3D PRINTING FOR MARITIME HERITAGE: A DESIGN FOR ALL APPROACH

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This thesis examines issues in accessibility to maritime cultural heritage. Using the Pillar Dollar Wreck in Biscayne National Park, Florida, this thesis presents an approach to public outreach based on the concept of Design for All. Design for All advocates creating products that are accessible and functional for all users, including those with visual, hearing, learning, mobility, or economic impairments. As a part of this thesis, a small exhibit was created that uses 3D products as a way to bring maritime cultural heritage to the public. It was presented to the public at East Carolina University's Joyner Library.

Additionally, this thesis presents a methodology for 3D printing scaled photogrammetry models of archaeological sites in full color. This methodology can be used to present a realistic depiction of underwater archaeological sites to those who are incapable of accessing them in the water. Additionally, this methodology can be used to present underwater archaeological sites that are inaccessible to the public due to conditions such as visibility, depth, or protected status.

The use of 3D modeling and photogrammetry in maritime archaeology is currently at the forefront of many methodological discussions. This thesis contributes to the field of maritime archaeology in that it takes archaeologists one step closer to answering the question of, "So

what?," particularly concerning 3D modeling and archaeology. This thesis presents a practical use for 3D photogrammetry models, as well as an accessibility strategy to expand the outreach potential for maritime archaeology.

3D PRINTING FOR MARITIME CULTURAL HERITAGE: A DESIGN FOR ALL APPROACH

A Thesis

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By

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1.1 Introduction

In recent years, use of photogrammetry to record underwater and maritime archaeological sites has become an increasingly popular tool to both document sites and to make them accessible to the public. The use of 3D imaging and modeling technology in archaeology is a dynamic part of the field with room for constant improvement. These techniques and products have the potential to vastly increase knowledge, of both the scientific and public communities, regarding underwater cultural heritage. Creating 3D models of submerged cultural heritage benefits both archaeologists and the public in many ways. Archaeologists can record information for relatively low cost, while leaving heritage *in situ* for future study. Additionally, 3D models of shipwreck sites and other artifacts allow the non-diving public to experience underwater cultural heritage virtually. There is also the potential to 3D print models and utilize them in museums and other public outreach settings, without having to take artifacts through the expensive and time-consuming process of conservation. 3D printing has the potential to allow the public to interact with artifacts and sites through touch, something that is often not possible with a fragile artifact.

In the past, accessibility strategies that aim to bring submerged cultural resources to the public have varied, with different degrees of success. But few, if any, of these strategies have focused on bringing archaeological sites to *all* members of the public, including people with impairments and learning disabilities, and members of the deaf or visually impaired communities. In their 2014 paper, "3D Printing for Cultural Heritage: Preservation, Accessibility, Research and Education," Neümuller et al. state "We expect that 3D Printing will not only become vital in the field of reconstruction of objects, but also for research, documentation, preservation and educational purposes, and it has the potential to serve these purposes in an accessible and all-inclusive way" (Neümuller et al. 2014). The authors also suggest the use of a "design for all" approach to develop guidelines for the 3D printing of cultural heritage sites (Neümuller et al. 2014). Design for all is a broad concept that aims to "enable all people to have equal opportunities to participate in every aspect of society" (EIDD Stockholm Declaration 2004). When applied to the management of submerged cultural heritage sites, this approach could allow greater accessibility to a broader audience.

This thesis aims to examine the capabilities of 3D modeling regarding the accessibility of archaeological sites and to examine the use of a "design for all" approach and its application to accessibility in archaeology. Additionally, it will outline the process of turning data collection in the field into a 3D printed model, and will examine the capability of the use of 3D models in the interpretation of a submerged archaeological site for the public. This thesis will use the Pillar Dollar Wreck, located in Biscayne National Park, as its primary case study. Additionally, a small exhibit displaying a 3D printed model of the Pillar Dollar Wreck, following guidelines based around the design for all approach, will be produced, with the potential for additional products produced through the use of photogrammetry.

1.2 Accessibility to Inaccessible Sites

In 2017, the Professional Association of Dive Instructors, better known as PADI, reported an average of 900,000 scuba certifications globally per year, and over 25,000,000 certifications since the agency opened in 1967 (PADI Worldwide Corporate Statistics 2017). While these numbers seem large, it equates to less than .3% of the global population. Additionally, considering that many shipwrecks are located in mostly inaccessible conditions to the average person, such as deep water or black water, the ability of divers or snorkelers to visit shipwreck sites is seriously limited.

Underwater archaeologists and submerged cultural resource managers are put in a unique position, as many in the recreational diving community place pressure on managers to open underwater archaeological sites up to visitors. The editors of *Submerged Cultural Resource Management: Preserving and Interpreting Our Maritime Heritage* state,

> "… that the main purpose of archaeology is recovering information from archaeological sites, rather than promoting access to sites. However, underwater archaeologists have found themselves, by default, in this position as a strategy to manage the behavior of those who desire to experience the tangible remnants of history…The determination of which sites are open and closed to public access is based on the principles of archaeology, rather than on the desire to provide an opportunity to experience history, traditionally the purview of historic preservation" (Spirek and Scott-Ireton 2003:3).

Spirek and Scott-Ireton call for a historic preservation based approach to managing access to underwater cultural resources, which takes some of the pressure off archaeologists and resource managers to deal with issues of accessibility on their own.

Other archaeologists and resource managers have called for or utilized the creation of marine sanctuaries and underwater preserves, shipwreck trails for divers and snorkelers, and permitting systems that control the number of divers allowed to visit a shipwreck site per year. However, all of these strategies require that the public have access to the water itself, be that by boat or by diving or snorkeling.

Cultural resource managers must also consider the remaining 99.7%, or greater, of the population that does not have immediate in-water access to submerged cultural resources.

