educational use. In the course of creating the VR Museum, literature on excavations of blacksmith shops and the blacksmith craft were examined. These formed the foundation for content presented in the VR Museum. While blacksmithing was chosen as a theme for this VR Museum, the same principles can be applied to other topics in future VR museums. This research contributes to the expanding literature on using video game technology for education. The research in this thesis is also at the forefront of new literature examining potential for VR.

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The process of developing this VR Museum involved four prototype versions and a fifth final version. In the course of development, various aspects of the VR Museum design and artifact implementation were experimented upon. The final version of the VR Museum was constructed as a showcase for possible exbibits in a VR museum. This includes teaching players about tools of blacksmithing which players can pick up for closer examination. The VR Museum also explored how to display 3-d models of objects that exist in the real-world captured by photogrammetry. The VR Museum has an exhibit showcasing how art images from the Cleveland Museum of Art can be displayed in VR and does not have to be 3-d object models. A VR version of a plan map is illustrated, showcasing features of a blacksmith shop that can be identified in an archaeological excavation. Another part of the VR Museum shows how VR is not limited by physical museum space by reconstructing several blacksmith shops in a forest environment with mountains visible in the distance.

The VR Museum has been released in the Western Michigan University VR Lab. The VR Museum was designed for use with the Oculus Rift and Oculus Touch controllers. Although not completed as a component of this thesis, the intention is to release the current VR Museum for free to a wider audience. Ideally, this would be in the form of publication in the Oculus Store under the Education category. Efforts have been made to show the VR Museum in other ways, including YouTube walkthrough videos, personal website (jrnau.weebly.com), and 360-degree screenshot captures from inside the VR Museum.

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APPENDIX A

SCREENSHOTS

This appendix contains images from the project and relevant video games. Many video games today incorporate the ability to capture screenshots of what appears on a computer monitor. This ability was utilized in the creation of the images in this appendix.

A#1: A screenshot from one of the pre-built castles in *Crayola 3D Castle Creator* (IBM 1998).

A#2: A screenshot from *Age of Empires: Definitive Edition* (Microsoft Studios 2018).
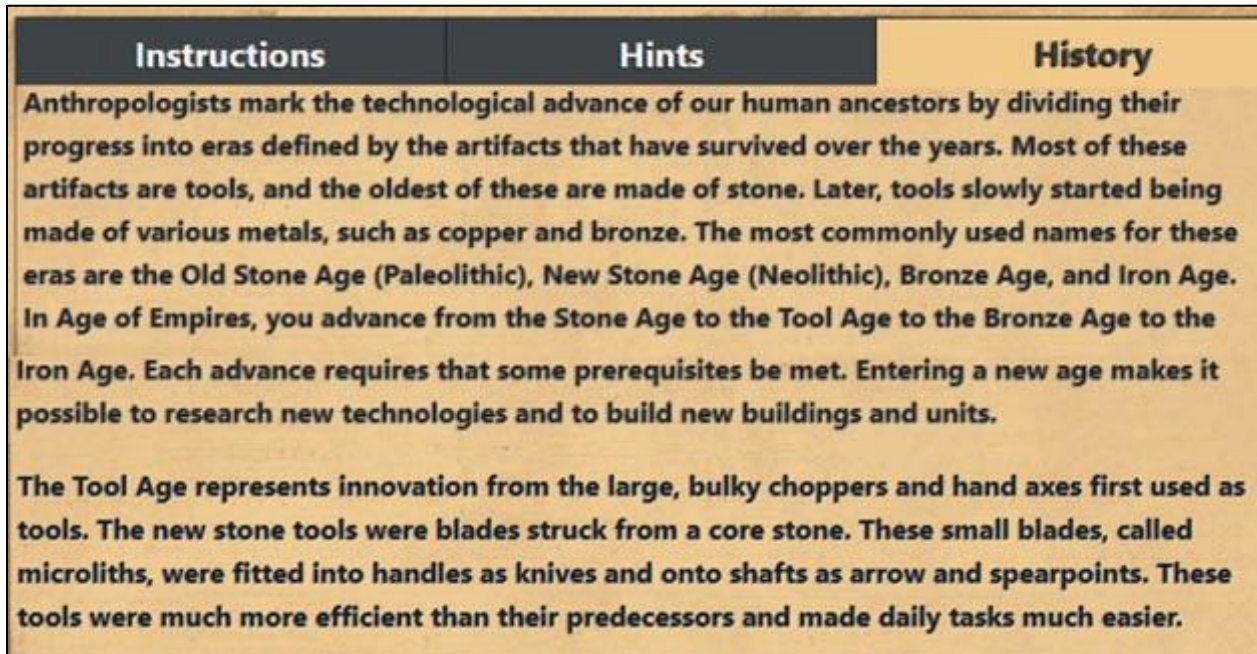
A#3: Screenshot of history text appearing in *Age of Empires: Definitive Edition* (Microsoft Studios 2018).

A#4: *Rise of the Tomb Raider* (Square Enix 2016), showing Lara Croft in foreground and a Byzantine ship frozen in a Siberian glacier in the background.
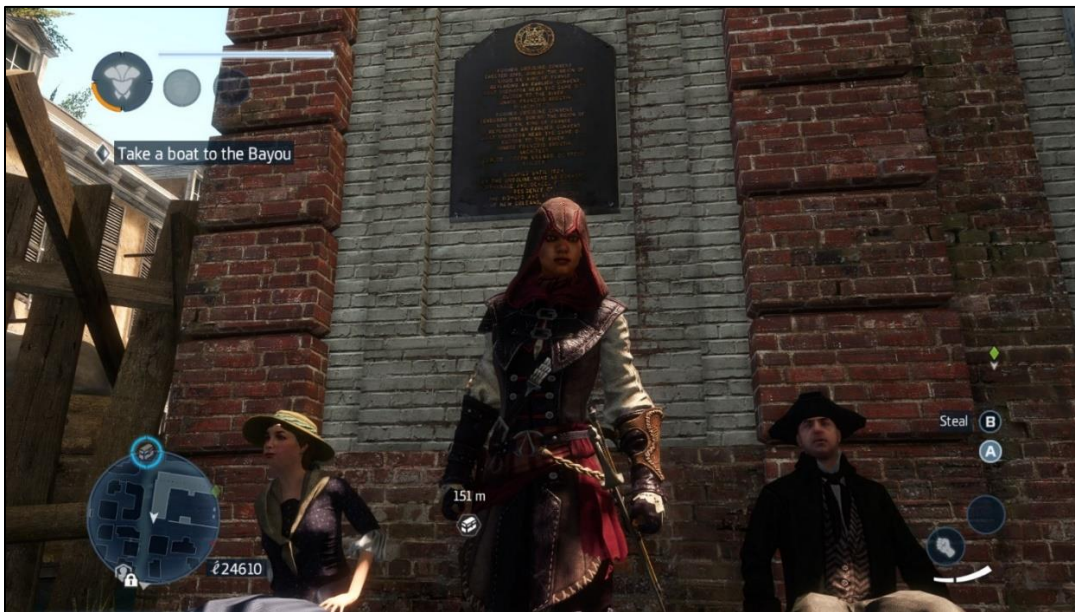
A#5: A screenshot from *Assassin's Creed Liberation* depicting the main character and a church with its present-day historical information plaque (Ubisoft Entertainment SA 2012b).

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A#6: Part of the Discovery Tour in *Assassin's Creed Origins*. This tour was about artisans in the reconstructed city of Memphis, and included a stop at an Egyptian blacksmith, although the narration did not describe Egyptian blacksmithing. The glowing line indicates the tour path to the next location with tour information, although players can freely roam the virtual world (Ubisoft Entertainment SA 2017).

A#7: A reconstructed castle in *Kingdom Come: Deliverance* (Warhorse Studios and Deep Silver 2018).

