

**Virtual Cultural Heritage: Virtual Reality Navigation of Cultural
Heritage Environments**

A Thesis

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by

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Dedications

This thesis work is dedicated to my grandparents, Eugene and Dolores Petrovich. Your support and love mean more than you can ever know. I know he would have been proud.

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Virtual Cultural Heritage
Virtual Reality Navigation of Cultural Heritage Environments
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With the plethora of digital devices that can provide information about almost anything anywhere the Virtual Cultural Heritage project implements a prototype for the integration of personal computers and off the shelf new media accessories functioning in concert in order to deliver cultural heritage information. The virtual experience is navigated through the use of Microsoft Kinect motion control technology, integrating both gesture recognition and full body control, giving an element of realism and control previously not available in VR simulations. The interactive VR environment explores the possibilities of Le Musée Imaginaire, or the Museum Without Walls. The short-term goal is to draw upon scholarly research in areas of history and archaeological interpretation in order to distribute that knowledge to a general public in a non-traditional, engaging and entertaining manner. The long-range goal is to develop collaborative interdisciplinary projects that explore developing technologies and their new media applications in matters of cultural heritage, education and tourism.

1. Introduction

1.1 Introduction

Today Philadelphia's Delaware Riverfront contains vestiges of prehistoric land use and early European settlement patterns, as well as remnants of America's colonial, post colonial and industrial periods. The ongoing research and excavation of these valuable resources shed light on our cultural heritage. PennDOT's I-95 highway expansion project parallels the Delaware Riverfront and the archaeological excavations being conducted by AECOM as part of the construction process have revealed valuable cultural heritage information not often found in history books [1]. The allure of these archaeological sites extends beyond the interests of professional archaeologists to researchers, curators, amateur archaeologists, and educators and their students. Neighborhood residents including the young and old, teachers, professionals and the curious living near the archaeological excavations have turned out in large numbers at annual events¹ sponsored by PennDOT to view recovered archaeological artifacts and to speak with AECOM archaeologists about the significance of the finds. The grass root appeal demonstrates public interest and an appetite for accessible information on cultural heritage topics.

To expedite communication about the archaeological sites and their interpretation among professional communities and to satisfy and further encourage cultural heritage interest and understanding among people living in and beyond the immediate vicinity of archaeological sites along the Delaware River, PennDOT agreed to accept a technical report for the I-95 project as a trial format in a publicly accessible digital

¹Annual public outreach events hosted by PennDOT and AECOM are as follows: "Before and Below I-95 in 2014" (2014), "Before and Below I-95 in 2013" (2013), "Digging the City" (2012), and "Before and Below I-95: Archaeological and Historical Discoveries 2011" (2011).

media platform. Platform requirements included 1) enabling archaeologists to post reports and share information with other professionals and to facilitate research and communication among researchers and agencies, and 2) easily make available a wide array of information including reports, maps, images and interactive 3D models of recovered artifacts to the general public.

As an employee of AECOM, I worked as an Interactive Media Specialist to design and implement the Internet based media platform. The media platform, dubbed “the I-95 Archaeology Smart Reports,” provides timely digital information, as it becomes available, to both professional communities and the public. The platform enables professionals to analyze and interpret data, while allowing the public to follow the archaeological process as it is unfolding in their neighborhoods. This innovative educational approach seeks in part to better inform the public and to encourage public support for future archaeology projects. This new digital form of publication and outreach represents a major shift from the recent analog past when a report was published usually aimed at professional audiences only and only after the project and analysis had been completed. The current iteration of the ongoing project is available to the public at <http://diggingi95.com/> as seen in Figure 1.1.

Beyond my employment, as part of my master’s thesis project I sought to further the possibilities of the digital report by using off the shelf new media technologies to further encourage involvement and enhance the experience of home visitors to the Internet site. In this age of ubiquitous media my research project explores the feasibility of creating a personal Virtual Museum using commercially available gaming hardware [2]. The growing popularity of inexpensive motion capture software like the Microsoft Kinect used in combination with a web browser makes it possible to transform static web pages into dynamic virtual reality experiences. In the case of cultural heritage it is now possible to realize “Le Musée Imaginaire,” or the “Museum



Figure 1.1: Homepage of the Digging I-95 website.

Without Walls” experience described by André Malraux in one’s home or anywhere the appropriate equipment is available.

Malraux claimed that the history of art had shifted from the halls of the classical museum to “that which can be photographed” [3]. During the eighteenth century when the discipline of the aesthetics or “fine arts” was being established, the focus of art was much narrower. Fine arts only referred to European art from the Renaissance onwards, plus a selection of Graeco-Roman works, though over time art from all cultures and across all time periods have been accepted under the heading of Fine Arts [4]. While these additions mold a more diverse art museum, it also creates issues of adaptability and access. Art is no longer confined to easel and canvas, and is therefore at times no longer easily transportable. Even those pieces that can be easily transported may not be available at one museum or another. Artwork from around the globe does not necessarily offer global accessibility. While the global collection of artworks surpasses the capacity of any one museum, Malraux coined the term *Musée Imaginaire*, to define the imaginary collection of all the artworks that we regard as

important [4].

Malraux was quick to acknowledge that the Musée Imaginaire is unique to each individual, as it is the ideal art museum that we carry in our minds. Malraux saw photographic reproduction as vital for the dissemination and appreciation of art while admitting that reproductions would never replace the original or eliminate the role of museums. Our individual ideal art collections are always part of our larger history and our unique understanding of art. However, the concept of personalized collections does not originate with Malraux. Sometime between the 14th and 16th century, the time of the European Renaissance, there developed a growing desire among the peoples of Europe to place mankind accurately within the grand scheme of nature and the divine [5]. This desire cultivated with the development of Wunderkammer. These Wunderkammer, Cabinets of Wonder, wonder-rooms, or Cabinets of Curiosity were often collections of rare, valuable, historically important or unusual objects, which were generally compiled by a single person for study or entertainment. Wunderkammer were small private spaces, created around a deeply held belief that all things were linked to one another through either visible or invisible similarities. Individuals believed that by detecting those visible and invisible signs and by recognizing the similarities between objects, they would be brought to an understanding of how the world functioned, and discover humanity's place in it [5]. Eventually these cabinets were absorbed into larger collections, often the collections of royals or nobles. The once small cabinets grew into collections that occupied entire rooms. These would then become institutionalized, leading to the development of public museums [5].

In terms of my thesis project, Malraux's Museum Without Walls is realized and expanded upon in several ways. In the virtual museum, we are our own curators. No two visits to the museum are the same, as there are no set paths that we must follow. Artifacts presented digitally have the ability to span cultural, chronological, and

geographical boundaries. In a physical museum there are many barriers that prevent objects from existing in the same space both in past and present. Finally, the virtual museum presents the largest storage possibility of any museum in existence. While storage space may never be infinite, virtual storage could hold the equivalent of several museums in a single room, or perhaps a single hard drive. This project's virtual museum presents updated solutions to the issues that spurred Malraux towards the creation of the Museum Without Walls.

Though my thesis project is modeled after the 3D interaction provided by the I-95 Archaeology Smart Reports, this project elaborates on and enhances several key areas of functionality. The project encourages greater engagement with the digital materials. It facilitates the use of more natural body controls as opposed to the use of a traditional keyboard and mouse. The number of available 3D interactive artifacts has been increased from two currently offered on the website² to 60 artifacts offered through the thesis project. The addition of an information pop-up for and with each artifact will enable users to view all relevant information in a single contained space instead of across multiple Internet pages. Initially the project was designed for integration within the existing website, however both technical restrictions and required permissions from the client have pushed this outside the scope of the current project. Future iterations of the website will seek to integrate this thesis project to facilitate access to a larger collection of artifacts and will also enhance the visitors' interactive experience.

²The Digging I-95 website has undergone several revisions and this original interactive artifact number holds true for the initial site launched in 2013. As of 2015, artifacts have been added and removed. The interactive artifact total as of March 2015 was three, with additional 3D artifacts available in pre-rendered video format.

1.2 Historic Background

European settlement along a section of the Delaware River known to Native Americans as Shackamaxon, “the meeting place of chiefs,” and presently known as the neighborhoods of Kensington-Fishtown, began with a wave of Swedish settlers in 1637 [6]. William Penn arrived 45 years later with land title to some 45,000 square miles granted to him by England’s King Charles II. Shackamaxon is the place where William Penn and Chief Tamanend signed the famed “Penn’s Treaty” in 1683 [7].

William Penn’s plan was to parcel off his land grant in 5000 acre plots, though the plots were later sold in much smaller increments. Some of the larger parcels became towns in their own right [6]. Kensington was formed after Anthony Palmer purchased a tract of land from Thomas Fairman in 1730. Palmer named the area after Kensington Palace in England [8]. The Kensington riverfront attracted shipbuilders and fishermen, who settled around the Gunner’s Run area and developed livelihoods based on the Delaware River [8]. The Kensington area thrived as industry expanded, enterprises included I.P. Morris Company (1828), a machine-building company, the Cramp Shipyard (1830), and Dyottville Glassworks (early 1830s) [9].

Following the advent of steam power in the 1830s, Philadelphia County which included the city of Philadelphia and surrounding towns of Kensington, Port Richmond, and Northern Liberties, underwent radical change as the Industrial Revolution gained momentum [10]. By 1838, a railroad from Reading to Philadelphia was completed to transport coal into the city [11]. In addition, a tidewater facility was installed along the Delaware River in Port Richmond to facilitate the movement of coal up and down the Atlantic seaboard [11]. By the 1850’s the Pennsylvania legislature declared all of Philadelphia County to be within the city limits of Philadelphia. Through the utilization of the Delaware River and its surrounding resources the city of Philadelphia became a major US industrial and economic center, and in fact a major world

industrial center. Following the American Civil War, Philadelphia was known as the “Workshop of the World” and due to its substantial industry, proudly boasted the title well into the 20th century [12].

1.3 The I-95 Highway Expansion Project

PennDOT is working on a long-term, multi-phase infrastructure initiative to improve and rebuild I-95 in Philadelphia including approximately eight miles of I-95 between I-676/Vine Street and Cottman Avenue [13]. The project is broken into five sections, with AECOM focusing on I-95 Section GIR, the Girard Avenue Interchange. Section GIR includes the rebuilding of three miles of Interstate-95 from Race Street to south of Alleghany Avenue and the reconstruction of the interchange at Girard Avenue in Philadelphia [1]. Section 106 of The National Historic Preservation Act of 1966 requires all federally funded agencies to undergo a review process when work could impact sites listed on, or with the potential to be listed on, the National Register of Historic Places [14]. To successfully complete Section 106 reviews, federal agencies must: 1) Gather information to decide which properties in the area that may be affected by the project are listed, or are eligible for listing, in the National Register of Historic Places (referred to as “historic properties”); 2) Determine how those historic properties might be affected; 3) Explore measures to avoid or reduce harm (“adverse effect”) to historic properties; and 4) Reach agreement with the State Historic Preservation Office/Tribal Historic Preservation Office (and the Advisory Council on Historic Preservation (ACHP) in some cases) on such measures to resolve any adverse effects or, failing that, obtain advisory comments from the ACHP, which are sent to the head of the agency [15]. Section 106 reviews do not give full approval or denial of projects, however they ensure that federal agencies consider historic preservation issues and the views of the public during project planning [14].