Museums with interpretive information and artifact displays are often the most popular platform for public interpretation. However, these museum displays commonly do not provide a realistic experience of visiting a shipwreck site to visitors. With the incorporation of 3D modeling and 3D printing, museums and other public interpretation platforms can take one step closer to presenting an experience to a non-diving person that is more like the experience of someone with the ability to visit an underwater archaeological site.

This thesis does not seek to lessen the importance or usefulness of marine preserves and shipwreck trails that provide in-water access to the public. Instead, it seeks to draw attention to and promote an accessibility strategy that creates a maritime cultural heritage product that can be enjoyed by all.

1.3 The Pillar Dollar Wreck

The Pillar Dollar Wreck, located in Biscayne National Park (site number BISC0035) in Homestead, Florida will serve as the case study for this thesis. Data collection was undertaken on the site during East Carolina University's Program in Maritime Studies 2016 summer field school, led by Dr. Jennifer McKinnon. This includes photogrammetric data, ship lines measurements using a goniometer, and traditional hand-drawn site plans.

The Pillar Dollar Wreck lies in 6.5 meters of water, close to the southern boundary of the park. The wreck is oriented on a bearing of 260/80 degrees, and its keel lists approximately 45 degrees to the north. There is a shallow patch reef in close proximity to the wreck, and is most likely the reason for its wrecking (McKinnon 2016:3). As Biscayne National Park is a popular destination for both locals and visitors, much of the park and its wrecks are heavily trafficked. However, as the site is often covered in sand and not completely visible to the public, and requires the use of a private boat to visit, it is an excellent case study for the discussion of accessibility.

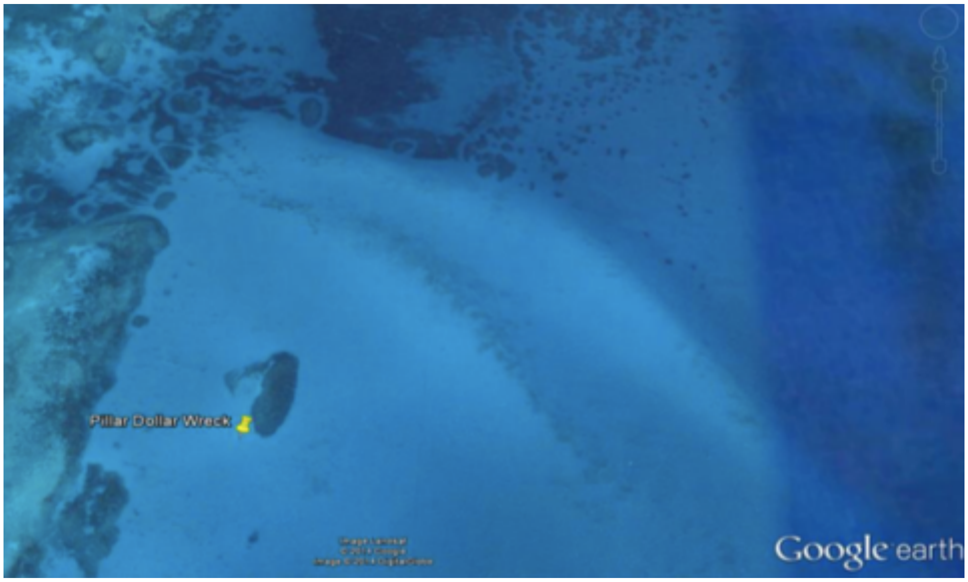


Figure 1. General location of the Pillar Dollar Wreck (J. McKinnon 2014).

The Pillar Dollar Wreck was heavily salvaged by treasure hunters in the 1960s and 70s. It was first described in Martin Meylach's *Diving to a Flash of Gold* in 1971. Meylach and his crew excavated the site in 1963, and claimed to have found cannons, Spanish pillar dollars (thus giving the site its name), a boarding cutlass, slave bracelets, candlestick holders, and a number of other small artifacts. The alleged pillar dollars date the site to between 1770 and 1778 (McKinnon 2016:5).

Bob "Frogfoot" Weller describes work undertaken on the site in his 2001 book *Galleon Alley*. He states that the site was found in 1965 by Art Sapp and Bobby Savage with a magnetometer, and then salvaged using airlifts. Several pillar dollars with dates ranging from 1760-64 were found (Weller 2001:96). He also states that Tom Gurr attempted to salvage the site in 1967 but found nothing (Weller 2001:97).

Biscayne National Park was created in 1984. At this time, the Pillar Dollar Wreck came under a management plan that included condition assessments of the site. An initial assessment of the site was conducted by National Park Service archaeologists, and was designated as a significant site (McKinnon 2016:6). Several archaeological assessments have been conducted since, including a survey conducted by John Broward, a Florida State University student, two field schools by East Carolina University (2014 and 2016), and continued archaeological assessments by National Park Service personnel (McKinnon 2016:6).

Unfortunately, little is known about the historical background and significance of the Pillar Dollar Wreck. While the wreck was carrying Spanish goods from the 18th century, this does not necessarily indicate that the ship is Iberian-built (McKinnon 2016:7). Using the approximate date from the pillar dollar coins found on the site, the ship was active until the 1780s. Maritime activity in south Florida at this time was largely British and Spanish, as the territory of Florida was volleyed between the two during the second half of the eighteenth century (McKinnon 2016:8). As such, the identity and origin of the Pillar Dollar Wreck remains a mystery.

1.4 Photogrammetry and 3D Printing

Photogrammetry is currently one of the most popular methods of creating 3D models for archaeology. By its most basic definition, photogrammetry is the use of a collection of photographs to take measurements and reconstruct sites. There are numerous software packages, many of which are user friendly and relatively cheap or free, that convert photos into photogrammetric 3D models. These include such programs as Agisoft Photoscan, 123D, and Autodesk Memento, all of which produce high-resolution, accurate 3D models. The past ten years have seen a vast improvement in this type of modeling technique. Photogrammetry is currently known as one of the easiest, cheapest, and most accurate forms of 3D modeling. Additionally, it is simple to export 3D models created with the use of photogrammetry as a .obj file, which are commonly used in 3D printing.