A#8: Making of a sword during a cinematic in *Kingdom Come: Deliverance* (Warhorse Studios and Deep Silver 2018).

A#9: One of the blacksmith characters in *Kingdome Come: Deliverance* that use the same animations and object meshes as every other blacksmith in the video game. (Warhorse Studios and Deep Silver 2018).
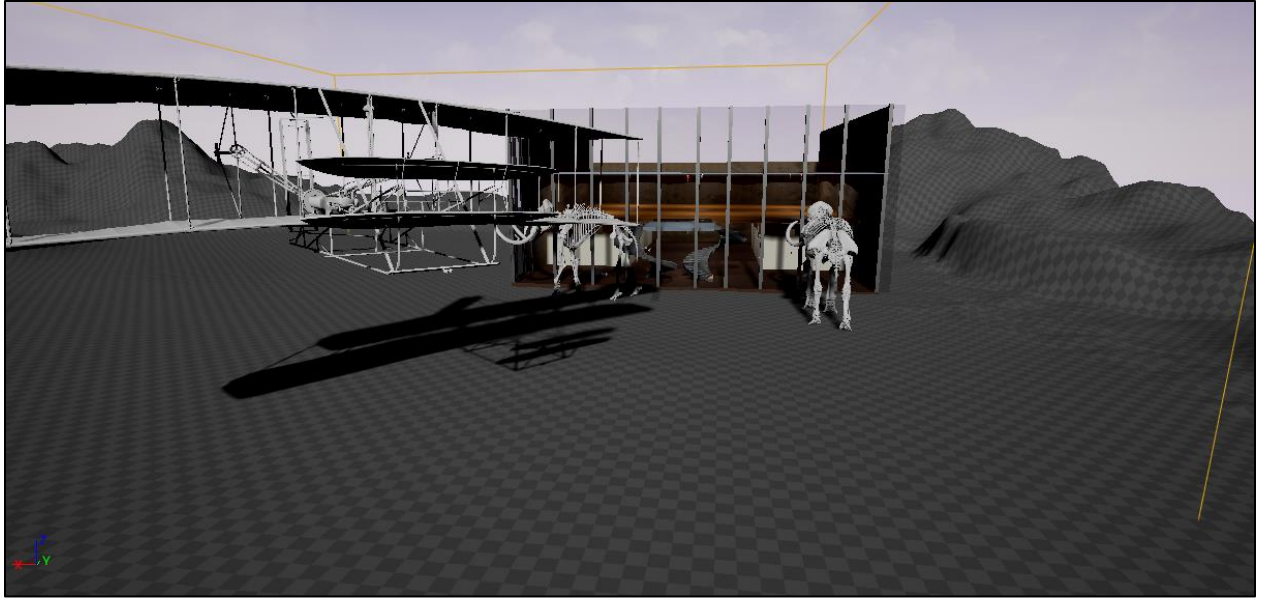

A#10: An open-air blacksmith shop depicted in *Kingdom Come: Deliverance* (Warhorse Studios and Deep Silver 2018).

A#11: A stone blacksmith shop depicted in *Kingdom Come: Deliverance* (Warhorse Studios and Deep Silver 2018).
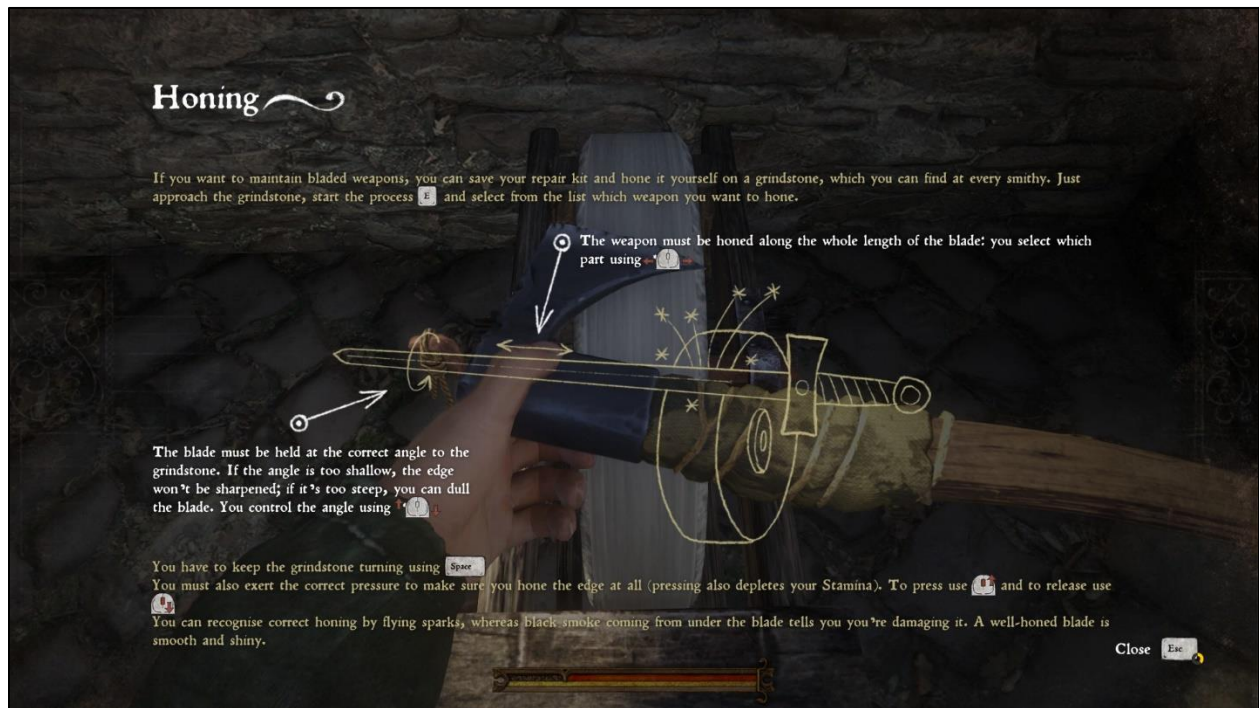
A#12: Instructions to players for honing blades in *Kingdom Come: Deliverance* (Warhorse Studios and Deep Silver 2018).
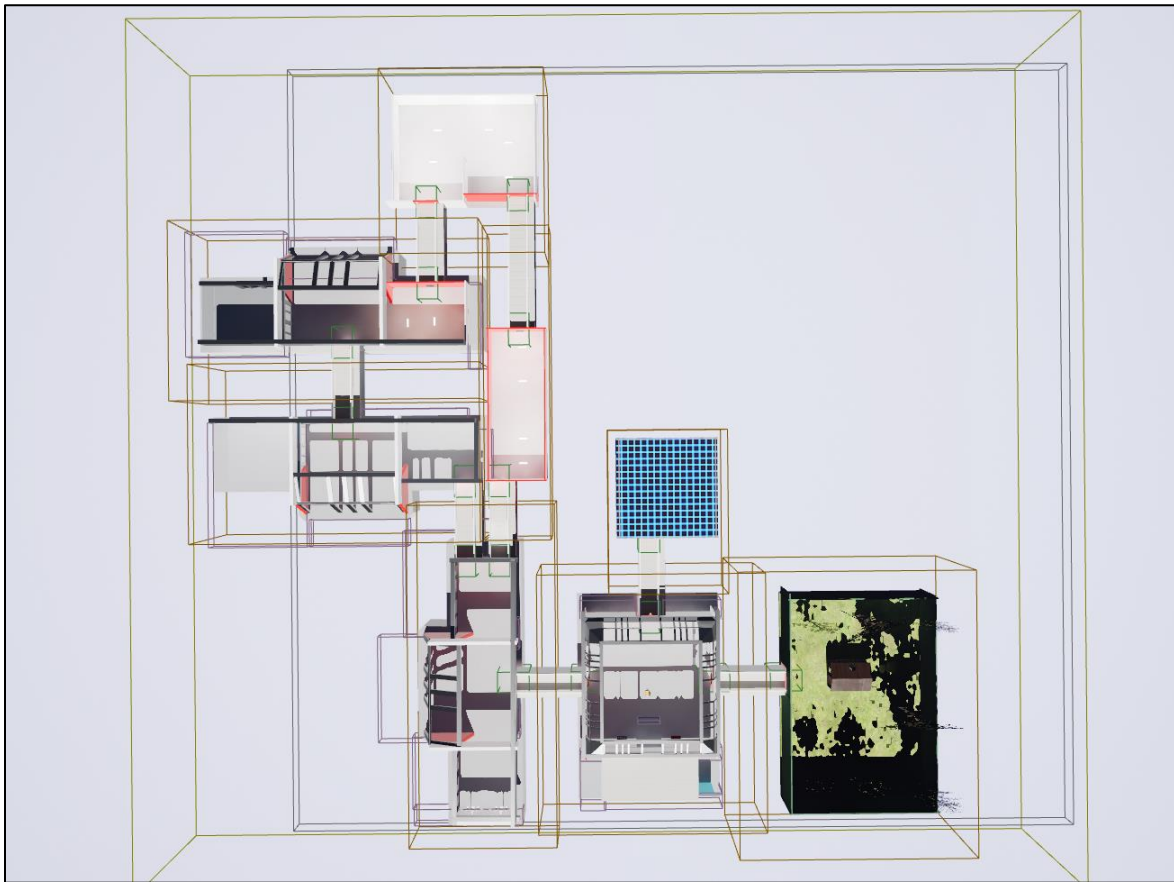
A#13: The first prototype version of the VR Museum featuring the Wright Flyer and mammoths digitized by the Smithsonian X 3D.
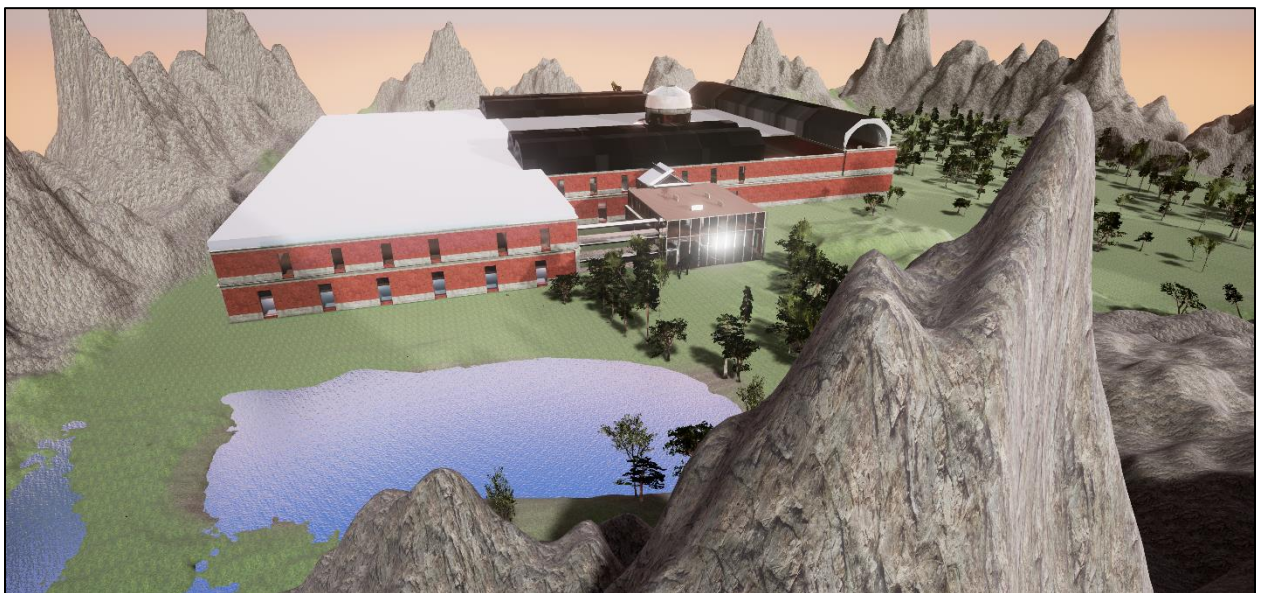