Required archaeology is being performed by AECOM, based out of the Burlington, New Jersey office. Archaeology is being performed to record Philadelphia's historic waterfront through scientific excavation and research. AECOM's area of potential effects was approved in 2001, with archaeological investigations beginning shortly after. Investigation in the GIR section is broken into six sections, from GR0 to GR5. While GR0 construction began in 2009 and completed the following year, sections GR4 and GR5 won't begin construction until at least 2018 and 2020, respectively [1]. While working on 20 pre-contact and historic sites, AECOM has recovered over 1,000,000 artifacts. In order to provide real time updates to both clients and the public, AECOM established the I-95 Archaeology Smart Reports [16].

1.4 AECOM Interactive Website

The AECOM I-95 Archaeology Smart Reports is a web-based application, accessible at www.diggingi95.com. The system makes information available that was previously accessible to only a select number of individuals and government agencies. By improving upon limitations of print reports information is made available faster than ever before. This format offers the public greater access to heretofore privileged information and encourages customization of content delivery and levels of interaction. Each digital report available on the website is accompanied by galleries of varying types, which include artifact photos, photos of excavations, as well as historic maps and photos. The galleries are not limited to still images, they often contain video of excavations or monologues by professional archaeologists. In addition, using their mouse, visitors to the site are able to inspect and manipulate 3D rendered artifacts as demonstrated by Figure 1.2. Also available are interactive maps, which show ongoing archaeological excavations as well as completed excavations that were conducted along Philadelphia's Delaware Riverfront as part of PennDOT's I-95

expansion project. The interactive maps are supplemented with georeferenced historic maps to demonstrate changes in land use over time. The digital report system is intended to provide interactive experiences in which visitors can explore cultural heritage artifacts and information of their own choosing.



Figure 1.2: Web-based 3D Interactive accessible from the Digging I-95 website.

My role in the creation of the digital platform involved the overall design, implementation of requested features, and population of content. Technical reports produced for AECOM clients represent a significant portion of the final deliverable product. For this reason, senior project staff have the final say in the material and information present in the end report. My input on the design was taken into consideration, but final approval was given by a supervising designer and archaeologists. In addition a list of features and functionality was requested regularly in the production

process. I was responsible for the research and design, but final approval came from members of the archaeological team. Archaeologists and historians also provided all content and had final say on its organization and upload date.

1.5 The Virtual Cultural Heritage Project

The goal of my thesis project is to demonstrate the feasibility of an in-home Virtual Museum, comprised of commercially available hardware and open-source software. The project utilizes emerging digital technologies to assist an agent in expanding his/her understanding of specific time periods, historic, and prehistoric artifacts. The project is based on current understandings of the role media plays in our daily lives and of virtual cultural heritage and exhibition. It seeks to make a contribution to the emerging field of digital cultural heritage by leveraging the artifacts recovered by AECOM and implementing the techniques of 3D scanning [17]. The project creates an inventory of cultural heritage artifacts that enhances accessibility of these assets enabling interested parties, their families and friends to virtually interact with the artifacts in the comfort of their own homes. The hardware portion of the project relies on the Microsoft Kinect, enabling users to control the Virtual Reality experience. Users use their bodies rather than a mouse or keyboard to scale, rotate and manipulate artifacts.

In general Virtual Reality experiences take place within a simulated environment, which can range from simplistic mock-ups to brick for brick recreations of physical sites. These can be visualized as the emptiness of the “Armory” in the Matrix, or the lush tropical environment projected within the Holodeck from Star Trek. These techniques have been incorporated in virtual cultural heritage projects such as the ACE (Armadillo Control Extensions) Viewer and the VT (3D Virtual Tour of Petra) [18, 19]. This project relies on visual simplicity, and a notion of x-reality where lines

between a virtual and a physical lines are blurred, this negates the idea of a totally immersive virtual world [20]. The methods used in this thesis are more suitable to the capabilities of a web based virtual reality delivery system that can easily be used at home. Agents may utilize motion controls provided by the Kinect to inspect virtual cultural heritage artifacts associated with specific historically significant sites. Once properly calibrated, Kinect hardware enables operators to use body movements as if interacting with an object. For example, using a grasping motion an operator can simulate holding a virtual object and rotate the object as if it were in his physical hands. The interface has the potential to go beyond physical world experiences including scaling of objects in virtual space. The project is a manifestation of an x-reality, a continuum between the physical and the virtual world [20]. Malraux's concept of an imaginary museum formulated over half a century ago, has been greatly augmented by an understanding of "living in media" and with technologies that allow us not only to see and collect, but to experience and interact with objects and contexts from a different time and place [2, 21]. Malraux's idea of an imaginary museum may have been influenced by German philosopher Walter Benjamin, as he had been reading Benjamin's famous essay concerning the consequences of photographic reproductions of art. Benjamin's essay, "Art in the Age of Mechanical Reproduction" acknowledged the disappearance of the aura and authenticity of a work while foreshadowing the emergence of virtual museums prior to the digital age [22].

2. Literature Review

2.1 Beyond the Age of Mechanical Reproduction

While the development of software (hypercard, QuickTimeVR, VRML) and new media (CD-ROM, World Wide Web, Virtual Reality) technologies have played a major role in the emergence of virtual museums, the origins of the idea of a virtual museum precedes the digital age. It may be argued that the inevitability of a virtual museum was foreshadowed by the German cultural critic Walter Benjamin's 1936 observation that the original was disappearing, and being replaced by an infinite number of copies [22]. Benjamin argued that reproductions lacked in a specific area: presence in time and space of the original work of art. Through its "aura", an authentic work of art demonstrates its history and place in time. Benjamin states that this aura is outside the sphere of reproducibility, therefore reducing an object's presence but enabling the reproduction to be enjoyed in new ways. The modern emancipation of art and the rise of recreations, especially in photography and film, have enabled many to use media as if they were "museum curators" amassing their own personal collections of curiosities. Whereas prior to the age of mechanical reproduction few individuals were able to access historical documents and artifacts, by the first quarter of the 20th century, the availability of cheap copies of substantial quality made it possible for more people than ever before to share in matters of cultural heritage [22].

Writing in the second quarter of the 20th century the Frenchman Andre Malraux held that the diversity of the world of art surpassed the capacity of any single art museum to hold it. Malraux conceptualized the Musée Imaginaire as an imaginary collection of all the world's most valuable works both inside and outside art museums [23, 24]. Like Benjamin, Malraux saw that photography and film called into question

the traditional role of the museum. The availability of photographic reproductions of artworks, both 2D and 3D artifacts, made art accessible and encouraged those who may never have previously entered a museum to interact with art on a new level [25].

Around the same time in the United States, Vannevar Bush was theorizing about the Memex, a conceptualized system for storing and retrieving data [26]. Bush envisioned the Memex as a device in which individuals would be able to store their books, records, notes and communications through the use of a document bookmarking list stored on static micro-film. The Memex would eventually be known as the inspiration for hypertext, and in turn the World Wide Web [27]. With these inventions it became possible to almost instantaneously share knowledge, images and sound around the world on a scale never before imagined. This opened the possibility for a new sense of presence. By the early 21st century Mark Deuze observed we are no longer living “with media” we are living “in media [2].” This new age of pervasive computing, according to Coleman is creating an x-reality where we routinely cross lines between the virtual and the physical world and where activity occurs at sites of engagements that may be partially in a physical and virtual world simultaneously [20]. My thesis project explores new possibilities for the ideas of virtual museums in the age of pervasive media and x-reality.

2.2 The Quest for a Virtual Museum

In recent years various approaches using digital technologies have attempted to create Virtual Museums. Some approaches aspire to be museums without walls, others have used digital technologies in physical museums to enhance visitor experience. There is however, no consensus on what actually comprises a Virtual Museum. While the writings of Benjamin and Bush may be helpful in understanding the desire to construct a Virtual Museum these thinkers did not directly write about or express

interest in the subject. Malraux did write explicitly about the idea of a virtual museum, but in his day analogue technologies could not take his idea beyond the possibilities of print or film as presentation media. Based on Benjamin's discussion on reproduction and aura, it's questionable whether a Virtual Museum needs to be an extension of physical space or something else entirely. The Virtual Museum has been described as a collection of digitally recorded audio, image, text, and other data of historical, scientific, or cultural interest that are accessed through electronic media [28]. While this description helps establish content types and a focus on what material might exist within a Virtual Museum, it lacks a commentary on user interaction and/or customization.

2.3 The Digital Extension of Physical Museums Accessible Through the Internet

White, Mourkoussis, and Darcy presented an advanced comprehensive museum-focused solution that could be customized based on individual client needs in the form of the ARCO (Augmented Representation of Cultural Objects) platform which provides methods for digitization, management, and presentation of artifacts within virtual environments [29, 30]. ARCO utilized photogrammetry techniques for data capture, and 3D modeling software to clean the obtained data. Once the data was captured, it was sent to a database and stored for user viewing. Users were able to browse collected data through a web interface, museum kiosks, or an Augmented Reality table-top environment. The web page browser allowed for the inspection of embedded 3D artifacts using special plugins, or 2D images of collected artifact data. 3D galleries took the form of physical galleries in order to mimic the architecture and layout of real world places. Finally, Augmented Reality QR codes were used in order to pass an artifact through a user's camera/phone and onto a desk where the QR

codes were placed. ARCO's use of a back-end database for artifact cataloging was its most useful feature, while several of its other techniques became dated quite quickly. ARCO's virtual reality presentation proved too time consuming in its effort to recreate physical museums. Ultimately, ARCO's largest contribution towards the concept of a Virtual Museum is its approach to cataloging digitized artifact information and making it available to individuals online.

The ART-E-FACT project suggested that the use of web services could enable institutions to make their content available to researchers, curators, and the public in ways not previously possible. While many virtual museums enable wide accessibility through the Internet [31, 32, 33], other virtual environments have been developed within a museum's physical space in order to bring about a more interactive element within museum exhibits [17, 34]. These virtual museums often take the form of serious or educational games in order to promote interaction. The ART-E-FACT system is composed of, "a storytelling engine that controls the virtual environment with virtual characters that interactively present a work of art, the rendering engine, the authoring tool which defines the story (presentation), the database that contains information about the cultural objects, and a gesture recognition system that detects hand gestures and infrared markers on dedicated objects." The project also provides for the use of 3D content generation tools. ART-E-FACT, aside from promoting visitor interaction, offers many advantages to museums and similar institutions. It allows users to discover information about the artifact that simple museum labels would not be able to describe. Through the use of VR and AR, museums have found cost-effective tools which aid in increasing a visitor's presence both within the museum and before or after a visit [35].

The SCULPTEUR project (Semantic and Content-Based Multimedia Exploitation for European Benefit) developed virtual environments for museums to create

and manipulate digital representations of museum artifacts. SCULPTEUR creates 3D recreations of artifacts and supporting audio/visual media and stores them in a database, and provides user toolsets to facilitate access and the manipulation of the stored data for educational purposes [36]. 3D models were reconstructed through the use of two complementary methods: a silhouette method and a multi-stereo method. SCULPTEUR also allows the import of new 3D data and the interoperating of remote SCULPTEUR interfaces, digital libraries, and legacy gallery systems. These tools also enable the auto-classification of collection content and searches the web for content missing from the collection. All of this information can then be exported for use in eLearning applications that broaden the way museum and gallery content can be distributed to users. SCULPTEUR's main purpose is the creation and management of distributed cultural multimedia repositories for major museums and galleries to enhance their collections.

Both ARCO and SCULPTEUR promoted the distribution of 3D artifacts to major institutions as well as individuals. While the ART-E-FACT project also supported a web distribution system, a large portion of the project's focus was on the creation of a storytelling engine that was capable of increasing a user's presence within the virtual environment. Another important aspect shared among all three projects was the use of databases in order to store and serve cultural heritage information to users. The projects above utilized varying methods of data storage, but came to the distinct conclusion that the creation and maintenance of a cultural heritage database is of great importance in sustaining a virtual museum environment. By using these and similar past projects as a basis, we can adapt key features for use towards the creation of a modern day virtual museum environment.