Digital 3D models can allow archaeologists to extract data from artifacts or sites without having to make repeat visits to a site. Additionally, it mitigates the need for an expensive and time-consuming conservation process. (Unless, of course, artifact excavation and conservation is a desired and necessary part of a project). Digital 3D models allow archaeologists to easily catalogue artifacts and sites, as well as share data with other researchers.

With the increase of internet accessibility, digital 3D models allow the non-diving public to access and explore shipwrecks and artifacts at leisure. This may also reduce damage to sites or artifacts, as the public now has the opportunity to "visit" the site without being physically present.

The use of 3D printing for outreach and educational purposes in maritime archaeology is a relatively unexplored tool. Several projects have been undertaken by large organizations and universities, such as the National Park Service Submerged Resource Center's 3D printing of small ship models and artifacts from the *USS Arizona,* Wessex Archaeology's 3D printing of the *Drumbeg* shipwreck site, and the work of both Louisiana State University and Virginia Commonwealth University in their archaeological 3D printing labs, both of which conduct 3D research on their respective projects, the Underwater Maya Project, and George Washington's Ferry Farm.

In 2014, researchers from the NPS Submerged Resource Center and Autodesk created 3D models of *USS Arizona*, both above and below the water, using a combination of LiDAR, Sonar, and photogrammetry (Krassenstein 2014). Small models of the ship were then 3D printed and given to survivors from the bombing of *USS Arizona*. Additionally, several artifacts found on deck of the ship were recorded using photogrammetry and 3D printed for use at the World War II Valor in the Pacific National Monument Visitors' Center (Brett Seymour 2017, pers. comm.)

In 2016, Wessex Archaeology scanned and printed the *Drumbeg* shipwreck site using photogrammetry, and printed a 3D sitemap. The team used a variety of software including Photoscan and Blender to create and prepare the model for printing (John McCarthy 2016, elec. comm.) The model is also digitally displayed on Sketchfab, an internet platform where users can upload and exhibit their 3D models.

In 2012, as part of the Underwater Maya Project, the Louisiana State University Digital Imaging and Visualization in Archaeology (DIVA) Lab was created to assist in the digital documentation of roughly 4,000 Mayan wooden posts found in a peat bog submerged beneath the seafloor. The posts, as well as related artifacts, make up 105 buildings used to mine salt. Using several different scanning and printing systems, the team imaged over 400 artifacts and printed over 600 3D replicas (McKillop and Sills 2013).

Additionally, using materials printed at the DIVA Lab, the Underwater Maya Project team opened two permanent exhibits in Belize that include plastic replicas of the site, accessible to visitors by boat (McKillop and Sills 2013). In this way, the public can visit the extremely fragile site without fear of damaging the artifacts.

The Virtual Curation Laboratory at Virginia Commonwealth University scans and 3D prints artifacts loaned to them from various museums and archaeological sites, including George Washington's Ferry Farm and the Virginia Museum of Natural History. These artifacts are scanned and printed, and often a 3D copy of the artifact is donated to the historic site for use in an outreach setting. This allows the public to interact with fragile artifacts, namely by touch, without the danger of damaging the artifact (Means 2014).

1.5 The Design for All Approach

As previously mentioned, the concept of “design for all” is broad. It aims “to make the use of products and services easier for everyone, and to ensure that the needs, wishes and expectations of users are taken into consideration in the design and evaluation processes of products or services” (Neümuller et al. 2014:122). The design for all approach outlines eight criteria: respectful, safe, healthy, functional, comprehensible, sustainable, affordable, and appealing (Design for All Foundation). These criteria can easily be applied to 3D modeling and printing for cultural heritage. Neümuller et. al suggest using those guidelines developed by the Art Beyond Sight Foundation or the North American Braille Authorities as a framework for developing similar guidelines for cultural heritage institutions. The authors site Alastair Somerville, “the real benefits of 3d scanning, modeling and printing come when we realize that they enable us to manipulate objects to any shape or scale we wish to enhance meaning” (Neümuller et al. 2014:123). The job of archaeologists, historians, and cultural resource managers is to extract and enhance meaning from the past, so that that knowledge can be shared.

3D modeling has already become an integral part of the archaeologist’s toolbox. 3D printing has the capability to further enhance the abilities of 3D modeling for public education and interpretation, conservation, and documentation. Standardized guidelines, particularly those based on a design for all approach, are necessary to create effective 3D printed models for public interpretation.

1.6 Research Questions

This thesis seeks to answer the following research questions:

Primary Research Question:

- Using the Pillar Dollar Wreck as a case study, how can the use of 3D models increase accessibility to inaccessible sites using a "design for all" approach for public interpretation and display?

Secondary Research Questions:

- What aspects of 3D models increase accessibility?
- What improvements can be made to the "design for all approach," and how can it be applied to the public interpretation of maritime cultural heritage?
- What is the "best practice" for designing 3D models using the "design for all" approach?
- What historical and scientific narratives can be extracted from the Pillar Dollar Wreck in the interpretation and 3D display?

1.7 Limitations

This thesis has the potential to be limited by the difficulty in creating guidelines for 3D printing using the design for all approach that is truly all-inclusive. This would require taking into account the special needs of *all* people with impairments and learning disabilities, as well as members of the deaf and visually impaired communities. This is nearly an impossible task. Instead, this thesis seeks to create guidelines for 3D printing tactile archaeological representations that makes inaccessible sites available to the public, while keeping the 3D printed interpretation true to the site.