A#14: The second prototype version of the VR Museum viewed from atop one of the surrounding mountains.

A#15: The third prototype version of the VR Museum.

A#16: View from above the fourth prototype version of the VR Museum. This view shows how there used to be five rooms in Section 1, each linked by a short hallway. The green room on the right side is Section 3 prior to expansion to a separate forest map.
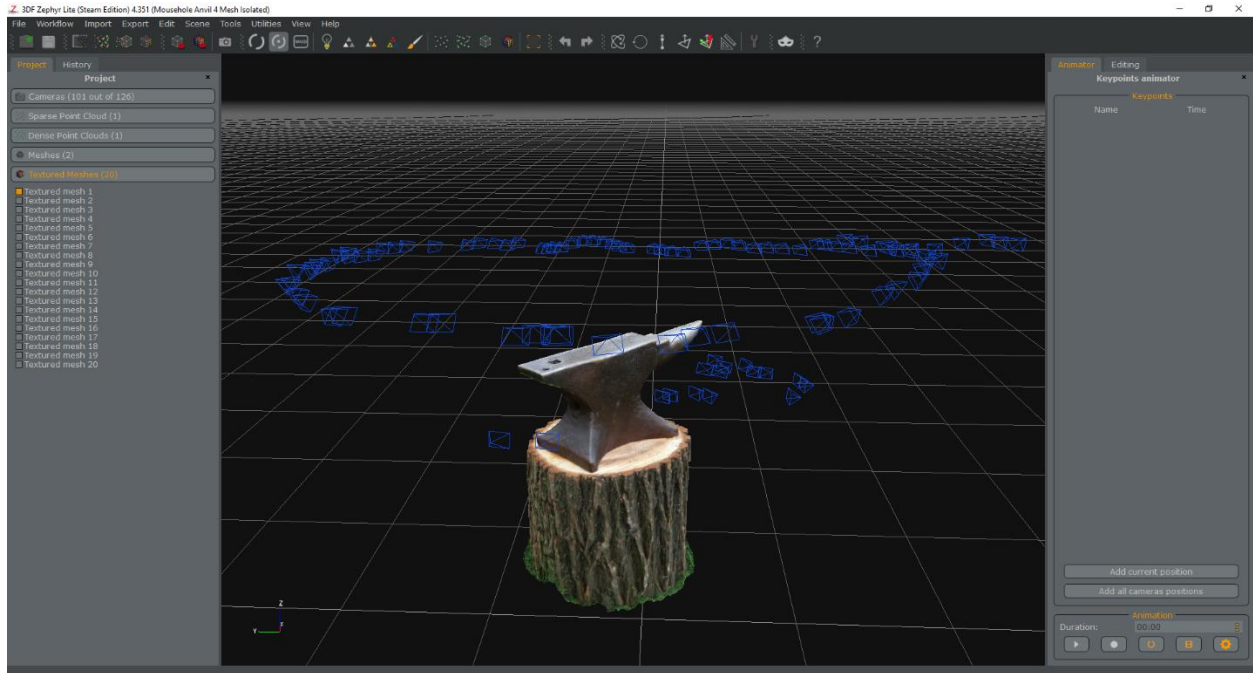
A#17: The Mousehole Forge anvil model processed in *3DF Zephyr Lite* using photogrammetry. Each blue square circling the anvil is the placement of the camera when photographs were taken. The panel on the left side shows the steps in creating a photogrammetry model from processing camera position to creating a final textured mesh. Each textured mesh in the list is a different level of detail, with 1 being the highest detail model and 20 being the lowest detail model.
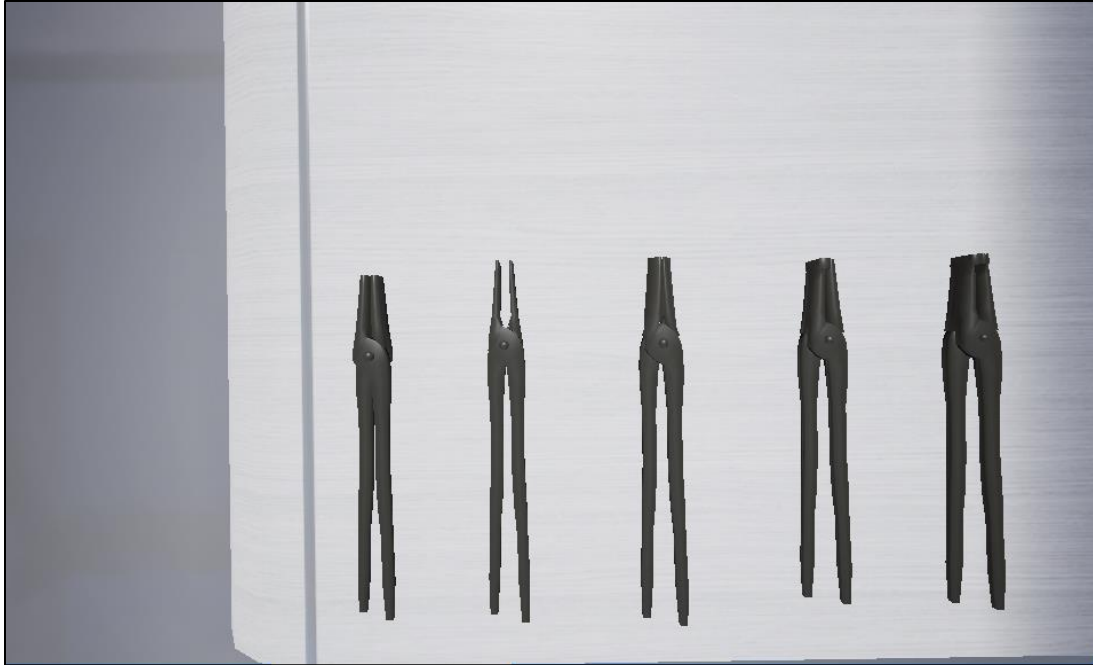