2.4 Institutional Immersive Environments

Introduced in 1991, CAVE (Cave Automatic Virtual Environment) was a system that utilized projectors and 3 to 6 screens depending on the complexity of the structure, to project a virtual world that placed a user into the experience instead of simply allowing him to be an onlooker [37]. At a minimum, the CAVE was composed of a front wall and two side walls, but could be built with a back wall, a floor, and a roof as well. CAVE systems would cost from \$30,000 to upwards of \$1,000,000 for advanced hardware and materials [37, 38]. Upkeep costs were high as was risk for potential damage because of constant user interaction. Space concerns also limited the use of such systems. While these CAVE systems offer visitors a unique experience, their size and cost make them a rarity inside museums and similar institutions. The Ars Electronica Center in Linz, Austria exhibits several CAVE projects, such as World Skin, a photo safari through lands scarred by war [39]. The NTT InterCommunication Center, or ICC, in Tokyo, Japan also displays several CAVE projects, such as Margaret Dolinsky's Blue Window Pane II. Blue Window Pane II is an art experience that stages the virtual environment as performance and projective construction. Participants discover a non-linear narrative through a subversive and confrontational stream of consciousness movement [40]. Despite some of their shortcomings, CAVE systems allow constant interaction between user and exhibit, transporting users to new locations and allowing users to transform an art installation with their interaction.

For another type of an immersive environment I turn to the several projects by Sarah Kenderdine with a focus on creating an experience for museum visitors as well as promoting interaction between the physical and the digital. Pure Land: Inside the Mogao Grottoes at Dunhuang digitally recreates a single Chinese cave temple from Dunhuang, a small town in northwestern China. There are more than 700 caves

at the site, while many are open for public viewing temples are periodically closed for preservation purposes. Pure Land immerses visitors in a 360-degree projection screen. Rich sound design, video segments, interactive 3D models, pictorial magnification and composited images are used to interpret and create an interactive virtual experience with a mural painted on one of Dunhuang's many cave walls [41]. Similarly, PLACE-Hampi places visitors in a 360-degree display and immerses them in 3D panoramic images, surround sound audio recordings, and computer animations of Indian mythological deities [42]. These technologies set the landscape of Hampi in motion interpreting archaeological imagery for a 21st century audience. We Are Like Vapours: Pacifying the South China Sea depicts the Pacifying the South China Sea scroll, created by an anonymous Qing painter over 200 years ago. Considered one of the jewels of the Hong Kong Maritime Museum, it is one of Hong Kong's most important cultural heritage artifacts. Again, visitors are surrounded on all sides as light, sound, and imagery combine to tell the stories of piracy along the Guangdong trade passages, appeasement, symbolism and force in order to place them in a modern context for the public to enjoy [43]. Finally, mARChive allows visitors to visualize 80,000 digital records from Museum Victoria through a 360-degree 3D display system [44]. Visitors are presented with an intuitive and creative platform that enables them to engage with a large portion of Museum Victoria's extensive collection, well beyond the fraction of the collection on physical display.

Kenderdine's Virtual Museum projects have varying goals and purposes, however, they hold distinct similarities. Both Pure Land and PLACE-Hampi use digital technologies to interpret for and enable visitors to virtually explore landscapes and locations either too far or too delicate for the average visitor to physically experience. We Are Like Vapours seeks to highlight a single artifact while expanding on its history and meaning. Finally, MARChive presents a large amount of archaeological records

at once, allowing visitors to curate their own experience while allowing as close to free reign of Museum Victoria's collection as possible. Despite these distinct goals, all four of these Virtual Museum installations approach their problems in a similar fashion. All utilize a 360-degree screen installation, which means these installations are often too large to transport safely or cheaply. The screens also increase the cost of the installation and represent institutional solutions that preserve the authority of traditional museum, that is, you must be physically at the museum to experience the museum's message.

2.5 New Technologies/ New Possibilities: Peripherals and Accessories

More recent Virtual Reality technologies, such as the Wii and Oculus Rift, are geared more towards gaming solutions than for Virtual Museums. However, they have been adapted for projects ranging from immersive gaming to Human Computer Interaction (HCI) and physical therapy and they can certainly play a role in developing the Virtual Museum [45]. The Wii is a gaming console released by Nintendo in 2006. The allure of this console for Virtual Reality is the Wii Remote Controller, which serves as a pointing device that detects motion in three-dimension [46]. The Wii Remote Controller, along with its Nunchuk accessory, function as interaction devices. These accessories not only allow pointing or hovering over information on a screen, but also the means for button inputs for selection, motion, and navigation within virtual reality environments. The Oculus Rift, recently purchased by Facebook, which seems to suggest social media development and SONY's Project Morpheus are Virtual Reality head-mounted display systems that are being developed to be more effective and more affordable to gamers than previous Head Mounted Display (HMD) technologies [47]. At a price point of \$300, the Oculus Rift is much more widely obtainable than previous technologies. The Oculus also boasts a 90 degree field of view (FOV) which

is almost double the FOV of competing devices [47]. The extended FOV serves as the Oculus' main strength, it has the attraction of enabling the wearer to block out the real world and create a strong sense of immersion. Similar to previous technology iterations, these current technologies are specialized in their function. For best use, the Oculus Rift and Wii Remote Controller(s) should be used together to create interactive VR environments. Today the Oculus provides the best orientation tracking available to the commercial market, while the Wii Remote Controller provides a large tracking volume that enables users to interact with the environment presented by the Oculus [48].

Another affordable technology that holds great promise in the quest of a virtual museum is Microsoft's Kinect as seen in Figure 2.1. The Kinect is a motion-sensing input device used in the Xbox 360 and Xbox One gaming consoles along with Window's computers. The Kinect utilizes an RGB camera, a depth sensor, and a multi-array microphone in order to provide control and interaction without the use of physical controller or keyboard [49]. Instead, the Kinect provides interaction through user body controls complete with gestures and verbal commands. The Kinect has been utilized in a wide variety of games and interactives, such as the Microsoft backed Kinect Sports, which provides players the chance to participate in several sports activities using their own bodies and movements over traditional controllers. Museums have also utilized the Kinect in special exhibits to increase interactivity between its collection and museum visitors. The Louvre in France installed an exhibit titled Spotlight on the Antinoe veil, which allows visitors the opportunity to interact with Greek fabric through several scenes across Greek mythology [50].

While these technologies have their inherent strengths, they also come with specific weaknesses that lessen a user's presence during VR interaction. Wearable peripherals directly interfere with a user's presence by adding weight, while also restricting



Figure 2.1: Microsoft's Kinect gaming peripheral for use with the Xbox 360 and PC

movement and/or vision. Immersive VR technologies come at a high cost, and are unusable in small space situations or by the average public user. The best solution is for the use of a VR device that is obtainable by the general public at low cost, a low space requirement, and will not interfere with a user's natural movement or overall use of their own body. The Oculus Rift is a lightweight peripheral that is offered at an affordable price, but still binds the user to the device itself. The Wii Controller has the same advantages as the Oculus Rift, but cannot serve as an immersive VR device on its own, but instead as a navigation tool. The Microsoft Kinect is capable of allowing users to act as the controller, which requires no additional equipment or wearable devices. It comes at a low price, and is usable in the same amount of space as the standard American living room [49]. While previous technologies including VR data gloves, HMDs, and full body suits helped pave the way for VR interaction, the Wii Remote Controller, Microsoft Kinect, and Oculus Rift improve on several deficiencies of these past products with focus on key issues such as price, space requirement, and mobility offer the potential to virtually present the content and knowledge of museums to a public beyond the walls of the physical museum [51].

A key issue in terms of these new and developing peripherals is how they interface with current museum content, archaeological sites, and cultural heritage content.

The Oculus Rift and Sony’s Project Morpheus are both suited extremely well to providing an immersive experience such as those detailed in sections above. These immersive experiences enable individuals to interpret information on their own time and in context of a modern presentation. Additionally, the Wii Remote Controller and Microsoft Kinect are capable navigation peripherals that enhance a user’s control over immersive simulations while providing them with a higher degree of presence over the traditional mouse and keyboard in terms of human-computer interaction. Of course their effectiveness as a research and education tool is always dependent on the strength of the interactive environment utilizing these peripherals. An examination of the 3D-Digging Project will demonstrate the successful use of related digital technologies towards research, education, and artifact distribution platforms.

2.6 Çatalhöyük: The 3D-Digging Project

Çatalhöyük is a Neolithic site located in Central Anatolia and is considered to be one of the first “cities” in the world. Excavated by J. Mellart in the 1950s-1960s and then by I. Hodder in the 1980s, it has retained its importance through the years for its introduction and experimentation of new methodologies and theoretical approaches of cyberarchaeology and applications of new media [52]. The site, dating from 7400-6000 BCE, is made up of two mounds: Çatalhöyük East and Çatalhöyük West, which span 2,000 years and demonstrate a unique continuity through time [53].

The project “3D-Digging at Çatalhöyük” began in 2009 as an on-site digital experiment to record every phase of an archaeological excavation in 3D. Utilizing an integrated approach consisting of laser scanning, computer vision, and photogrammetry, the project looked to document and make available the excavation process on computers and virtual immersive systems for both education and research [53]. From 2009 to 2012, various experiments in 3D laser scanning and computer vision

were undertaken in order to create an integrated workflow pipeline. The invention of this workflow has created a stable and optimized pipeline through which 3D models and their associated textures are quickly taken from the field to refined product in a short amount of time. However, manual application of photographic textures inhibits the project's ability to automate the current pipeline. By 2012 PC tablets were also being used in order to display georeferenced drawings of site locations. This portable format created new means of 3D data sharing and collaboration and offered a needed in-between step from data capture to final interpretation for field work [53].

The workflow established during excavation was able to generate large amounts of point clouds, 3D models, and metadata that were then georeferenced into the same geographic space. All models and data were optimized for the DiVE system at Duke University. The DiVE is a research and education facility dedicated to exploring techniques of immersion and interaction: it is the fourth six-sided CAVE-like system in the United States. The DiVE is a 3 by 3 by 3-m stereoscopic rear-projected room with head-and-hand tracking with real-time computer graphics [53]. Users are provided with a fully immersive experience where users can literally walk into a virtual world. Stereo glasses provide depth perception while a handheld wand controls navigation and virtual object manipulation. This digital immersion increases a user's presence, fostering 3D connections otherwise not visible in the real world.

The 3D-Digging Project has demonstrated that it is possible to create an integrated workflow with little to no impact on the time it takes to perform archaeological excavations. More importantly, the project showed that immersive virtual reality systems may play a larger role in the development of more advanced systems of interaction and the understanding of acquired data [52]. 3D libraries and museums may constitute the core data of future research of all kinds, replacing the traditional written reports or physical institutions. The 3D-Digging Project demonstrated the

use of 3D immersive systems as a means for the dissemination of professional works towards education and research. Furthermore, the 3D-Digging Project also targeted non-traditional consumers through novel means of interactivity.