Additionally, while the 3D printers available at East Carolina University are sufficient, they lack many new technical approaches, which limits some of the design approaches that can be tested and evaluated. Therefore, this thesis may be limited by funds and availability of technology.

1.8 Significance

Very little research has been conducted on the topic of 3D printing and underwater archaeology. Therefore, the results of this thesis will add considerable knowledge to the field. It will offer suggestions on how best to conduct 3D modeling with 3D printing as the end result for underwater archaeology. 3D prints of models open a wide range of outreach possibilities. 3D printing allows the non-diving public to experience a tangible piece of submerged cultural heritage.

Additionally, the use of a design for all approach to 3D printing for cultural heritage will help archaeologists and resource managers to better make underwater cultural heritage accessible to all people.

2 Historical Background

This chapter provides a brief historical background of Florida during the 18th century. Then, it provides a history of Biscayne National Park and its management to present day. This chapter also addresses the archaeological history and the history of treasure hunting on the site, as well as brief histories of significant artifacts found on the site. It addresses the identification of the Pillar Dollar Wreck, or lack thereof, and concludes with a brief discussion of ship construction.

2.1 South Florida History During the 18th Century

Prior to European contact, Florida's first people likely came to the area approximately 13,000 years ago. The Calusa people were South Florida's first people, relying heavily upon the estuarine resources of the area (Smith et al. 1997:6). Sadly, the Calusa were completely wiped out by the middle of the 18th century due to European contact, which brought enslavement, warfare, and European diseases (Smith et al. 1997:7).

The first contact of Europeans with Florida and its native people came with Ponce de León in 1513. Ponce de León and his crew came into contact with the Calusa people during his first voyage to Florida. One of these meetings was at St. Lucie Inlet, Biscayne Bay (Hoffman 2002). The Calusa offered fierce resistance to the presence of Europeans, but were among the tribes completely extinct by the mid-18th century.

The first permanent settlement in North America, St. Augustine, was founded in Florida in 1565 by the Spanish. Florida's most important role during this time was its position along the

Gulf Stream, which allowed Spanish ships to travel from the Caribbean through the Florida Channel to South Carolina, before sailing across the Atlantic towards Europe. Because of the gulf stream, Florida's coasts were far more important than its inland areas at this time (Smith et al. 1997:8). In addition to St. Augustine, two chains of Catholic missions were established in an attempt to Christianize Florida's native people (Smith et al. 1997).

The first Spanish period of colonial Florida was also characterized by the invention of the galleon. These ships were small and fast, and became famous for their use in the treasure fleets of the Spanish Crown (Smith et al 1997:8). The use of a convoy system of ten vessels or more in transporting goods was necessary to protect the Spanish trade monopoly on the area. These ships were often at risk of being attacked by pirates and privateers, as well as other nations who attempted to weaken the Spanish monopoly on trans-Atlantic trade (Price 2016). In addition to human threats, Spanish fleets were also in danger of hurricanes along the Florida coast, particularly in the narrow Florida Straits (Smith et al. 1997:8).

In 1763, Spain handed control of Florida to the British by way of the Treaty of Paris. This period of British control lasted from 1763 to 1784. The British attempted to move the Florida economy towards one based on commercial plantations, rather than an outpost subsidized by the government to protect shipping interests. Florida was incorporated into the British colonial mercantile shipping network. Animal hides, indigo, sugar, timber, citrus, rice, and naval stores were exported from Florida to other parts of the British Empire, and slaves were imported to the colony for the first time to provide labor for the newly established plantations. The British period also opened the interior of Florida via river navigation, and Florida's first road, the King's road, was established. The establishment of infrastructure and a colonial plantation economy increased European populations along Florida's rivers and coastal areas. Due to the coastal geology of the region, common vessel types during Florida's British period included small frigates, brigs, schooners, and sloops (Smith et al. 1997:10) that could navigate shallow areas.

In 1779, Spain took advantage of Great Britain's distraction during the American Revolution and invaded the western part of Florida. In 1783, the British ceded Florida back to Spain in exchange for the Bahamas and Gibraltar (Smith et al. 1997). While Florida's British period was short, it is important in its history due to the development of both internal and coastal infrastructure, adding products to its economy, and vastly changing the socio-economic climate of the territory through the establishment of slavery.

The second Spanish period was also relatively short, lasting from 1784 to 1821. Trade with native populations, continued agricultural production on Florida's plantations, and the export of naval stores remained important to the economy. Maritime trade continued between Florida and much of the Eastern coast of the United States, as well as with French settlements in the Gulf of Mexico (Smith et al. 1997). At the time of the sinking of the Pillar Dollar Wreck, this trade would have accounted for much of the maritime traffic in South Florida and the Florida Keys.

2.2 History of Biscayne National Park and its Management

The area of Biscayne National Park was first protected in 1968 by Public Law 90-606. This law established Biscayne National Monument. In 1974, under Public Law 93-477, the area was expanded, and redesignated as a National Park by an act of Congress, Public Law 96-287 (Management Plan) in 1980. The 1966 national monument proposal stated that the area represented the best remaining example of tropical forest in Florida, containing rare examples of terrestrial, marine, and amphibious species, some of which are not found in the rest of Florida.

Additionally, the report states, “Most significant of all the area’s attributes are the clear, sparkling waters, marine life, and the submerged lands of Biscayne Bay and the Atlantic Ocean. Here in shallow water is a veritable wonderland” (Proposal 1966:18).

Figure 2. Coral Reefs of Biscayne National Park (NPS, 2017).