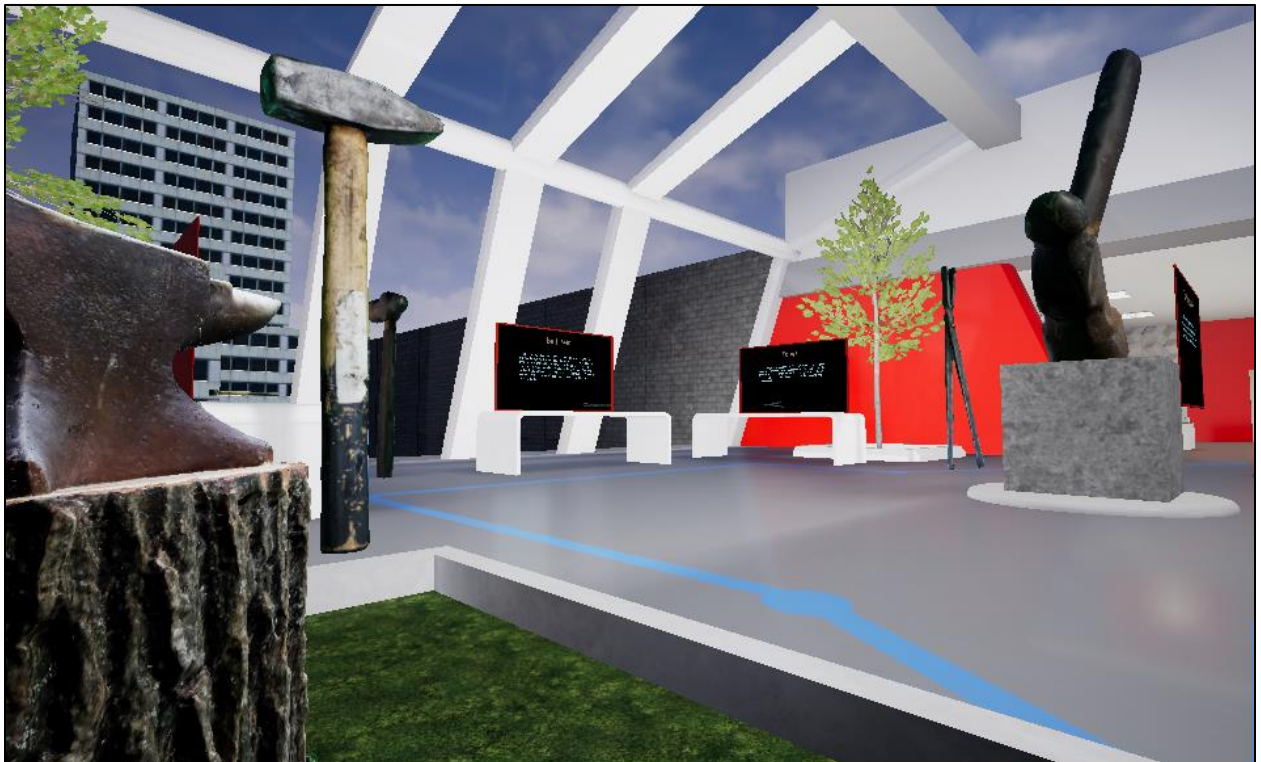A#18: The Starting Menu in the final VR Museum version.

A#19: A view of the Hub from the starting location of the player in the final VR Museum version.
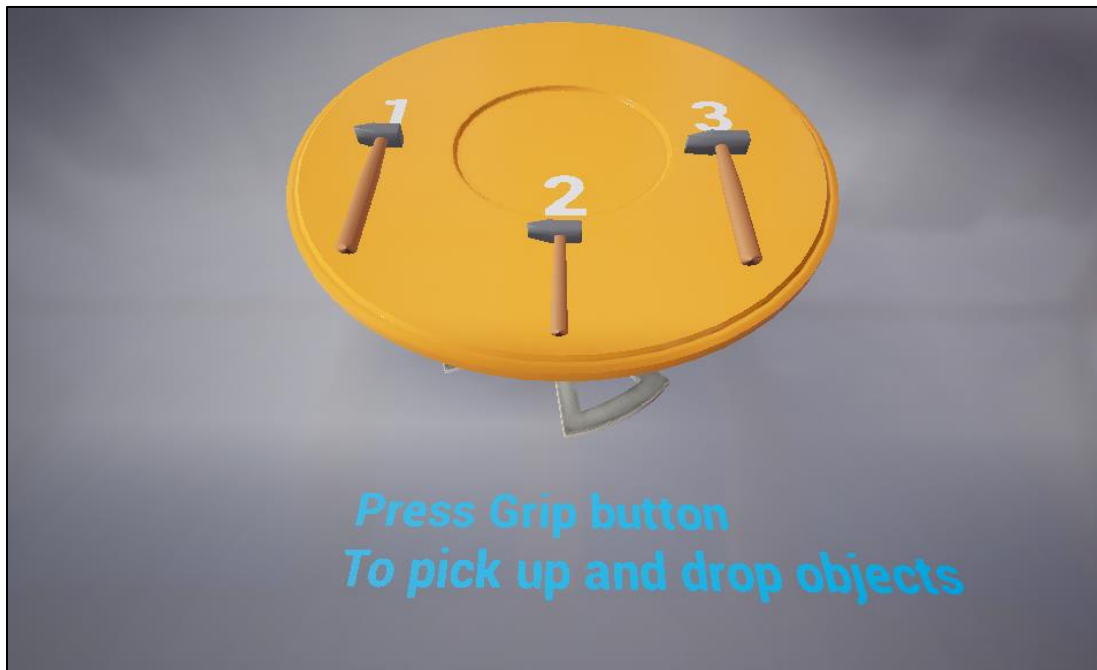
A#20: The hammer models made for this project in Section 1 Room 1 in the final VR Museum version.