The 3D-Digging Project not only allowed users to interact with data, but also enabled users to use digital information to obtain knowledge in new ways through interacting with an immersive experience. The project demonstrates early attempts at placing digital artifacts in a greater context of discovery by connecting the field experience to the immersive virtual environment. However, the 3D-Digging Project is not without similar issues to those discussed in previous projects. Though 3D data was optimized for the DiVE at Duke University, it has not been made widely available to general audiences. Text records have been made available online through a database search and download. Non-professional consumers are granted access to this information through the project's website, but are unable to interact with the excavation process or digital artifacts within the immersive environment without access to the tools at the DiVE. This project has developed an optimized workflow for the creation of the virtual experience, however it is still hindered by the photographic texture application process. This step removes the potential for an automated pipeline, which leads to slower artifact and site integration for end users. Despite these issues, the 3D immersive system allows for user observation within a mediated experience which enables the creation of new forms of knowledge and understanding. The immersive experience allows for the distribution of professional and research-related works through interaction at the DiVE by allowing consumers to view information in a modern context, a process which my project looks to emulate and expand.

2.7 Beyond the Immersive Experience

The success of the type of Immersive Virtual Reality (VR) experiences described above is based on how well the simulation totally transports the museum visitor to some digital space or time other than his current physical location. Bolter's concept of remediation describes this illusion of non-mediation as immediacy, or transparent immediacy [54]. Coleman, however, contends that instead of focusing on a distinction between the physical world and a virtual world the "networked generation," those who grew up in the age of the internet, seamlessly works across the physical and the virtual simultaneously. In our age of pervasive media almost all communication involves some form of mediation. According to Coleman, "*The most important characteristics of networked media and networked subjectivity align in the phenomenon of virtual presence (the sense of being somewhere via mediation) . . .*" [20]. This notion of presence, linked to a theory of agency which Coleman defines as "*how we understand ourselves as actors in an environment. . .*" together with Deuze's observation that unlike the 20th century we no longer live with media, we now live in it, we now live "a media life" [2] serve as the inspiration for my Master's thesis project.

With an understanding of Benjamin and Malraux, we can say that a Virtual Museum is more than a collection of digital objects composed in a variety of media. It has no real place or space, and its objects can be disseminated all over the world simultaneously [55]. Through its capacity to provide connectedness and various points of access, the Virtual Museum lends itself to transcending traditional methods of communicating and interacting with visitors while being flexible enough to address their needs and interests. The Virtual Museum provides the ability for visitors to transition from observer to participant by allowing them to curate their own immersive experience. Dynamic technologies combine to form the basis of the immersive experience that provides novel means of interaction for both novice and experienced

visitors. Coupled with an understanding of Deuze and Coleman, we can add that the Virtual Museum should be accessible anytime anywhere. With these additions, we see the realization of Colemans x-reality and the evolution of the Virtual Museum into an entity capable of surpassing the limitations of physical institutions.

3. Methodology

This thesis project was produced in two major sections. Section One included gaining access to and digitizing relevant artifact collections. Section Two consisted of producing the digital interface and Kinect integration necessary to create the Virtual Reality experience informed by current theory and practice in digital cultural heritage.

3.1 Artifact Collections and Selection Criteria

To provide a representative sample of artifacts to users, sites were chosen based on their ability to contribute residential (Remer Site), industrial (Dyottville Glass Works), and prehistoric (Hope Farm/Richmond Hall) artifacts to the virtual experience. Additional criteria called for the location of the sites to be in or around the city of Philadelphia, making them more accessible to nearby individuals and researchers, while also promoting their use in future cultural heritage and tourism projects. Although many sites may be artifact bearing, often times little is known about actual use or functionality of the artifact. Such sites were excluded from the project. The selected sites each have a rich backstory related to the landowners or former occupants that shaped the site's use over time. These histories are detailed in Appendix B.

Artifacts collected from the three sites were selected for digitization based on several considerations including construction material, size, and the level of detail. While some higher detailed artifacts were selected to explore and demonstrate the capabilities of the 3D scanner, many artifacts were selected for being simple or without high density areas of small features. This digitization criterion helped to speed up the scanning process as I sought to select artifacts that could be easily scanned. For

example, bottles, brick, and prehistoric stone artifacts that easily fit on the scanner's turntable, were selected for scanning. A historic window decoration that was very detailed and much too large to fit the turntable was not chosen. These selection criteria reduced the time needed for manual alignment and cleanup of the data after the artifact was scanned. A discussion of my scanning techniques appears later in this section. Though my selection of these criteria will serve to demonstrate my digital media skills, it does not represent my archaeological knowledge of the artifacts.

Throughout the digitizing process, over 200 artifacts were scanned varying from ceramic, bone, glass, wood, clay and more. While not every artifact digitized was included in the final product, this scanning experience allowed for the development of a scanning pipeline and a pipeline for integration into a useable format to be discussed later in this section. The most surprising revelation of this experience was the discovery that glass could be scanned fairly easily. Glass is generally difficult to scan because rather than reflecting the laser beam, transparent glass allows the laser beam to pass through. Most of the glass I worked with was in the ground for at least a century and had been covered with patina. This clouded the glass and enabled reflection of the laser beam allowing the artifact to be more easily scanned. Not all of the glass artifacts possessed a patina layer, in these cases glass artifacts were lightly brushed with talcum powder in order to enable scanning of these glass surface details. Other glass artifacts were filled with fine sand in order to capture flat surface areas.

3.2 3D Scanning and Artifact Digitization

3D scanning of selected artifacts was conducted using a non-contact (passive) stereoscopic system of scanning [24]. For the purposes of this project, the Next Engine 3D Scanner and the ScanStudio HD software package were used to digitize the artifact collection. Scanning was initiated by placing an artifact on the scanner's automated

turntable. With the artifact secured, ScanStudio HD was booted in order to change required settings. Each scan had several settings which largely impact the outcome of the digitization. Most scans were set to either single scan or 360 degree scan, meaning either only the side of the artifact facing the scanner was captured, or the turntable automatically rotated the artifact in order to digitize each side of the artifact and piece them together. Scans could also be set in either quality or time priority modes such as Quick, SD (Standard Definition), or HD (High Definition). A quick scan, generally two minutes per captured view or 12 minutes for a 360 degree scan, would capture the least amount of data or points per square inch and take the least amount of time. A standard definition scan would take a moderate amount of time, roughly four minutes per captured view, and also capture a medium amount of data. The HD scan would take the longest at roughly 36 minutes for a 360 degree scan, or six minutes per captured view, but capture up to one-hundred and sixty thousand points per inch. Settings could also be changed based on an artifact's material, allowing the 3D scanner to know if an artifact was Light, Neutral, or Dark in color. While each setting ultimately displayed a different level of success in capturing detail, the Neutral scan setting proved to be the best choice regardless of artifact material or color. Finally, the scanner required either a Macro or Wide setting which was dictated by both the size of the artifact being scanned and the distance at which the artifact was placed away from the scanner. Once settings were finalized, the scan was initiated and left to complete. This process was repeated for each individual artifact, taking additional single scans to fill in missed areas where imperfections arose. Following each completed scan, the author took supplemental photographs in order to apply these images as textures to a 3D model at a later date.

Multiple scans were stitched together or registered within ScanStudio HD in order to constitute the virtual artifact shown in Figure 3.1. Depending on the scan quality

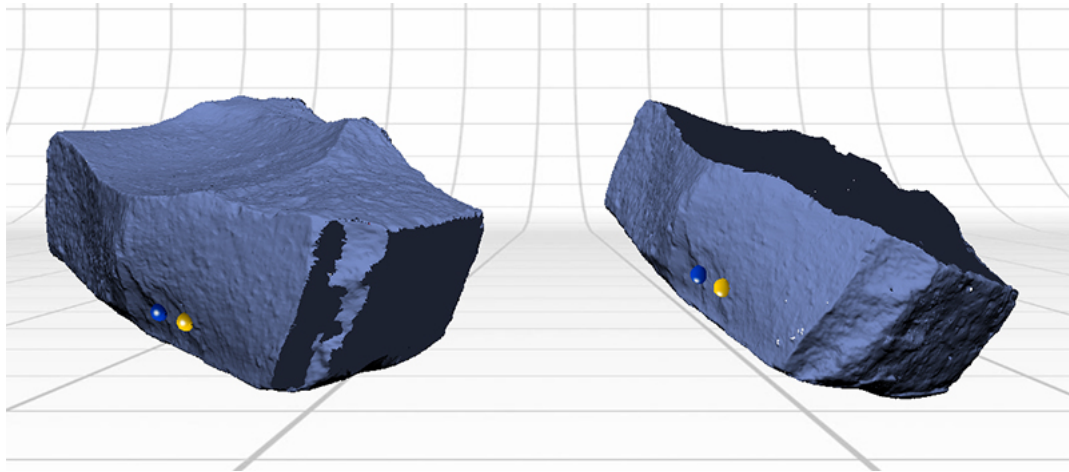


Figure 3.1: Registration process inside ScanStudio HD. Two halves of an artifact are pieced together to form a water-tight 3D model.

setting utilized, most artifacts required polygon count reduction following the merging of multiple scans to create a single model. As the scanner was generally capturing millions of points of data per artifact, file sizes grew exponentially. Fortunately, all 3D models can have their polygon/point count reduced to some degree while still maintaining a high level of detail at a fraction of the file size. A comparison of a model before and after decimation can be seen in Figure 3.2. The scans were then taken to the clean-up room within ScanStudio HD while further cleaning was performed in Geomagic Qualify, a higher quality 3D model/point cloud manipulation application.

Sets of scans for each artifact were then cleaned of digital debris which ranged from scanning errors to non-manifold edges, spikes, creased-edges, self-intersections, and holes that were picked up in the scanning process. Within Geomagic Qualify, the MeshDoctor tool was run on each artifact. This includes algorithms meant for cleaning disconnected edges or areas with no thickness (non-manifold), flattening of small pyramidal shapes caused by errant points (spikes), and areas where the model geometry intersects itself as shown in Figure 3.3. After MeshDoctor has run, holes