The 1966 National Monument proposal proposes the boundaries of the protected area to extend to the 60-foot depth line in the Atlantic to the east, between Boca Chita and Sands Key to the north, through Broad Key and along the northern boundary of John Pennekamp Coral Reef State Park to the south, and to parallel the mainland along its western side. This created a public use National Monument of approximately 100,500 acres, 4,000 of which were land, and 96,500 of which were water. The primary goals of the 1966 proposal were to protect the natural resources of Biscayne Bay, as well as to protect submerged lands from changes in marine channels, commercial dredging and filling, and the water pollution of Miami. Additionally, it hoped to establish two visitor centers, one in Homestead and another in Key Largo, for visitors to congregate and take part in on and off water activities, such as boat tours and snorkeling. The proposal even suggests the use of “closed circuit underwater television” and “submerged viewing rooms” (NPS Proposal 1966:24). In addition to the two visitor centers, the monument hoped to establish three visitor contact points, on Elliott Key, Sands Key, and Adams Key. These visitor contact points would offer boat docking facilities, nature trails, picnic areas, and the interpretation of archaeological and marine features (NPS 1966).

The 1966 proposal briefly mentions the potential for submerged archaeological sites within the National Monument boundaries. This was supported by several small artifacts found on Sands Key during early investigations into the creation of a protected area. Specifically, the proposal states that pirates based themselves from several of the islands located within the National Monument, Elliott and Old Rhodes Key. This included such pirates as the Black Caesars. The proposal claims that Black Caesar the Second was said to have kept loot and prisoners on Elliot Key. It also states that Confederate General John Breckinridge sailed through Biscayne Bay to Elliot Key, where he escaped through Caesar’s Creek with what was left of the Confederate treasury (NPS 1966).

There were also known residents of Elliott Key and Adams Key, as both islands were granted to various settlers in the late 19th century. The proposal recognizes the potential for archaeological sites related to farming and homesteading during this time (NPS 1966).

Biscayne National Monument was expanded in 1974, and then further expanded when it was redesignated as a National Park. By 1980, the park included Boca Chita Key, famous for its 1930s era decorative lighthouse, the Ragged Keys, and Safety Valve shoals.

Figure 3. Biscayne National Park Boundaries, 1983. (BNP General Management Plan, 1983).

In 1983, a general management plan was written that included a development concept plan, a wilderness study, and an environmental assessment. This management plan hoped to instate management solutions for the recently expanded park, which now received more visitor use. The plan hoped to grant access to the non-boating public by establishing a public boat system that would visit the keys and coral reefs in the park, to improve the interpretive program, particularly at Elliott Key, to maintain current park development sites, to prevent further development within the park and to return the Ragged Keys and Soldier Key to a natural state and allow access to the public to these keys. Additionally, the management plan designated Boca Chita as a day use area for the public, prepared a cultural resource preservation guide to aid in management and site monitoring, and institute an integrated program to reduce visitor impacts to archaeological sites (NPS 1983).

The cultural resource management plan was based in compliance with the National Historic Preservation Act of 1966. All cultural resources would be preserved on site, if possible. If any area containing a cultural resource would be affected by construction or other human use, the park would adopt a least-impact management alternative. If impact was unavoidable, it would be mitigated through professional data retrieval using controlled excavation, recording, or "other acceptable means" (NPS 1983). The management plan laid out a monitoring system to evaluate and document archaeological sites within the park (NPS 1983).

Particularly regarding submerged archaeological sites, the management plan states that, "When funds are available, historic research and a systematic archaeological survey to locate, record, and evaluate submerged archaeological resources will be conducted" (NPS 1983:41). In particular, this plan hoped to survey the Offshore Reefs archaeological district, a 30 mile area of archaeological preserve, in hopes of revising the boundary.

In addition to archaeological survey, the park hoped to provide mooring buoys for the public at nonsensitive submerged archaeological sites that were deemed sturdy enough to "withstand intensive visitor use" (NPS 1983:41). At highly popular or sensitive sites, underwater signage would be installed to provide information regarding the protected status of those wrecks to visitors (NPS 1983:41).

Additionally, the 1983 management plan hoped to found interpretive programs that would foster public respect, appreciation, and knowledge of submerged archaeological sites, and to train park staff in underwater cultural resource management and recognizing the signs of illegal salvage operations (NPS 1983).

In 1998, a Historic Resource Study (HRS) was conducted on the park by Jennifer Brown Leynes and David Cullison of the National Park Service, as part of the park's effort to comprehensively document all historic structures and landscapes within the park. The HRS was to "serve as a tool for future site planning, resource management, and the continuing development of interpretive programs at the Park" (Leynes and Cullison 1998). However, it does not attempt to evaluate the significance of any of the defined resources. This study focuses on terrestrial historic resources within Biscayne National Park, particularly those of Boca Chita Key. Ultimately, the HRS makes recommendations to maintain and interpret the Honeywell complex on Boca Chita Key, and to update project statements for the park's cultural landscape inventory and cultural landscape report. Additionally, it recommended that the park should establish a building file system for historic structures within the park (Leynes and Cullison 1998). It does not appear that an HRS was ever conducted for submerged archaeological sites.

The park's final general management plan was released in 2015, to provide updated management strategies for the next 15 to 20 years. The ultimate goal of this management plan is to restore coral reef ecosystems within the park and to improve visitor experiences. The plan states that snorkeling and scuba diving are popular park activities, particularly from December to August. Most visitors who engage in scuba diving come as part of a dive club or with a local dive shop. Snorkeling is more common, as people who come to the park to engage in other activities may also snorkel. Snorkelers and scuba divers have the opportunity to visit six of the park's shipwrecks through the Maritime Heritage Trail, established in 2011. These wrecks include *Arratoon Apcar*, *Erl King*, *Alicia*, *Lugano*, *Mandalay*, and a 19th century wooden sailing vessel. Access to these wrecks is by boat only. The park installs mooring buoys at the sites, and produces waterproof cards containing information about each site for visitors (NPS 2015).