A#21: The models of tongs made for this project in Section 1 Room 2 in the final VR Museum version.

A#22: Section 1 Room 3 exhibiting the photogrammetry models made for this thesis in the final VR Museum version.

A#23: A long hallway in Section 1 showcasing blacksmith-themed artwork from the Cleveland Museum of Art in the final VR Museum version.
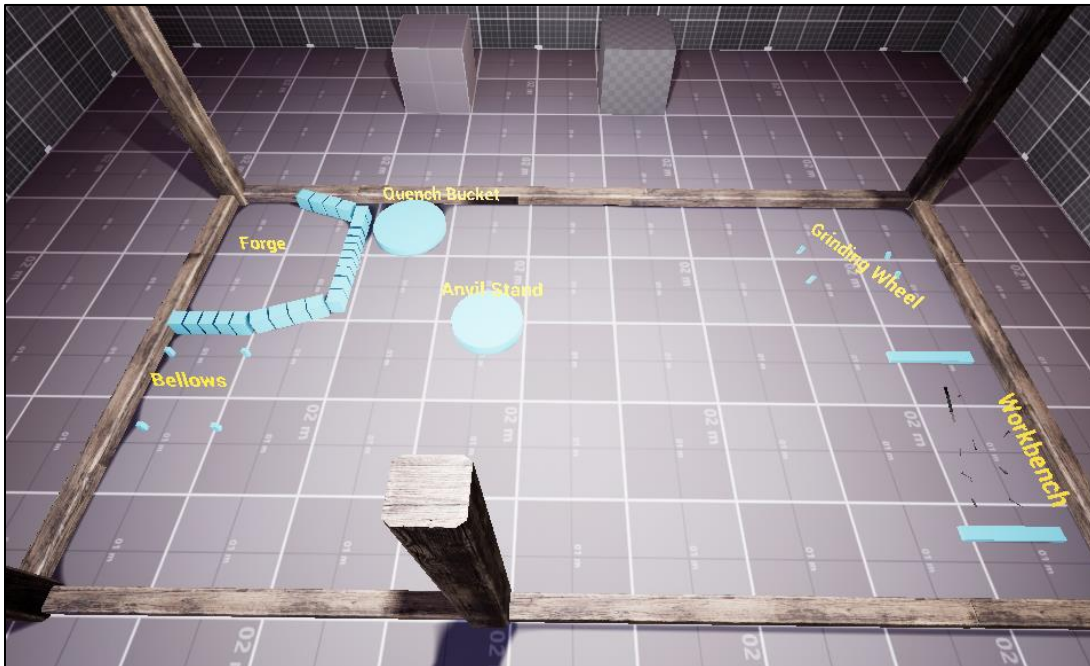
A#24: The illustration of a plan map in VR of a blacksmith shop in Section 2 in the final VR Museum version. The blocks at the back of the room are one meter square.

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A#25: A view from the player starting location in Section 3's forest map in the final VR Museum version.

A#26: The reconstructed blacksmith shops in Section 3 in the final VR Museum version. The open-air shop is on the left. The shop based on the Griswold Shop is the smaller one at the front right. The larger stone shop at the back right is inspired by the Fort St. Joseph, Ontario shop's layout. The fenced-in area straight back is the location of the teleporter and website signs in Section 3.

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A#27: Inside the larger stone shop, with a sign about work spaces in a blacksmith shop visible. The sign has an Answer button that players can click to reveal the answer to a question posed on the sign.
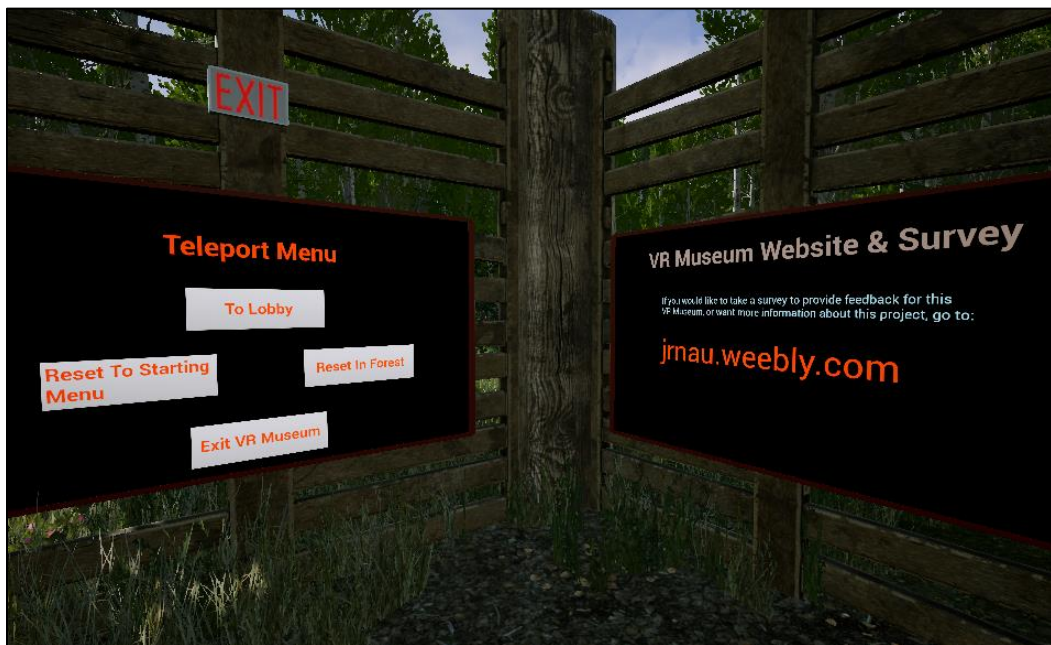
A#28: A view of the teleporter and website signs in Section 3. Buttons on the teleporter sign can be clicked by the player to send the player to different locations of the VR Museum or to exit the program.

APPENDIX B

TEXT APPEARING IN THE VR MUSEUM

This appendix contains all the text that appears in the VR Museum.

Section 1 Room 1:

Blacksmithing Hammers

While today there are many different hammer designs for various uses and traditions, the cross pein hammer is perhaps the most recognizable blacksmith hammer.

On the table are three cross pein type hammers. One is based on a Norse artifact. The other two hammers are modeled after modern hammers.

Can you identify which of the three hammers is the Norse artifact? The answer is on the back of this sign.

The Norse Hammer

Hammers 1 and 2 are both modern cross pein hammers.

Hammer 3 is the Norse hammer.

The wedge that forms the cross pein shape of the hammer is offset to the lower side of the Norse hammer. The modern hammers move this to the center, which places the cross pein in the center of the hammer's mass to more effectively move the metal being hammered.

Because Norse hammers have a cross pein, it suggests Norse blacksmiths used similar techniques as modern smiths. Understanding past techniques helps experimental archaeology, where artifacts are reproduced by modern blacksmiths.

Hammer Handles

The models of the two modern hammers used actual dimensions taken directly from their original samples.

The same could not be done for the Norse hammer's handle. This is because the wood handle was not preserved with the hammer head artifact. Sizes of handles can be correlated to hammer head size, but lengths of handles are a matter of personal preference of the blacksmith.

Aside from wood, can you think of any other materials that may not preserve alongside associated artifacts that limits reconstructions of artifacts? The answer is on the back of this sign.

Artifact Preservation

Generally, if an artifact is made from organic materials such as wood, leather, or fabric they will not preserve. Non-organic artifacts such as stone would remain preserved. If an axe is made of stone, the stone of the axe head would preserve while its wood handle would not.

There are exceptions when organic materials do preserve. This includes very wet environments such as shipwrecks or bogs, and very dry environments like deserts.