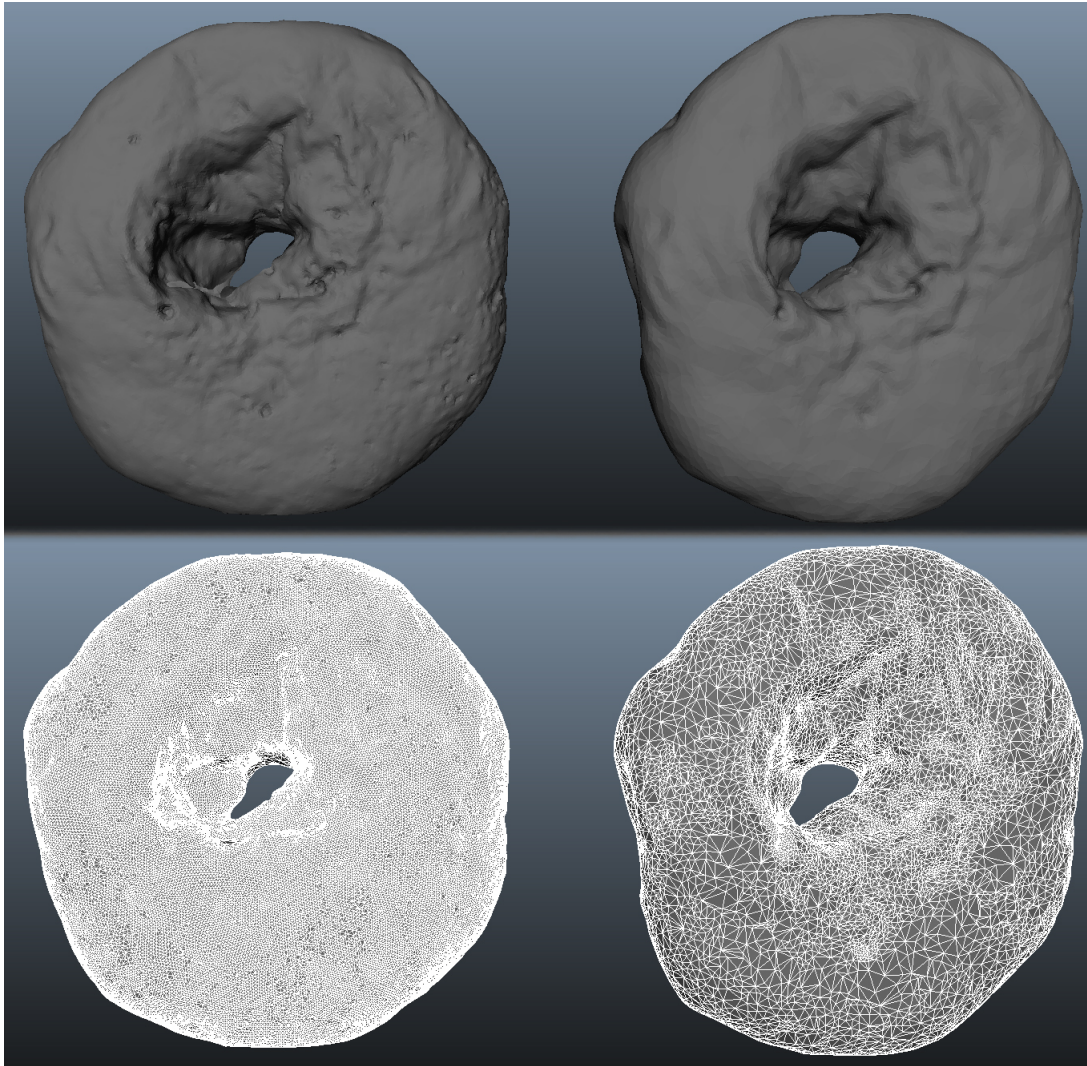


Figure 3.2: Decimation process to reduce polygon density on 3D scan. The original scan (left) displays a large polygon count with a high level of detail, while the decimated model (right) sacrifices some level of detail for more practical polygon count.

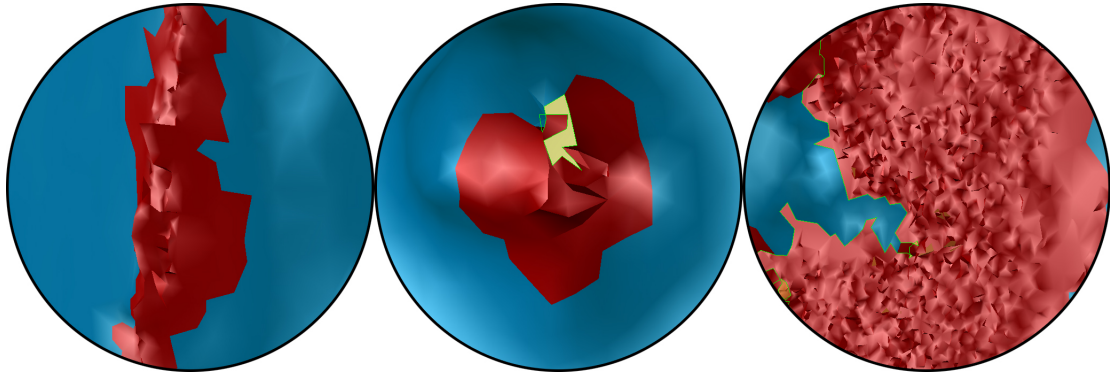


Figure 3.3: Demonstration of issues cleaned by MeshDoctor algorithms including: Self Intersection (left), Small Holes (center), and Spikes (right).

in the model are manually filled in order to prevent the use of the incorrect hole filling algorithm. Following this, MeshDoctor is run once again to ensure there are no issues with the overall 3D mesh. Once the mesh is clear of all discernible flaws, the artifact 3D model was exported to 3D-Coat, a 3D modeling, texturing, and sculpting program.

From here, the model can be processed in two different ways. Initially, models were imported into 3D-Coat, particularly useful for painting and texturing directly onto a 3D model. In 3D-Coat, models were made less dense in terms of polygon number and arrangement, and their edge flow was improved while turning a high polygon model to a low polygon substitute as demonstrated in Figure 3.4. The next step involved laying out a model's UV coordinates, which enabled the creation of a 2D image representation for a model's 3D surface. With UVs created, a model's texture could be painted on top of the 3D surface while minimizing image stretching and distortion. The low polygon model was textured inside 3D-Coat using the aforementioned supplemental photographs, though the 3D scanner's own photos were sometimes used for additional detail. In addition to photo-real textures, a texture map used to fake the lighting for various bumps and indentations across a 3D surface was applied to the low polygon

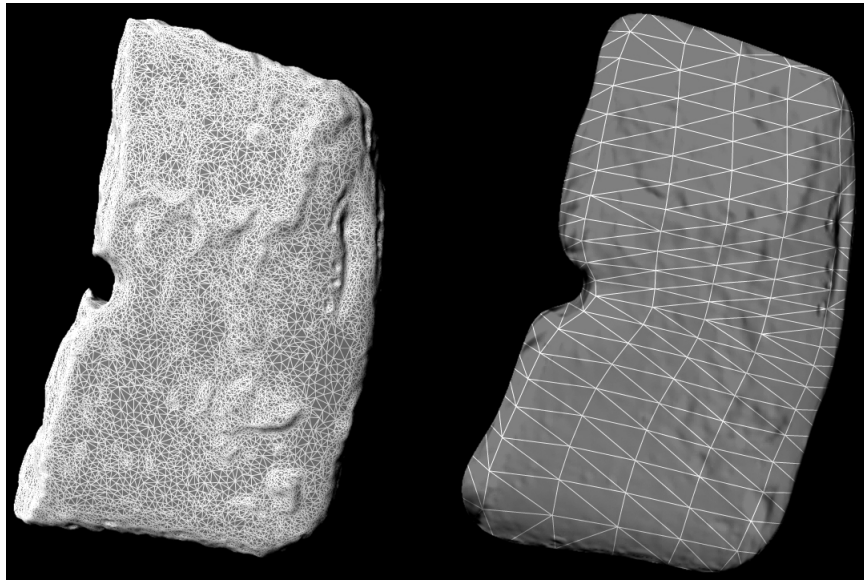


Figure 3.4: Comparison of high polygon model (left) and the low polygon substitute with normal mapping (right).

substitute. The model was then ready for export and use inside Unity 3D, a video game development, interactive installation, and architectural visualization program.

Retopologizing and manually laying out a model's UVs proved too time-consuming to perform for a collection of sixty artifacts, so this part of the process was automated within 3D-Coat. While manually performing these operations provided complete control over polygon density, edge flow, and overall model topology, the automatic tools within 3D-Coat perform sufficiently for the purposes of this project. The only downfall is the potential for a slight downgrade in model quality, but since these objects are not being animated the topology does not matter as much as it would otherwise. Therefore, as long as the texturing step was done properly, the models would appear no different than their manually created counterparts. Once the polygon reduction and UV layout operations were performed, the object could be textured as normal, and then exported for Unity integration. See Appendix A for an artifact

inventory.

3.3 Navigation of Virtual Environments Using Modern Gaming Peripherals

The subsequent section of the project required the creation of a virtual environment in which digitized artifacts could exist for exhibition. Based on the definition of the virtual museum developed in the section Beyond the Immersive Experience, p. 22 of this report, the virtual environment for this project was approached as an abstract space with no real place or space.

Though Walter Benjamin was writing in the 1930's, his discussion on mechanical reproduction can easily be applied to artifact reproduction and digitization. Benjamin would have argued that a reproduced artifact is detached from its tradition, and therefore loses a level of authenticity, this loss of tradition brings a reproduction into the distinct life-situation of the viewer. The reproduction is therefore removed from its past uses and can be utilized for new or modern purposes. In terms of the creation of digital artifacts, though they may lack the weight and aura of the physical, they enable viewers to use them as an educational tool, create their own story, and curate their own virtual experience. Just as Benjamin saw the age of mechanical reproduction as a freeing experience due to its expansion of available imagery, the digital age and digital reproductions of cultural heritage artifacts free users from geographic restrictions and physical limitations enabling new interpretations and possibilities. For Malraux, the concept of the Museum Without Walls expanded the traditional role of the museum and the meaning and function of art. Based on the arguments of Benjamin and Malraux, we see the possibility of the reassembling of art objects and reproductions to create a new user experience and understanding of these cultural heritage artifacts.

While it would have been possible to reproduce a museum space or design a

space to mimic several existing institutions, an abstract space more suitably furthers Coleman's statement that we are beyond virtual reality where it is no longer necessary to make a distinction between the virtual and the real, as we are both digital and real. We can infer from Coleman's argument that perhaps there is no need to create the illusion that the user is in a museum. The physical space of a museum is less important than the reality of the object, where it existed, its function, and its story throughout time [20].

An x-reality approach to the material fusing the virtual with the physical world involved creating menus, menu items, lighting artifacts, and user interaction within 3D space in order to create a location that allows for comfortable navigation among the artifacts, but also surpasses the need to embellish the virtual environment with references to an illusionary museum world. Instead the agent may explore the artifact and known information about it from any place with the required equipment and an internet connection. In order to allow for this simple navigation, interactive environment breaks down artifacts into the three sites from which they were found, and then presents twenty artifacts from each site as a list of scrollable items controlled by waving one's hand, shown in Figure 3.5. All artifacts can be inspected from this menu which then allows further details and artifact manipulation on a deeper level. This step in the process occurred within Unity 3D, which allowed for the integration of the scanned artifact assets and the beginning of Kinect development.

The most difficult technical challenge posed by this project was working with the Microsoft Kinect. Though the collective knowledge on Kinect functionality and research grew rapidly throughout this thesis project, there were several issues that arose that hindered the Kinect's integration into this project. The first issue that arose was with installing the proper drivers required by the Kinect. Microsoft's Development Kit was not available as this was early in the Kinect's development cycle.

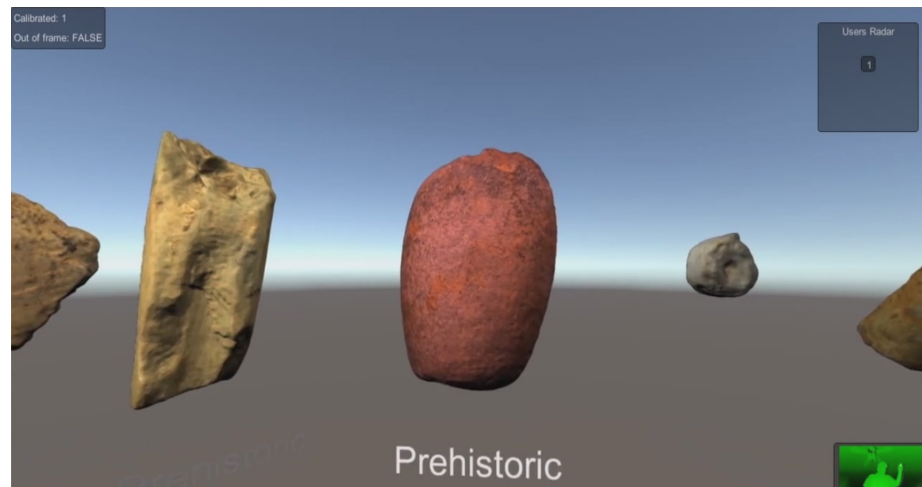


Figure 3.5: Prehistoric artifacts being selected within the interactive application.