2.3 Treasure Hunting and the Pillar Dollar Wreck

The Florida Keys are infamously known for their association with treasure hunting, due in large part to the common misconception that Florida's waters are teeming with Spanish treasure ships. While many of these shipwrecks were salvaged at or near the time of their sinking, there are some well-known shipwrecks that were salvaged in modernity that became popular in the news. These include such wrecks as the 1715 Spanish fleet wrecks. The state of Florida has allowed the salvage of shipwrecks since the 1930s, which has caused a "mass consumption of maritime heritage" (Price 2016), as well as the compromising of numerous archaeological sites (Price 2016). The Pillar Dollar Wreck is no exception.

The Pillar Dollar Wreck is first mentioned in Martin Meylach's *Diving to a Flash of Gold*, published in 1971. In 1963, Meylach and his crew salvaged the wreck. He notes removing two cannon, an unidentified amount of Spanish pillar dollars, dating between 1770 to 1778, iron spikes and hinges, spoons, pieces of pottery and glass, a pair of slave bracelets, a hoarding cutlass, a pair of pewter candlestick holders, and other pewter artifacts. Meylach states, "Her timbers and ballast may conceal treasure still unfound… She is a treasure galleon in every respect" (Meylach 1971). See Appendix A for a full transcription of Meylach's book excerpt on the Pillar Dollar Wreck.

In 1965, the wreck was found again by Art Sapp and Bobby Savage, as stated in Bob "Frogfoot" Weller's book *Galleon Alley*. He states that Sapp and Savage, operating off the salvage boat *Norma*, used four-inch airlifts to excavate the site. Several pillar dollars dating between 1760 and 1764 were found, but "nothing else of great artifactual value" (Weller 2001). Weller also states that Tom Gurr and his crew visited the site but found "nothing at all" (Weller 2001), but does not specify when this event occurred (Weller 2001). See Appendix B for a full transcription of Weller's book excerpt on the Pillar Dollar Wreck.

The Pillar Dollar Wreck is also mentioned in Carl Ward's *Shipwreck in the Florida Keys* (2014). Ward states that himself and several other unknown salvors salvaged the site in 1966, but only "spikes" were removed (Ward 2014).

In 1986, after the Pillar Dollar Wreck had fallen under the jurisdiction of Biscayne National Park, park ranger Matthew Fulmer stopped three divers, Sidney Monroe Hood, William Hood, and Eric G. Hampton for a fisheries check, only to find buckets containing artifacts encrusted in marine growth, an underwater metal detector, and NOAA nautical charts with red circles drawn around areas located within the park. The men removed approximately 50 artifacts from a wreck site, most likely the Pillar Dollar Wreck, that included a coral encrusted pocket watch, a padlock, and large hull spikes (McKinnon 2015).

It is possible that other unknown illicit activity occurred on the site, but the above cases are the only ones with documentation.

2.4 Archaeological History

After the creation of Biscayne National Monument in 1968, the Pillar Dollar Wreck came under the jurisdiction of the National Park Service. Under the park's management plan, the site received semi-regular condition assessments. The first site report for the Pillar Dollar Wreck was completed in 1984 by Brewer and Wild, as part of a primary assessment of cultural resources within park boundaries. Brewer and Wild deemed the site "significant" and in need of further assessment.

The Pillar Dollar Wreck was assessed again in 1985 by John Broward, a Florida State University student. This was an initial on-site survey, at which time the Pillar Dollar Wreck was assigned site number BISC-0035.

In 1987, an ARPA damage assessment was proposed by Florida State University, but it is unknown if this assessment occurred.

In 1992, the National Park Service conducted a post-hurricane assessment of the site after Hurricane Andrew, which devastated the Florida Keys. No damage from the hurricane was noted, but there was evidence of some looting activity.

There are no known condition assessments between the years 1992 and 2004. From the years 2004 to 2010, either a condition assessment or a post-hurricane assessment was conducted. Two condition assessments per year for the years 2011 and 2012 were conducted, during which an illegal mooring on the site was found in 2012 (McKinnon 2015).

In 2014, Dr. Jennifer McKinnon, Dr. Lynn Harris, and a group of Masters students from East Carolina University conducted a Phase III survey on the Pillar Dollar Wreck under SEAC permit BISC 2014-001. This investigation included full-scale survey, excavation, and mapping. Goals of the project were to determine the vessel type, period, and cultural affiliation, study the distribution of the site, attempt to understand the possible reasons for wrecking, examine the cultural and natural impacts on the site, study the condition of the wooden structure and artifacts, examine construction details specific to cultural or temporal affiliation and provide possible wood identification, examine the artifact composition and context, and to make future management recommendations for the protection of the wreck (McKinnon 2015). McKinnon concluded that a catastrophic event or events impacted the hull structure of the wreck, as the garboard, hull planking, frames, and keel are disjointed. Additionally, the floors are no longer attached to the keel, and there are gaps between the hull planking and garboard (McKinnon 2015). A site identification has not been made. This is due in part to the contrasting cultural diagnostic features found on the wreck, including construction features and timber identifications (McKinnon 2015).

Figure 4. East Carolina University Excavation at the Pillar Dollar Wreck, 2014 (C. Lawson, 2014).

Figure 5. East Carolina University Excavation at the Pillar Dollar Wreck, 2016 (J. McKinnon, 2016).

East Carolina University returned to the Pillar Dollar Wreck in 2016 to continue excavation. The main goal of the excavation was to continue to uncover and record the site in full. Specific goals included the excavation of mobile sediment overlying the shipwreck structure, the collection, conservation, and curation of significant artifacts which may provide cultural or temporal affiliation or are in danger of being looted, full recording of all wooden structure, timber sampling for wood species and ship construction origin identification, and the publication of a site report. Research questions remained the same as those from the 2014 excavation. A significantly larger portion of the hull was excavated in 2016 than in 2014. However, few artifacts and no original context was found. The hull structure was recorded both manually through a traditional hand-drawn site plan, and photogrammetrically in 3D (McKinnon 2017). As the photogrammetric data for this thesis was collected during the 2016 excavation, the methods used will be discussed more in depth in the methodology chapter of this thesis.