Corrosion of metal is another factor in preservation. While in the ground for hundreds of years, much of an artifact can corrode to the point that there can be more rust than the artifact itself. If the core metal under the rust remains, then it is still possible to see the general shape and grain structure of the metal.

<u>Section 1 Room 2:</u>

Forges

The forge is the fireplace of the blacksmith shop. In the 1800s coal became the common fuel for the fire instead of charcoal. With the Industrial Revolution, coal was mined extensively, whereas charcoal was more difficult to produce.

Forges were often made of stone walls with rubble and sand filling the middle. The sand would have a pit for the fire, with a tube connecting to the bellows. The bellows pushes air through the tube to feed the fire. Some forges were made of clay and later forges were made of steel.

Bellows designs also varied, with some made from wood. The railroad and farmers had small portable steel forges with built-in bellows or manual-crank fans. Today there are forges with electric blowers and forges that use propane rather than coal.

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Forging Temperatures

Most blacksmithing is done while metal is hot and malleable. There are several temperature ranges of ferrous (iron-based) metal marked by the color of the metal being forged. Typically, forging is done when metal is an orange color. Certain steels require forging within a specific temperature range.

Black Heat ends at 1000 degrees Fahrenheit. The metal may not look hot as it is not glowing but is still dangerous to touch with bare hands. At this heat range some hammer marks can be smoothed out. Actual forging is not done in this range because the metal can fracture.

Red Heat starts at 1000 degrees Fahrenheit with a dull red glow. Until about 1700 degrees, steel undergoes an atomic transformation that makes it malleable so it can be forged into new shapes. It is also in this range that metal is annealed, or de-stressed from being hammered. Steel will also lose its magnetism in this range.

The Forging Range of steel begins around 1800 degrees with a bright red color. It goes through a bright orange color around 2000 degrees. Depending on the steel, the upper limit for forging metal can be from about 2200 degrees to 2500 degrees when it starts to get a yellow color.

The White Heat Range begins around 2100 degrees with a bright orange color. Past the maximum Forging Range of 2500 degrees, the metal will begin to burn. The surface of the metal starts turning to liquid and will start sending off sparks like a fireworks sparkler. At the edge of this range metal can be forge welded. This process joins two pieces of metal as one new piece. The color goes from bright yellow to white as the temperature increases. At 2900 degrees Fahrenheit ferrous metal turns liquid. As a liquid it can be smelted into new metal or cast into molds.

Anvils

Anvils provide a hard surface on which a blacksmith can hammer hot metal into shape.

They are made in various sizes and shapes. Early anvils were not much more than a square block of metal like one of the anvils on this table. The style commonly recognized as an anvil is the London pattern designed in the 19th century. A London pattern anvil is shown in the next room. The large anvil on the left is a German anvil type with a rounded horn on one end and squared-off horn on the other.

Other anvil shapes included the stump or bick anvil like the one at the front left of this table. Stump anvils, tending to be long and narrow, are driven into wood stumps. They are useful for working on odd-shaped pieces where the large flat surface of other anvils would not be suitable.

Tongs

Tongs are used to hold the hot metal that blacksmiths forge. Sometimes a blacksmith can work with metal long enough that it is safe to hold onto the end of the metal. For smaller pieces, tongs are necessary. They let the blacksmith pluck the hot metal from the forge fire and hold the metal while hammering.

Tongs are fundamentally the same regardless of size. The main difference in tongs is how their ends are shaped for holding metal. Metal that is round would not be held efficiently in tongs made for rectangular metal. The tongs on the left side of this table were modeled to be identical except for what shape metal they can hold.

Hammers

These tables represent some of the variety of hammers blacksmiths use, from cross pein, ball pein, rounding hammers, to wooden mallets. Each hammer shape moves metal in different ways. Big hammers can move more metal than smaller ones but can still be used in delicate work. Heavy hammers are not always used because they can be more difficult to control and cannot be swung as efficiently all day.

Wooden Mallets

Wooden mallets like the ones on the far-right table are used for straightening and bending pieces without damaging the hammer-work. The wood can burn slightly, but the soft wood won't damage things like twists. Hammers made of soft metal, like brass, are also sometimes used for gentler hammering or to be used with other tools such as chisels and punches. It matters less if a wood or brass hammer face gets damaged.

Sword Production

The right side of this table has a rectangular bar with a tail, and a sword. These are the beginning and end of forging a sword. The starting metal is dawn out to a rectangular shape for the basic sword shape. A tail is forged on one end for the handle. Then the tip is forged to a point.

A smith had to forge as closely to the finished sword shape as possible. Prior to modern electric tools, grinding and polishing swords to the final shape was a lot of work. The grinding wheel to the right had to be turned with a crank by hand. Other grinding wheels had foot pedals. The hanging bucket is for water to help metal cool from friction on the grinding wheel.

After the sword was shaped, it had to be tempered. Tempering releases stress on the metal accumulated from hammering and makes the metal hard enough to maintain its sharp edge. Sometimes the inside and edges of a sword would be made of different steels and tempered

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differently so that the inside is more flexible. When the forging work is complete, the tail is put through the wood handle.

Section 1 Room 3:

Photogrammetry

All the blacksmithing objects in this room were made with photogrammetry. This process involves taking digital photographs of real objects. Software then analyzes these images to calculate a 3-dimensional model of the object.

Mousehole Anvil

Introduction Button: Mousehole Anvil

This is a London-pattern anvil made by Mousehole Forge in England. It dates to around 1840.

The base and middle block of the anvil were forged as one large piece with a mechanical hammer running on water wheel power. The horn and steel face on top were forge welded on. The steel face provided a harder layer to work directly upon compared to the softer iron of the rest of the anvil.

Photogrammetry Button: Photogrammetry of the Anvil

To make this model photographs were taken in a circle around the anvil and stump to be used for photogrammetry. Software analyzes where the photographs were taken in relation to one another. Then the software matches many points between the images. The points, or vertices, are connected to make a solid model made up of triangles. Then the photographs are overlaid on top of the model.

Number of Photographs Used: 101

Number of Triangles: 874,079

Number of Vertices: 2,119,221

Hundredweight Button: Hundredweight System

The Hundredweight System was a measure of mass formerly used in Britain. The first number is the hundredweight, where 1 hundredweight equals 112 pounds. The second number is

how many quarters of a hundredweight, at 28 pounds per quarter. The last number is a simple count of left-over pounds. Together, they add to the total weight of the anvil.

The anvil is marked 1.3.6 on one side. This number indicates the weight of the anvil in the English Hundredweight system. This translates to 202 Lbs. or 92 kg. Heavier anvils are harder to transport but makes forging work easier. Good anvils provide a bounce with hammer blows that also makes forging easier for a blacksmith.

Parts of an anvil, Feet Button: Anvil Feet

The feet are part of the base of the anvil. The ends reach outward to help balance the mass of the anvil. The narrow ends could be held down by hooks hammered into the stump to help keep the anvil from moving while hammering heavily on it, as indicated by scarring in the metal on two opposite corners.

Parts of an anvil, Neck Button: Anvil Neck

The middle of the anvil is the neck and where the markings are. On the front and back of the neck, as well as the bottom of the base, are small square holes. These holes give this anvil brand its name – Mousehole. These holes are where giant tongs would be used by several blacksmiths to hold the anvil block while it was being forged.

Parts of an anvil, Horn Button: Anvil Horn

Anvil horns sticking out the front are one of the key features of a London Pattern anvil. Horns provide a surface on which metal can be given curved bends or hook shapes. Even when not bending metal around the horn, working metal on a horn moves the metal in different ways than a flat surface which a blacksmith can utilize.

Parts of an anvil, Step Button: Anvil Step

The step is the small flat space at the base of the horn. This area provides a secondary flat working surface on the anvil. The step has a softer surface than the steel plate of the main face.