Third party drivers were created for Windows operating systems that required only executing installers for SensorKinect, NITE, and OpenNI. However, Kinect testing for this thesis project was conducted using the Mac OSX. The installation process for these drivers was much more tedious on Unix-based operating systems, though ultimately proved successful in the end. A detailed process breakdown is no longer required as Microsoft has released a non-commercial development kit.

The second issue arose in how to approach the 3D interaction. There were potentially two ways Kinect interaction could be established within the project. The first involved the user viewing the scene from a first-person perspective. The user can be tracked by the Kinect while a stand-in skeleton geometry is used to provide the physics that allows forward and backward progress, turning, and also picking up objects within the 3D environment. The first person perspective however, suffers from the constraints of proper collision between the skeleton geometry and the artifacts within Unity 3D. The user's avatar may not properly interact with the scanned 3D artifacts and therefore requires additional attention for minimal gain, essentially

pushing this method outside the achievable range of this project. Collision tracking with body controls is still largely experimental, as user depth from camera and proper hand tracking play large roles in the feasibility of this scenario.

Similar to the first method, in the chosen method of configuration the user views the space from a first-person perspective, with a stand-in skeleton geometry acting as their virtual body. Instead of the camera searching for the hands and their proximity to virtual objects, this method involves gestures that are read by the computer and trigger certain actions based on the specific gesture performed. Gestures were programmed, and actions were connected to each individual motion, enabling object translation, rotation, and even scaling within the virtual environment. Having established a prototype of this method early on, it was used exclusively throughout the Kinect portion of the project. The setup required a reference point on the Kinect skeleton geometry and several templates for usable gesture configurations. Once the templates were established, a user could wave his/her hand in the proper configuration to perform an action. The Kinect reads the motion and if the user's hand went through the proper path of points, the program performs an action. While this version of gesture recognition is somewhat simplified, it allowed for a short installation time and some customization.

With Deuze's observation that we are no longer living with the media, but rather live in it, along with Coleman's notion of presence and agency, it was best that the interface for the interactive environment was kept simple. There is no traditional UI, and instructions are presented on a singular page off the title screen of the interactive. Menus are controlled through simplistic gestures, such as a swipe from left to right. In order to select a location or object from within the environment, a user simply hovers over it for an extended period of time and pushes their hand forward in the air. This focus state is analogous to simply hovering a mouse over a computer screen

and then having an action be performed. Once the focus state has been activated, a user will be taken into a separate environment, populated with lists of artifacts from the location they have chosen or specific information on a single artifact. The control scheme again allows users to move artifacts horizontally and vertically around the screen, rotate them around multiple axes, and finally scale/zoom both inward and outward to allow varying levels of object detail. These controls promote a user's sense of presence in the environment, allowing him a sense of holding the digital artifact in his hand as opposed to simply viewing it on screen. Again we look to Coleman's theory of agency to shape this experience as a player in an interactive world, as opposed to a remote user simply viewing a dissociated interaction.

4. Conclusion

In the creation of the Virtual Cultural Heritage Project we aimed to create a Virtual Museum available to users in their home using commercially available gaming hardware, such as the Microsoft Kinect. This project invites users to interact with cultural heritage artifacts on a new level not previously available in traditional museums, turning them from passive observers to active participants capable of curating their own virtual experience. Through the use of body controls and gesture recognition, users are able to merge both the virtual and the real towards a realization of Coleman's x-reality. We also looked to the concepts of presence and aura, applying them to increase a user's sense of immersion in the virtual environment. Through the use of site and artifact histories, we created an environment through which users can interact, explore, and educate themselves within both worlds of the virtual and the real.

The basis for the Virtual Cultural Heritage Project was inspired by the works of Walter Benjamin and Andre Malraux. Benjamin's observation concerning the disappearance of the original and its aura were the inspiration for this project's focus on presence within virtual environments. Benjamin's argument that the reduction of the aura enabled reproductions to be utilized in new and exciting ways along with Malraux's idea of the Museum Without Walls and the expansion of the role of the traditional museum came to be the motivation for this project's use of an interactive virtual environment to reach a new potential audience, the networked generation, equipped with off the shelf home gaming equipment. The works of Beth Coleman and Mark Deuze were also influential in terms of the project's features and functionality. Coleman's notion of x-reality, that we are beyond virtual reality where it is no longer necessary to distinguish between the virtual and real, laid the basis

for the development of an abstract virtual environment instead of working towards the creation of an accurate museum visualization. Deuze's observation that we are no longer living with the media, but instead living in the media aided in the shaping of the virtual environment interface and how individuals interact with the virtual artifacts.

As demonstrated above, the overall theoretical framework discussed throughout this paper played a large role in the development of this project. From the creation of the project's core concept to the improvements in interface and interactivity, the theoretical framework of the above authors have successfully aided in the shaping of this thesis project.

The Virtual Cultural Heritage Project was not without its limitations. The Kinect was the first version of Microsoft's motion gaming hardware and therefore suffered from several hardware limitations. A comparison of the hardware technical specifications between the original Kinect and Kinect 2.0 can be viewed in Appendix C. Due to some of these limitations, the Kinect does not have the fidelity required to track individual fingers as well as minute details associated with the bending and stretching of hands and arms. Overall, the Kinect 2.0 provides improved facial tracking, motion tracking, and resolution which provide much more precise and accurate motion capture playback.

While this project demonstrated new methods for improving glass material scans, there are still issues associated with accurately texturing glass artifacts in the Unity interactive environment. Accurate glass materials have long been replicable in pre-rendered computer graphics however real time graphics, such as those used in this project, are very much limited by the software and hardware utilized to make them. In this case, real time computer graphics can easily simulate the glass of a window pane or door, but the real time simulation of a thick, multi-layer glass object such

as a bottle or glass cane proved both difficult and time-consuming, as well as too graphic intensive for use on an everyday user computer. Due to these issues, some of the glass objects presented in the interactive and Appendix C may not accurately reflect the physical objects.

Finally, though a custom pipeline was developed for streamlined integration of data from 3D scanner, to model decimation, and then to model texturing, the workflow ultimately proves too slow for a single individual to complete efficiently. While over 150 artifacts were scanned, only 60 are represented in the final interactive. Though some of these were excluded due to the selection criteria detailed earlier in this paper, many more were excluded because it was not feasible to texture every digital reproduction manually. The Next Engine scanner does provide texture mapping at the time of data capture, however these textures do not carry over once post-processing has been carried out. As seen in the Çatalhöyük project, manual application of photographic textures is still inhibiting the development of an automatic pipeline. These limitations, though not overly detrimental to the success of this project, did affect the number of artifacts available to the viewer and were ultimately the reason for the number of the current selection.

Future iterations of the Virtual Cultural Heritage Project could benefit from several improvements that fell outside the scope of the current project.

As previously discussed, the Kinect 2.0 has made huge leaps in both technical performance and available features. Aside from the increased resolution detailed in Appendix C, the Kinect 2.0 is also capable of viewing in the dark just as well as in a well lit room. Its improved data transfer rate, 60% higher field of view, and ability to track up to six bodies at once enables new possibilities in cooperative interaction in virtual environments. The Kinect 2.0 is a much more powerful gaming peripheral that has major implications in other fields of study. Ultimately, these

improvements could be integrated into this project in a myriad of ways. At the simplest level, improved tracking and data transfer speeds allow for better feedback as well as improved gesture recognition, increasing both usability and a user's presence inside the digital environment. Though a switch from the original Kinect to the Kinect 2.0 would have been a detriment to this project's progress, future iterations should utilize the most recent Kinect technology.

Future versions of this project also have the possibility to extend outside of the home into field visits and walking tours through the use of Augmented Reality (AR). AR walking tours have the potential to guide individuals through archaeological sites while displaying 3D overlays of buildings, historic or prehistoric sites, in situ artifacts and 2D images through a smart phone's camera. Once a user has finished with the on-site tour, he may return to the in-home version of the project in order to view the desktop version of the project utilizing the Kinect, which should elaborate on information found in the walking tour. A combination of these technologies would also benefit use inside a museum with augmented reality QR codes which can then be transitioned to the home for continued education and learning. This integration of technologies would create a prototype towards the use of mobile devices, desktop computers, and digital accessories functioning in concert to deliver cultural heritage information.

Much like the ARCO, SCULPTEUR, and ART-E-FACT projects, this project could benefit greatly from a queryable database for both storage and the serving of cultural heritage information. While this project's current visual selection system provides vivid imagery and a means for users to browse artifacts when they may otherwise not know what they're looking for, a database would enable users to find what they want quickly and without the need to search through the other existing artifacts. The use of a database would also improve quality of service, preventing the

interactive from loading everything at once and instead only serving the user with the exact query or search results. These additional technologies and improvements would greatly increase this project's ability to serve as a tool for the spread of cultural heritage information to non-traditional consumers. Though these current solutions were outside the scope of this project, they should be catalogued and integrated in future versions.

Despite the accomplishments of the Virtual Cultural Heritage Project, the technology utilized since the project's inception has already become quite dated. As mentioned previously in this section, the Microsoft Kinect 2.0 has made large strides in what were previously limitations of the first Kinect peripheral. These improvements in data transfer rates and head/digit tracking can increase a user's presence within a virtual environment and also allow for the use of more natural and numerous body gestures. However, if this project were to be started anew with contemporary Virtual Reality peripherals not only would the technological limitations be reduced, the end product would be shaped differently based on a changing set of technical limitations and technological availability.

Since this project's conception, a myriad of powerful Virtual Reality and interactive peripherals have been made commercially available. These peripherals enable users to immerse themselves in virtual worlds through Virtual Reality headsets such as Facebook's Oculus Rift or Sony's Project Morpheus, project and interact with Augmented Reality holographics with Microsoft's HoloLens, control interfaces with non-traditional media controllers such as Microsoft's Kinect 2.0 or the Leap Motion, or experience the environment's of virtual worlds through temperature, vibration, precipitation, and windflow with the FeelReal. The availability of any one of these products at the time of this project's conception would have enabled a new approach and additional features within the virtual environment. However with the combina-

tion of multiple technologies, it is possible to further realize the Museum Without Walls. Based on the discussion of current technological limitations and what aspects of hardware limit a user's sense of presence within a virtual environment, we can make an accurate assessment of what current technologies would best enable interaction with cultural heritage artifacts. If the Virtual Cultural Heritage Project were to begin today, the application would continue to utilize the Unity3D game engine, but the hardware involved would combine the capabilities of the Kinect 2.0 as well as the HoloLens.

The Microsoft Kinect 2.0 performs similar functions to the Kinect involved in the original project: tracking overall body movement and positioning, while offering improved gesture tracking and data transfer speeds. The Microsoft HoloLens is the first wireless holographic headset. It enables individuals to "pin" or place holograms in their physical environment. The computer headset utilizes high definition lenses coupled with spatial sound to enable users to see and hear holograms around them. Holograms can be moved, shaped, and altered with a user's interaction with the digital holograms or the physical world on which the holograms are attached. Gestures are utilized to shape, create, and size holograms while eye direction and gaze are utilized for navigation and exploration. Voice commands are also enabled to allow hands free navigation while still interacting with the digital projections. The HoloLens utilizes transparent lenses that allow users to view both the digital and physical objects with which they are interacting. Though the Microsoft Kinect 2.0 requires an active cable connection for both power and data transfer, it does not impair a user's movement based on cable length because it is not a wearable peripheral. Similarly, the HoloLens is a wearable peripheral that does not require an active cable connection for either power or data. This allows increased user mobility and reduces overall weight of the product, meaning an increased level of presence for users. Though the weight

of wearable peripherals and the movement restrictions that are inherent with cabled peripherals have been discussed as issues with Virtual Reality in the past, the specific set of circumstances discussed with these currently available technologies makes them an ideal combination towards realizing the Virtual Museum.