2.5 Artifact History

During excavation, artifacts from the site were chosen for analysis and curation. These include glass, brick, ceramic, glass slag, fired clay, bone, stone charcoal, lead, UID iron, and iron fasteners (McKinnon 2015). For this thesis, models of an iron fastener and of a ceramic sherd made of Guadalajara Polychrome were created and 3D printed.

The Guadalajara Polychrome, also known as Mexican Type-A ware or Aztec IV, Tonolá Ware, Tonalá Brunida Ware, or "native Aztec pottery," (McKinnon 2015) was chosen due to its unique history. This type of ceramic, manufactured somewhere between 1650-1810 (Charlton and Katz 1979) or 1780-1830 (Barnes 1980) was believed to have cosmetic and medicinal effects when consumed (McKinnon 2015). Guadalajara Polychrome was highly valued by Europeans, and shipped in large quantities from the Americas back to Spain. Garcia Saiz (2003) suggests that the consumption of a paste made from the clay may have had a similar effect to consuming hallucinogens, as a trance-like state was sometimes reported after eating the clay. Additionally, when water was stored in vessels made from Guadalajara Polychrome, the clay gave it a distinct smell. It was known as "fragrant water," or *agua de olor* (Garcia Saiz 2003). Garcia Saiz states, "The delight that women found in this odd delicacy led to a habit called *bucarofagia* {a penchant for eating *búcaros*}. Their consumption became a common practice among Spanish women, reflecting a tradition that had been introduced throughout the Mediterranean by the Arabs" (Garcia Saiz 2003).

Figure 6. Guadalajara Polychrome (J. McKinnon 2015).

It would not have been uncommon for ships traveling from the Spanish-held parts of the Americas to carry vessels made from Guadalajara Polychrome, as the clay was very valuable. Even shards and dust from broken vessels were sold on the European market. In fact, they were so valuable that by the end of the sixteenth century, some pottery shops were attempting to recreate the Guadalajara Polychrome vessels from similar materials (Garcia Saiz 2003).

While Guadalajra Polychrome was most prominent on the Iberian peninsula, it also spread to other parts of Europe during the eighteenth century, and was commonly featured in many paintings of the time. One of the first known artists to paint Guadalajara polychrome in his work was Juan Van der Hamen. In his painting *Bodegón con Dulces y Ceramica,* the artist depicts a vessel made from Guadalajara polychrome next to candy and fruit, perhaps indicated that the vessel too, was an edible good (Garcia Saiz 2003).

Figure 7. *Bodegón con Dulces y Cerámica* by Juan Van der Hamen. (Natonal Gallery of Art, Washington DC, 2017).

The piece of Guadalajara polychrome found on the Pillar Dollar Wreck depicts a daisy pattern. Floral or animal scenes were common themes found on Guadalajara polychrome vessels (Garcia Saiz 2003). This artifact, while typical of the time, depicts an interesting cultural and personal perspective on the Pillar Dollar Wreck.

Additionally, an iron fastener from the Pillar Dollar Wreck was recreated using photogrammetry and 3D printed in plastic. More detail of the fasteners found on the Pillar Dollar Wreck can be found in the Ship Construction section of this chapter.

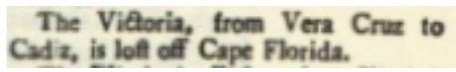
2.6 Site Identification

At this time, no positive identification of the wreck has been made (McKinnon 2017). However, the Pillar Dollar Wreck is referred to as *El Nauva Victoriosa* by several sources. The first and most detailed of these is Singer's *Shipwrecks of Florida: A Comprehensive Listing* (1998:107), in which Singer states that a Spanish nao, captained by Joseph Varan, left Cadiz on November 3, 1770, bound for Vera Cruz.. The ship wrecked in 1771 near the head of the Florida Keys by hitting a reef in approximately ten feet of water. The crew and many items aboard the ship were removed the following day. The wreck eventually settled to the west of the reef, in a sandy area. Singer notes that the wreck was salvaged in the 1960s and 1970s, and became known as the "Pillar Dollar Wreck" due to the large amount of pillar dollars found at the site. See Appendix C for a full transcription of Singer's description.

El Nauva Victoriosa is also mentioned in Robert F. Marx's *Shipwrecks in the Americas* (1987). It relays much of the same information as Springer, stating that the ship was lost sometime in 1771 at the entrance of the Bahama Channel, near Key Largo, with only the crew being saved.

Finally, *El Nauva Victoriosa* is mentioned in *The Caribbean and the Atlantic World Economy; Circuits of trade, money and knowledge, 1650-1914*. The authors state, "One anomalous cargo category was that of sumptuary goods, represented by a single shipment of specie on *El Nauva Victoriosa* bound from Spain to Vera Cruz in 1771. This seems unusual given the almost continuous shipments of metallic riches along the reciprocal route, from Mexico to Spain. One possible explanation is that by the 1770s, just prior to dismantling the *flota* system, so little silver resources remained in Mexico that specie for troop payments or other needs had to be imported from the stockpiles in the metropole" (Leonard and Pretel 2015).

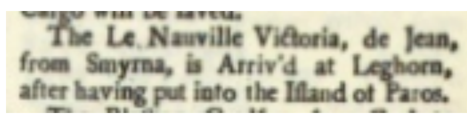
In searching for records of *El Nauva Vicoriosa* in primary documents, a note about a ship called *Victoria*, which sank off Cape Florida on its way from Vera Cruz to Cadiz in 1771 was found in the records of Loyd's of London for the years 1770 to 1771. Founded in 1688 and still in business today, Loyd's of London insured many merchant ships in the eighteenth century (Lloyd's 2017). Figure 2.7 shows the short excerpt from the register that mentions *Victoria*.