Steps are sometimes used as cutting surfaces, but this is not a best practice as it damages the anvil. Softer metal plates, such as copper, can be fitted over the step to protect the anvil from being damaged.

Parts of an anvil, Face Button: Anvil Face

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The face of the anvil is the large flat surface on top. This is the main work area of an anvil. On some anvils this was their only work area. The face of this anvil is not completely flat. The center of the face, where most work would be done, has worn down from continued use by blacksmiths.

The edges of the face are rounded rather than sharp right angles. Sharper edges can leave marks in the metal being worked. Since sharper edges have their uses, some anvils will have a combination of rounded edges in the center and sharper edges in less used areas.

The face of this anvil is kept polished because pits and rust could leave marks in worked metal. The photogrammetry process does not work as well with such shiny surfaces and left the face looking rougher than it really is.

Parts of an anvil, Heel Button: Anvil Heel

The back end of the anvil face is the heel. Some forging work is done on the heel if the shape makes it easier. On a London-pattern anvil like this one, the main features of the heel are the hardie hole and pritchel hole.

The hardie hole is the square one. Various tools can be made to fit into the hole. One such tool is a kind of chisel that sits in the hole, leaving a blacksmith's hands open to hold the metal being cut and a hammer to strike from above the hardie.

The small round hole is the pritchel hole. This is a multi-purpose hole. Tools can be made to fit the pritchel hole. Pritchels are also used when punching holes through metal.

Cross Pein

This is a large modern-made cross pein hammer. Although there are other handle materials used for modern hammers, wood is still used for blacksmithing hammers. Some materials would be too likely to melt when touching hot metal. The wood handle of this hammer has burn marks where hot metal has accidentally touched it, but otherwise remains intact.

This hammer is on the large side but has been in use as a primary forging hammer. The hammer head weighs about 2.2 lbs. The average weight for primary forging hammers is 2 lbs. Occasionally it must be reground to shape due to deformation of the cross pein end or pitting in the hammer face.

Ball Pein

This ball pein is modern-made, but dates to somewhere in the middle 1900s. The wood handle has darkened with age. The main feature of this kind of hammer is the ball shape at one

end. This moves metal radially – in all directions at once. The other end with the hammer face is round and slightly domed. Pitting is visible along the sides of the hammer head. This is partly caused by rust.

Tongs

These tongs were hand forged. They are not old but made by a modern blacksmith. These tongs feature a "touchmark" of the craftsman who made them located just below the domed rivet on one side. Notches are set into the tips of the tongs to help hold hot metal.

Section 2:

Cutaway of A Blacksmith Shop

This room depicts a blacksmith shop reduced to a couple features that could be found archaeologically. This shop is reproduced in full in Section 3's forest. The blue shapes represent features that could leave traces to be found archaeologically and correspond precisely to objects in the reconstructed blacksmith shop.

The wood beams designate the walls of the shop.

Grids

The room's floor and walls feature meter scale grid. The cubes at the back are each 1 meter in size. A basic unit of excavation in archaeology is a meter square. Where building interiors are being excavated, a grid of ropes is sometimes placed to designate meter square zones even when the whole interior is excavated. This helps to record precisely where features or artifacts were found so that the data can be analyzed later.

Identification of Features

Sometimes a feature such as a forge can be identified by stone remnants left behind. The whole forge may not remain intact, but the outline of a forge may—represented by the blue cubes. It also helps to compare the locations of features.

A bellows, for instance, would be expected to be found next to the forge. The leather and wood of the bellows would not preserve, but stains in the soil from posts holding the bellows up may remain—represented by the four blue markers next to the forge. When digging, archaeologists must look for changes in soil colors and textures and note their location, shape,

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and depth. The anvil stand is another feature that would be expected near the forge and could leave soil stains.

Other features could leave behind metal debris. If the quench bucket was left behind when the shop was abandoned, the wood may leave staining. It could also leave behind the metal rings that hold the wood together.

The workbench could be identified by proximity to windows, which would be located by windows glass fragments. Workbenches could leave staining in the soil. Metal debris would also be expected beneath the workbench. This is an area that may have been cleaned less. The type of metal debris can be different from one location in the shop to another. Soil analysis can determine the amount of iron in the soil, expected to be higher around the anvil and workbench.

Section 3:

The Blacksmith Shop

Blacksmith shops are highly variable architecturally. They can be open air or closed within walls. However, there are certain features common to most shops.

Explore the reconstructed blacksmith shops in this forest to learn more about the identification of spaces archaeologically and how these spaces were used.

Open-Air Shops

Not all blacksmith shops are enclosed buildings. Shops open to the air provide good ventilation and are simpler to construct. While open-air shops can be nice in the summer to let breezes through while standing next to a hot forge, they would not be as desirable in certain climates. Some shops have walls that open in addition to the main doors to help with ventilation.

One of the disadvantages of open-air shops while forging is that they can let in too much light. Although workbenches tend to be near windows for accessibility to light, anvils are often in darker areas. Blacksmiths depend on seeing the color changes of hot metal to know its temperature. If there is too much light, it can become harder to accurately see the color of the glowing metal.

Window Glass

Window glass can be differentiated from bottle glass by being clear and flat.

Finding window glass fragments near remains of a wall can indicate where windows were.

In a blacksmith shop, windows are most important near the workbench to provide good light. In this shop, most of the windows are concentrated around the workbench.

Shop Floors

Floors of blacksmith shops must take into consideration hot metal being dropped. Some shops, like this one, had dirt floors. Other shops had stone floors. Or, like the one next door, they had wood floors despite the potential to catch fire from hot metal being dropped.

Workbenches

Workbenches provide a space where a smith can work with small parts and files.

Workbench locations can be identified by three things:

1. Workbenches tend to be placed near windows. If a shop has windows concentrated in a certain area of the shop, that is likely where the workbench will be found.

2. Workbenches have wooden legs that may leave post molds in soil being excavated. These post molds look like dark stains in the shape of the post. If more than one post mold is found, distance between the post molds can be measured to determine workbench size.

3. Small metal parts and shavings from filing can be found beneath the workbench that indicate the kind of work done at the workbench.

Spaces in a Blacksmith Shop

There are four spaces in a blacksmith shop that can be identified archaeologically.

1. Work Space - this is where the blacksmith works on forging or repairing items.

2. Domestic Space - this is an optional space, depending on shop size and function, where the smith can take meal breaks or meet with customers.

3. Storage Space - this is where the metal stock and extra tools were kept.

4. Refuse Space - the contents of this space can include remains of meals, scrap metal, and clinkers (waste byproducts of the forging process).

1. Work Space

This space consists of a forge, anvil, workbench, leg or post vise, and other equipment in active use for the blacksmith's work.

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The work area can be identified archaeologically by remains of the stone forge and soil stains left by wood. It also has a higher concentration of iron in soil.

Do you see any objects in this work area that could preserve, and would identify the space as a work area, but still not be found in an archaeological excavation of this shop?

Work Space, Answer Button

The metal tools could preserve. However, it is uncommon to find them in an abandoned blacksmith shop. Tools such as the anvil and vises would be removed at the time the site was abandoned. If a tool was not broken, it can be re-used in another blacksmith shop.

2. Domestic Space

Domestic space in this shop consists of a table with chairs, a cabinet in the back corner, and a small furnace.

Sizes of the domestic space varied from shop to shop. Some shops do not have any dedicated domestic space. Other shops were adjoined to larger secondary rooms.

3. Storage Space

This corner and a loft area are dedicated to storage space in this blacksmith shop. Other corners in this shop are also used as small storage spaces to minimize wasted space.

Included in this storage space is an extra tool. It is a stump anvil, ready to be moved into the work space when needed by the blacksmith.

4. Refuse Space

Refuse space is represented by coal on the ground next to this blacksmith shop. Another refuse space is behind the stone shop with a large pile of coal and other material mixed in.