The upgraded application would feel familiar to those using the current iteration, however new capabilities enabled by substantial technological upgrades create a deeper and much more capable Virtual Museum experience. The upgraded application would begin by asking for player calibration for the Kinect 2.0. By utilizing the HoloLens, the interactive would no longer be constrained to a television or computer monitor, but instead would be as mobile as the user's HoloLens headset. Users would be prompted to choose from a menu on their pop-up display allowing them to browse artifacts, construct their own collection, or view help information regarding the interactive's controls. The help screen would demonstrate the use of various body and hand controls used by the Kinect 2.0, while also explaining how the HoloLens should be worn and operated. By selecting the "Browse Artifacts" option from their heads up display, users would be presented with pre-sorted artifacts based on their site of origin. After selecting from a prehistoric or historic grouping, users would be presented with a listing of all the sites bearing artifacts. Users could then browse through all the artifacts belonging to an individual site, navigate between sites, or switch between prehistoric and historic catalogues. Though this section is very similar to the current iteration of the project, it improves upon the initial concept by freeing users from having to use a screen in order to view and interact with artifacts. The next section will utilize more of the HoloLens' capabilities by providing individuals the ability to customize their experience in order to curate their own virtual museum, reminiscent of the Cabinets of Curiosity of the past.

While allowing individuals to interact with pre-made virtual environments enables

the distribution of virtual artifacts and information, it's lacking in terms of customization towards users' individual interests. By utilizing the HoloLen's ability to "pin" holograms to real world objects, we are able to curate a virtual museum using our physical surroundings. Once a user has selected the "Construct a Collection" option, he would be presented with a listing of all artifacts as well as detailed filters based on information such as construction material, size, weight, age/time period, and the site of origin. Search tools also enable users to utilize a virtual keyboard on their heads-up display, allowing both keyword and exact match searches if there is a specific artifact an individual wants to explore. Once a user has found an object of interest, they would be able to pin it to a spot in their physical location. Users could continue to populate their physical space with artifacts of their choosing, or auto-populate their space based on similar tags or frequently chosen characteristics from the list of filters. After having chosen their artifacts, users would then be able to walk around their physical location in order to inspect artifacts in 3D while also viewing artifact summaries and other pertinent information. The configuration of artifacts could be saved, loaded, and shared with other users of the platform. Users are able to navigate through the museum they have created while displaying a narrative they have constructed from artifact histories. In comparison to the original application, this upgraded version would be capable of more fully realizing a combination of Malraux's Musée Imaginaire and the customization aspects of the Cabinet of Curiosity.

The Virtual Cultural Heritage Project demonstrates that it is feasible to create an immersive experience utilizing only commercially available hardware and has the potential to offer purveyors of cultural heritage information opportunities to attract non-traditional prospects. Those entering the virtual environment can curate their own experience, based on their interests without set or limited paths. A virtual environment enables us to transcend existing physical and geographic limitations.

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Appendix A. Glossary of Terms

AECOM An infrastructure and support services firm providing support in the markets of transportation, environment, energy, oil and gas, high-rise buildings, government and more. AECOM is headquartered in Los Angeles. Following its merger with URS Corporation, AECOM boasts approximately 100,000 employees operating worldwide.

Agency The possibility of self-determinant action; how a subject understands himself as an actor in an environment, as well as how a subject's effect on an environment might be gauged. A more narrow definition by Coleman presents agency as user creation with networked media tools.

Advisory Council on Historic Preservation (ACHP) The Advisory Council on Historic Preservation (ACHP) is an independent agency of the United States government that promotes the preservation, enhancement, and productive use of the nation's historic resources, and advises the President and Congress on national historic preservation policy. ACHP is the only entity with the legal responsibility to encourage Federal agencies to factor historic preservation into Federal project requirements.

Area of Potential Effects (APE) The geographic area or areas within which an undertaking may directly or indirectly cause changes in the character or use of historic properties, if any such properties exist.

Georeference To associate something with locations in physical space. The term is commonly used in the geographic information systems (GIS) field to describe the process of aligning geographic data such as physical maps or rasters to a known coordinate system so it can be viewed, queried, and analyzed with other geographic data.

Mediation The process of mediating. To mediate is to act through or be dependent on.

Multi-Stereo Method See Photogrammetry.

Museum Without Walls Andre Malraux's montage of artistic photographs from around the globe. His montage stretched throughout time from Roman sculptures to impressionist paintings.

National Historic Preservation Act of 1966 (NHPA) The legislation which established ACHP in 1966. The goal of which is to have Federal agencies act as responsible stewards of the nation's resources when their actions affect historic properties.

Perceived presence The extent to which a VR environment becomes dominant, or when users respond to situations in the VR environment more so than in the physical world.

Photogrammetry The use of photography in surveying and mapping to measure distances between objects. The output of photogrammetry is typically a map, drawing, measurement, or a 3D model of some real-world object or scene.

Presence The sense of being there in a mediated environment, or the degree to which users feel as if they are somewhere other than the location in which they are experiencing the digital simulation. Presence is also judged on the extent to which individuals feel they visited a place, rather than just viewing images generated on a computer or other digital technology. Presence can be considered as a psychological state in which virtual objects are experienced as actual objects in sensory or cognitive ways. In the world of pervasive media, presence is defined as the perceptual illusion of non-mediation.

Shape-from-Silhouette Method (SFS) A 3D model or shape reconstruction method which estimates the size and shape of an object by utilizing silhouette images of the original object. By using multiple views of the same object, the field of view for each still image aids in the constructing of a volume that is guaranteed to contain the original object.

Simulacra A likeness or similarity; Used to describe a representation of another thing, such as a statue or a painting, especially of a god; an image without the substance or qualities of the original

State Historic Preservation Office (SHPO) The state historic preservation office (SHPO) is a state governmental function created by the United States federal government in 1966 under Section 101 of the National Historic Preservation Act (NHPA). The purposes of a SHPO include surveying and recognizing historic properties, reviewing nominations for properties to be included in the National Register of Historic Places, reviewing undertakings for the impact on the properties as well as supporting federal organizations, state and local governments, and private sector.

Tribal Historic Preservation Office (THPO) In 1992 the U.S. Congress adopted amendments to the National Historic Preservation Act (P.L. 102-575) that allow federally recognized Indian tribes to take on more formal responsibility for the preservation of significant historic properties on tribal lands. Specifically, Section 101(d)(2) allows tribes to assume any or all of the functions of a State Historic Preservation Officer (SHPO) with respect to tribal land. The decision to participate or not participate in the program rests with the tribe.

URS Corporation An engineering, design, and construction firm and U.S. Government contractor. Headquartered in San Francisco, URS has over 50,000 employees in roughly 50 countries. Now AECOM.

X-Reality Defined by Coleman as a state of pervasive mediation that encompasses both the virtual and the real. In short, we are neither virtual or real, but instead we are networked individuals whose technologically mediated exchanges directly impact our worldly experience.

Appendix B. Site Listing & Descriptions

Site I - 1026 Shackamaxon Street, Remer [56]

This domestic home site, located at 1026 Shackamaxon Street in the Kensington neighborhood of Philadelphia, is named for the family that occupied this property in the late 1700s and early 1800s. The first member of the family to reside on the site was Matthew Remer (circa 1758-1804). Matthew's father Godfrey immigrated to Philadelphia from Germany in the early 1750s and eventually settled in the village of Kensington, as this area was known at the time. Godfrey was a butcher by profession and built a house for his growing family on Shackamaxon Street, near the corner of Richmond Street (this property is now underneath I-95).

In 1778, Godfrey purchased an adjoining property which included the current 1026 parcel for the newly married Matthew, who moved into a frame house already constructed on the site. A ship carpenter by trade, Matthew served during the Revolutionary War in a militia artillery regiment raised from the men living along the Kensington waterfront. During the war, his most notable contribution to history occurred on the eve of George Washington's famed crossing of the Delaware River to attack Hessian forces in Trenton, New Jersey. As men and equipment were being assembled for that assault, Matthew Remer was one of six men who were handpicked to inspect and repair the boats that would carry Washington and his troops, across the ice-choked river.

After Matthew's death in 1804, the home was passed to his widow Sarah, and then their children upon her death in the 1820s. By the late 1830s, Matthew and Sarah's daughter Elizabeth Conner Strawn had become the sole owner of the property after buying out her siblings. Upon her death in 1853, she divided the property and the four houses that had been erected upon it by this time among her four daughters, with Eliza Conner receiving the frame house on the current 1026 parcel. Eliza resided in the house at 1026 for brief durations from the 1850s through the 1870s, but usually rented it out to a number of tenants, which including a policeman, a comb maker, a cigar maker, and a poultry seller.

In 1879, Eliza returned to the house with her son John C. Smith, who was employed as a wood turner. John married Theresa Bierker, and together they may have operated a funeral home for a time as a side business. When Eliza died in 1898, John and Theresa bought out the other heirs, moved the frame house to the rear of the property, and constructed a two-story brick home in the front. The Smiths continued to reside at 1026 Shackamaxon with their daughters Bertha and Gertrude into the 1920s, when John and Theresa died.

In 1928, Gertrude sold the house to Francis and Helen Matthews, who in turn rented it to Catherine Mulholland and her son, and then to the family of Helen Matthews's brother, Martin Watt. Francis Matthews' mother, Anna Matthews, and nephew, Philip Mallon, resided in the rear dwelling until Anna's death in 1935. Philip

subsequently moved into the main dwelling and was replaced by boarder John Davis.

In 1940, the Matthews sold the house to Bernard and Bessie Betlejewski, who used it as a rental property for nine years before selling it to Edward and Catherine Herlihy, the final owners of the house before it was seized under eminent domain for the construction of I-95.

Site II Cumberland Street, Hope Farm/Richmond Hall [57]

Throughout the historic period lands contained within the study area had escaped intensive development, and consequently have never experienced the kinds of ground disturbances that characterize most urban environments, and neighboring sections of Philadelphia. Situated atop a low, Late Pleistocene-age terrace adjacent to the Delaware River, this area from the mid-17th through early 19th centuries consisted of open meadow or agricultural grounds contained within the expansive rural estates of Swedish and English colonists. In the mid-19th century the project area became part of the Reading Railroad's massive Port Richmond Coal Yard along the Delaware waterfront, and was buried beneath several feet of fill and active rail sidings. While the train track had been removed from this property prior to excavation, the project area remained devoid of development and conditions within the site had not changed appreciatively in the past 100 or more years.

During the 17th century, lands along the west bank of the Delaware River were first settled by Europeans and became incorporated into the colony of New Sweden. By the 1650s lands encompassing the present study area had been broken out into distinct land grants, were cleared, and were being actively farmed by members of the Cock, Rambo, and Nelson families among others. These individuals regularly interacted with groups of the local Lenni Lenape tribe, who continued to inhabit the vicinity.

After 1664, this area was transferred to English control, and gradually the early Swedish colonists were bought out and replaced by British settlers looking to establish large rural estates along the shores of the Delaware River. In or around 1709, English planter Anthony Palmer moved from Barbados to the Philadelphia region, purchased the land containing the study area, and established a country home which he named "Hope Farm". Palmer eventually enlarged his land holdings to nearly 700 total acres and built an estate for himself and his family on the terrace overlooking the river, approximately 200-250 feet east of the current study area. The estate consisted of the main house and several outbuildings, and included at least three enslaved Africans to help work the land and keep house. Between his arrival and death, in 1749, Palmer served for more than 40 years as a provincial councilor for Pennsylvania, and in 1747 became governor of the colony.