Analysis of refuse space material can reveal more than just what kind of fuel a smith used for their forge. Other refuse can include food remains, showing the diet of the blacksmith. A smith could also have thrown out forged items in these spaces deemed to be too broken to be salvageable.

There can also be several small refuse spaces within the blacksmith shop. These spaces can include debris the smith has not cleaned out yet. These spaces can also contain the forged items that a blacksmith has set aside to attempt repair or to salvage raw material later.

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In an active shop, the smith may also put aside hot metal in these areas to let them gradually cool. Go inside the stone shop and look under the bellows for an example.

<u>Other Texts Throughout VR Museum:</u>

Reception/ Lobby Title Sign:

VR Museum

created by J.R. Nau

(On a second sign next to the title sign:)

Blacksmithing and Archaeology

VR Museum Website & Survey

If you would like to take a survey to provide feedback for this VR Museum, or want more information about this project, go to:

jrnau.weebly.com

Cleveland Museum of Art metadata text:

1973_184_Caption:

Blacksmiths, after 1887. Émile Jacque (French, 1848-1912). Oil on fabric; The Cleveland Museum of Art, Mr. and Mrs. William H. Marlatt Fund 1973.184

1921_1444_Caption:

The Blacksmith Shop. Charles-Émile Jacque (French, 1813-1894). Etching; The Cleveland Museum of Art, Gift of Leonard C. Hanna, Jr. 1921.1444

1995_69_Caption:

The Blacksmith, 1771. Richard Earlom (British, 1743-1822), after Joseph Wright of Derby (British, 1734-1797). Mezzotint; The Cleveland Museum of Art, James Parmelee Fund 1995.69

2010_160_Caption:

Study for The Blacksmith's Shop: Remembrance of Le Tréfort, 1854. François Bonvin (French, 1817-1887). Watercolor with gouache and iron gall ink; The Cleveland Museum of Art, Bequest of Muriel Butkin 2010.160

Directory:

Section 1

A series of rooms introducing blacksmithing and archaeology.

Section 2

A room of grids showing archaeological features in a 3D plan map.

Section 3

Teleporter to a forest with several reconstructed blacksmith shops.

Reset to Beginning

This button will reset the VR Museum to the beginning of the lobby.

Reset Button

Reception/ Lobby tutorial sign text for navigating VR Museum:

Follow arrows and lines

on the floor to progress

EXIT signs lead back

to this reception hall

Reception/ Lobby text on reception desk suggesting where to go next:

Go to Section 1

For the 1st activity

Reception/ Lobby tutorial text on reception desk

Try picking up some objects

With the grip button

Tutorial text by tables with objects:

Press Grip button

To pick up and drop objects
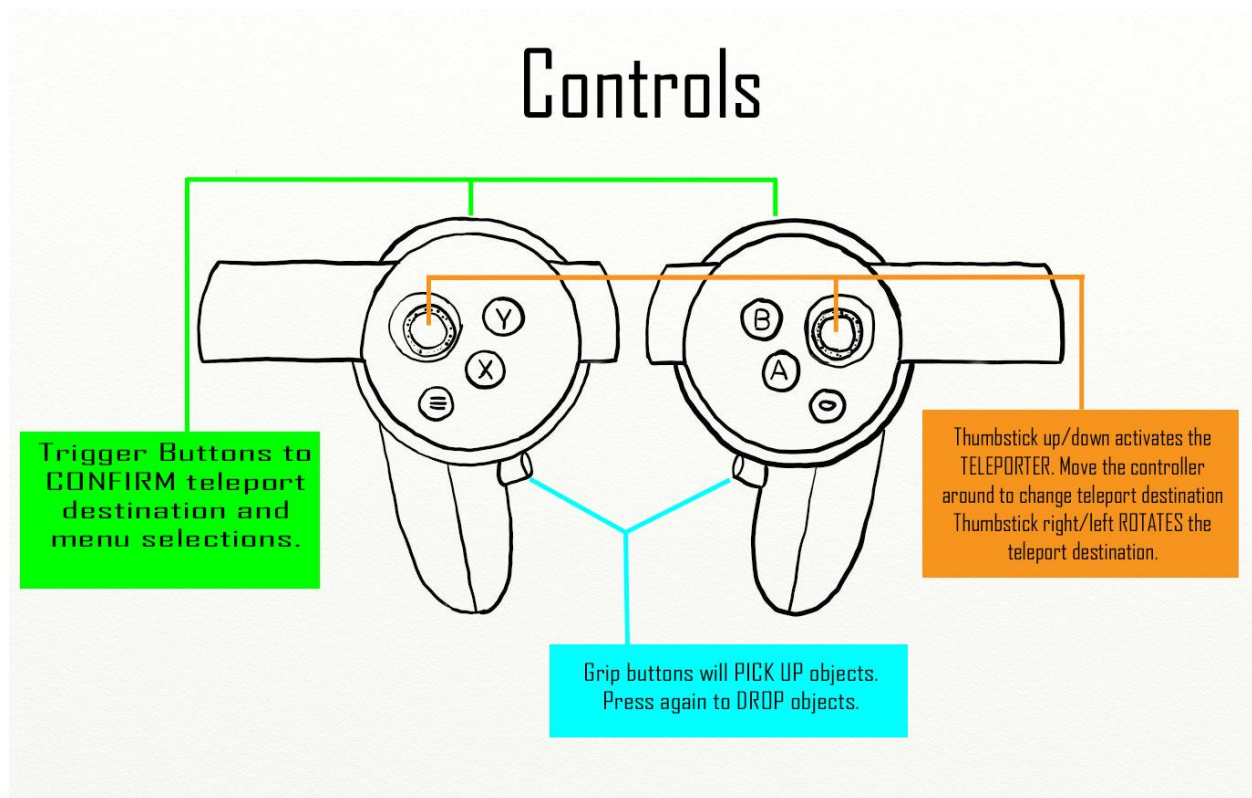

Tutorial text by signs with scrollbars:

Aim at scrollbar

Hold trigger and move to scroll

Tutorial text by signs with buttons:

Aim at buttons

Press trigger to click

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VR Controls:

Controls

Trigger Buttons to CONFIRM teleport destination and menu selections.

Thumbstick up/down activates the TELEPORTER. Move the controller around to change teleport destination Thumbstick right/left ROTATES the teleport destination.

Grip buttons will PICK UP objects. Press again to DROP objects.

APPENDIX C

LIST OF SOFTWARE AND CONTENT USED FOR THE VR MUSEUM

This Appendix contains a list of the software and Unreal Engine Marketplace content used, and a

list of artwork from the Cleveland Museum of Art featured in the VR Museum.

Software used:
- Unreal Engine 4
  - Epic Games
- Blender
  - Blender Foundation
- 3DF Zephyr Lite Steam Edition
  - 3Dflow SRL

Epic Games sample content:
- Blueprints
- Content Examples
- Scifi Hallway
- Water Planes

Unreal Engine Marketplace content used:
- Analog Ambience Collection
  - Voltz Supreme
- Artisan Tools Pack
  - SvitchMark
- Cheap Ambient Lighting System
  - Ben Burkart
- Customizable Grid
  - Zaroa.net
- GameAnalytics
  - GameAnalytics
- GameTextures Material Pack
  - GameTextures.com
- Medieval Armory
  - DM Studio
- Medieval Blacksmith Workshop
  - Pixel Legend

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- Medieval Craftsman Tools
  - Brock Amundson
- Modular Fantasy House
  - Next Level 3D
- Procedural Nature Pack Vol. 1
  - PurePolygons
- QA Office and Security Room
  - QAtmo
- Scanned Poplar and Aspen Forest with Seasons
  - Tirido
- Sci-Fi Doors Sound FX
  - IndieGameModels
- VR Integrator Radial and Dockable Menus
  - W3 Studios
- Wood and Wood Floor Volume 1
  - Plan B Studios

Cleveland Museum of Art attribution and metadata text:

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