Palmer resided at Hope Farm for some 25 years before selling the property and moving a short distance to the south to Thomas Fairman's former estate in what is now the neighborhood of Kensington. Sometime around 1729, Hope Farm was purchased by English immigrant William Ball. Ball either enlarged Palmer's existing manor house or built a new one entirely, and changed the name of the estate to "Richmond Hall" (the surrounding modern neighborhood Port Richmond derived its name from Ball's estate). Ball remained in residence here until his death, in 1740, when the estate passed to his son, William Ball, Jr. After the son's death, in 1810, the property remained in the family until 1821, after which the legal disposition of the land seems to have been tied up in ongoing court battles for some time.

In 1837, at least a portion of the former Ball estate was sold to the Philadelphia and Reading Railroad for the construction of their massive Port Richmond Coal Terminal complex, though it is not clear if this initial purchase extended south to include the study area. Historic maps from the 1840s show a handful of non-railroad related buildings in the general vicinity of the study area, including “McQuaid’s Tavern”, along the north side of Cumberland Street, and a Steam Boiler Factory to the north of the former Richmond Hall house location. By and large, however, maps from the mid-19th century period seem to indicate that the land encompassing the excavation area remained undeveloped, if not completely vacant.

Sometime between 1867 and 1875, lands containing the study area were incorporated into the Reading Railroad Port Richmond Coal Terminal. At this time the area was likely filled in with several feet of fill to accommodate the laying of track. Within this sprawling complex, this location seems to have played a somewhat peripheral role, and was never a part of the main arterial track lines that brought thousands of tons of coal to the riverfront wharves every day. Though a number of small buildings were constructed in this area over successive decades, available map information suggests that these primarily served as weigh stations and freight platforms, or fulfilled other secondary railroad related functions. The use of this terminal for coal shipments declined after World War II, and eventually most rail lines through the property fell into disuse and were removed. Under Conrail’s ownership of this property, beginning in 1976, areas in the vicinity of the study area were vacated and allowed to become overgrown. Today no active rail lines traverse this portion of the former Port Richmond Terminal property.

Site III Richmond St and Plum St, Dyottville Glass Works [58]

In 1771, Robert Towars and Joseph Leacock built the first glass factory in the area, the Philadelphia Glass Works; it was located on the property immediately north of the Dyottville Glass Works. In 1774, John Hewson erected a calico printing works between the north bank of Gunner's Run and the Philadelphia Glass Works. In 1816, John Hewson Jr. became a partner in the firm Hewson, Connell —& Company and announced that they would build a new glassworks on their lot, which adjoined the old glassworks* lot. City directories list their glass factory on "Queen near Gunner's Run" from 1817 to 1822.

In 1816, John Hewson Jr. constructed the Kensington Glass Works on the site of the former printing works. This brick building, with stone foundations and a single furnace chimney, was probably the 1816 glass factory structure that Thomas Dyott took over in 1830 and operated until 1838. The bank of Gunner's Run was probably wharved with a timber bulkhead in the early nineteenth century. After Thomas Dyott's business failure in 1837, the glassworks remained idle for a few years. The Lehigh Coal and Navigation Company acquired Dyott and other lands along the riverfront and built a coal depot that became Port Richmond. The company rented the former Dyottville Glass Works to Henry Seybert in 1842. Seybert sold his interest in the factory two years later to Henry Benner and others, and a series of business partnerships continued the glassworks under the name of Dyottville Glass Works until 1923.

*In general reference, glassworks appears here in its contemporary, single-word usage.

Appendix C. Artifact Inventory

Remer Site Artifacts



Projectile Point



Chert Point



Projectile Point



Projectile Point



Chert Point



Sewing Thimble



Stoneware Kiln Furniture



Stoneware Kiln Furniture



Gun Flint



“Shackamaxon” Spectacles



Coin



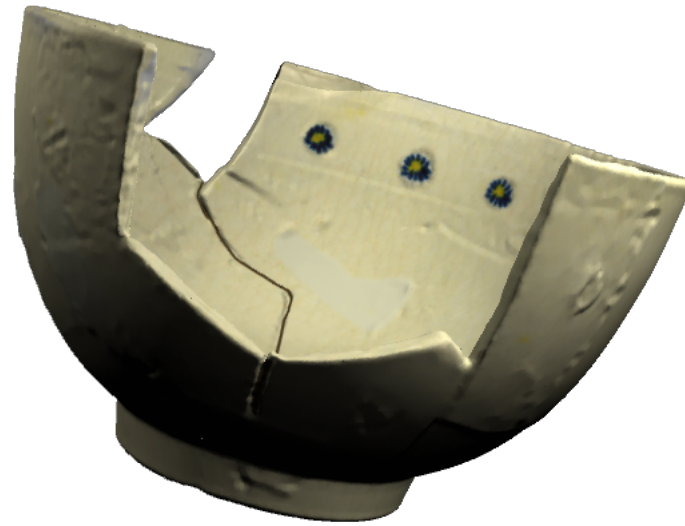
Bone Button



Rusted Nail



Refined Redware Teapot



Tea Cup



Tea Saucer



Teapot



Teapot



Bone-handled Fork



Creamware Plate

Hope Farm/Richmond Hall Artifacts



Gorget



Argillite Preform



Prehistoric Ceramic



Prehistoric Pipe Stem Fragment



Ground Stone Tool



Crinoid (fossil)



Argillite Biface



Jasper Biface



Projectile Point



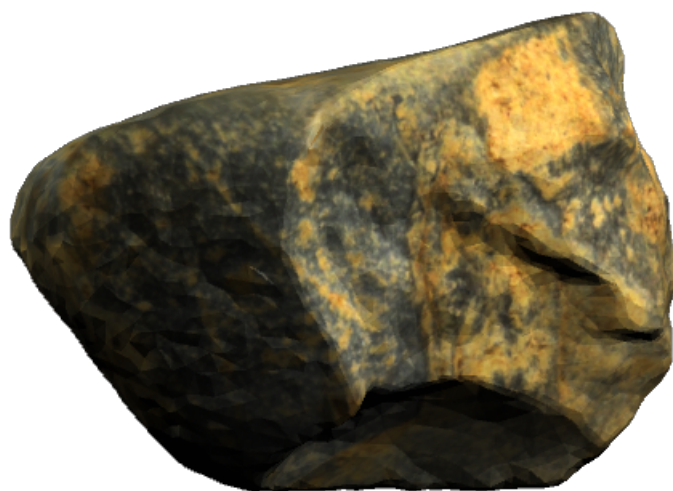
Flake Tool



Quartzite Biface



Utilized Jasper Flake



Pebble Tool



Prehistoric Ceramic Sherd



Nepheline Raw Material



Argillite Point



Argillite Point



Pipe



Prehistoric Ceramic



Rim Sherd

Dyottville Glass Works Artifacts



Hand Axe



Melted Glass



Melted Glass



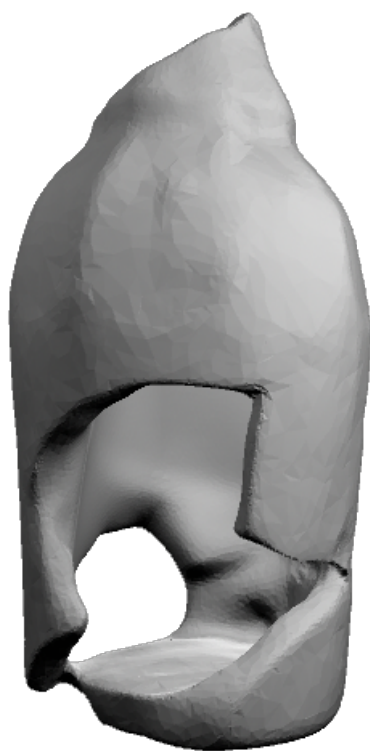
Washington & Taylor Flask



Pipe Fragment



Louis Hillemann Bottle



Body and Base of Small Bottle (possibly cologne)



Body Fragment of Figural Flask with Portion of "Ship the Franklin"



Crucible/Melting Pot Fragment



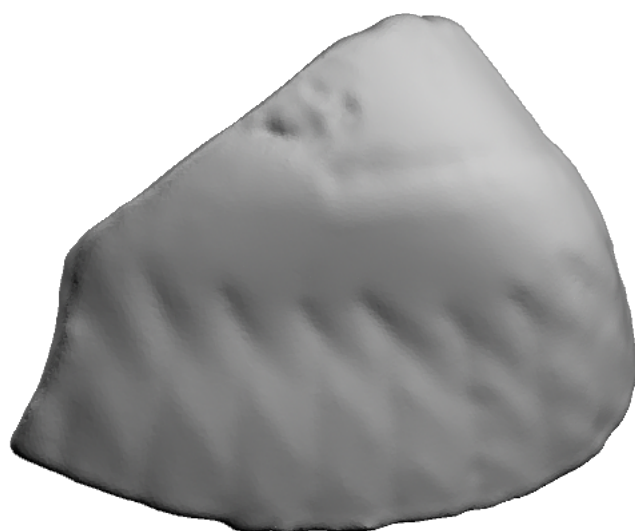
Melted Bottle Finish/Lip



Mouth & Shoulder of Snuff Bottle



Base Fragment "Turlington's Elixir" Bottle



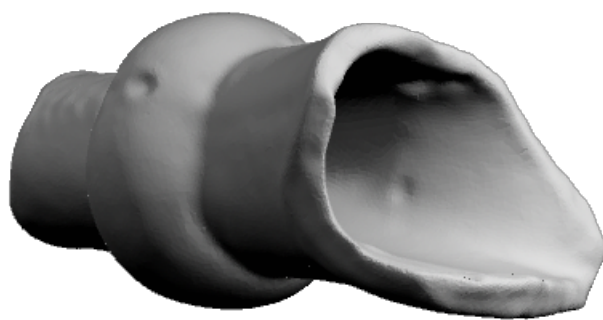
Shoulder Fragment of Ribbed/Pocket Flask



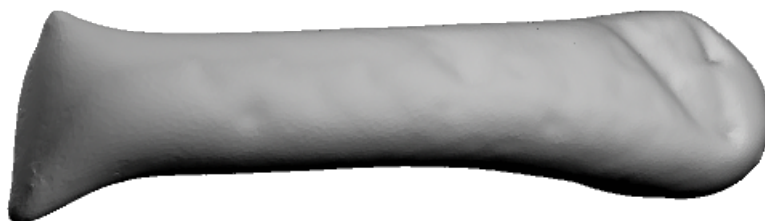
Flass Flask



Body Fragment from "London" Mustard Bottle



Neck and Finish of Figured Cologne Bottle



Unidentified Tooled Glass Fragment



Glass Cane



Melted Bottleneck & Lip



Grape Pungent Bottle

Appendix D. Kinect Technical Specifications Comparison

Feature	Kinect 1.0	Kinect 2.0
Color Camera	640 x 480 @ 30 fps	1920 x 1080 @ 30 fps
Depth Camera	320 x 240	512 x 424
Max Depth Distance	4.5 M	4.5 M
Min Depth Distance	40 cm in Near Mode	50 cm
Horizontal Field of View	57 degrees	70 degrees
Vertical Field of View	43 degrees	60 degrees
Tilt Motor	Yes	No
Skeleton Joints Defined	20 joints	26 joints
Full Skeletons Tracked	2	6
USB Standard	2.0	3.0
Supported OS	Win 7, Win 8	Win 8
Price	\$299	\$150