The Victoria, from Vera Cruz to Cadiz, is loſt off Cape Florida.

Figure 8. Mention of *Victoria* in Lloyd's List (Lloyd's List 1770-1771).

Additionally, a record for a ship with a name similar to *El Nauva Victoriosa* was found in Lloyd's List in the records for November of 1771. This ship, called *Le Nauville Victoria*, was reported after *Victoria* was lost off Cape Florida. The record of *Le Nauville Victoria* states "*Le Nauville Victoria*, de Jean, from Smyrna, is arrived at Leghorn, after having put into the island of Parros" (Loyd's List 1771). An image of this record is displayed in Figure 2.8.



The Le Nauville Victoria, de Jean, from Smyrna, is Arriv'd at Leghorn, after having put into the Iſland of Paros.

Figure 9. Mention of *Le Nauville Victoria* in Lloyd's List (Lloyd's List 1770 – 1771).

While *Victoria* and *Le Nauville Victoria* have similar names or travel routes to the reported *El Nauva Victoriosa*, there is still little evidence that either of these ships could be the true identity of the Pillar Dollar Wreck. Neither of the ships appeared in Lloyd's Register for the years 1770 to 1776, meaning that their size was likely not recorded by the insurance agency, making it impossible to compare construction data. Additionally, the name *Victoria* may have been a common name for an eighteenth century merchant vessel, meaning that multiple recordings of ships by the same name could occur. The record of *Victoria* and *Le Nauville Victoria* serve as an example for the difficulties in historical and archival research when identifying an unknown shipwreck that no longer has its original archaeological context.

2.7 Ship Construction

McKinnon (2017) compares known measurements of seventeenth and eighteenth century Iberian tradition or used shipwrecks with the Pillar Dollar Wreck. Of the known archaeological examples, the Pillar Dollar Wreck is the largest of all, as its largest scantling measures 550 tons. The scantling measurements suggest that the Pillar Dollar Wreck would have been an extremely large, heavily built ship (McKinnon 2017).

Fastener patterns of the Pillar Dollar Wreck support the theory that it could have been Spanish built, as Spanish shipbuilders often used iron fasteners in place of wooden ones in an effort to prevent degradation of the wood (McKinnon 2017).

As part of this thesis, ship's lines from the scantlings will be taken using the photogrammetry model created for 3D printing. If successful, this may suggest a better picture of what the Pillar Dollar Wreck may have looked like as a sailing ship. This process is further discussed in the Methodology and Results chapter of this thesis.

2.8 Conclusion

Throughout the history of Biscayne National Park, efforts have been made to provide greater access of the park's numerous natural and cultural resources to the public. The use of closed-circuit underwater television, submerged viewing rooms, glass bottom boat tours, guided snorkel and scuba dive trips, the placement of public access mooring buoys, and the creation of a maritime heritage trail were all proposed as management strategies to increase accessibility to Biscayne National Park's submerged heritage. While not all of these tools were implemented by the park, many of them have allowed diving and non-diving visitors alike to see a glance of the underwater world.

The identification of the Pillar Dollar Wreck is still a work in progress. However, visitors to Biscayne National Park are still able to enjoy the shipwreck as a cultural resource. It is hoped that this thesis will bring archaeologists one step closer to identifying the shipwreck and allow access to its history for all.

3 Literature Review

3.1 Introduction

3D modeling has become an important component of virtually every maritime archaeologist's toolbox in recent years. 3D modeling allows archaeologists to rapidly record sites or artifacts in great detail, digitally preserve sites at risk, bring sites in inaccessible places to the public, and engage with online viewers from all over the globe. With 3D modeling, the capacity for engaging museum and archaeological site visitors expands to accommodate a public that is increasingly accustomed to interactive museum displays and exhibits.

There are numerous ways of recording archaeological sites and artifacts in 3D. These include photogrammetry, structured light, laser scanning, digital reconstruction using a total station, ground penetrating radar, and LiDAR. Additionally, there are a variety of software packages, often used in combination with one another, to process 3D data into a model. This is further supported by the use of additional software used to 3D print a model, particular to the 3D printer that is used. While the steps to creating and printing a 3D model can seem long and complicated, the benefits of using hands-on displays in museums or for archaeological outreach far outweigh these perceived complications.

This chapter seeks to provide an overview of current uses of 3D printing and modeling in maritime archaeology and history outreach settings and discuss how and why this is important to the future of the discipline. The chapter begins with a discussion and introduction on how 3D printing is currently being used in archaeology and museums, followed by a section on current research and 3D modeling and photogrammetry. It concludes with a discussion of how 3D printing is being used in the field of maritime archaeology in particular.

3.2 3D Printing in Archaeology

In his 2014 paper entitled "Handing the Past to the Present: The Impact of 3D Printing on Public Archaeology," Allen Huber studied statistics of Smithsonian museum visits, comparing the National Air and Space Museum to both the National Museum of American History and the National Museum of the American Indian. In 2012, the Smithsonian Institution's National Air and Space Museum received an estimated 6.8 million visitors. The same year, the combined number of visitors for the National Museum of American History and the National Museum of the American Indian totaled 6.4 million (Huber 2014). In 2016, the combined number of visits for these museums totaled an estimated 4.9 million, while the number of visits to the National Air and Space Museum had escalated to an estimated 7.5 million visitors (Smithsonian Institution, 2017). The National Air and Space Museum includes traditional exhibits, as well as attractive, interactive features such as combat jet simulators and demonstrations on topics related to flight and space. The National Museum of American History and the National Museum of the American Indian include almost solely traditional exhibits that do not allow the visitor to interact with materials. Huber suggests, "a key difference between science museums and history museums lies in the barriers that a history museum is forced to put up between its visitors and its exhibits. Hands-on exhibits are crucial to drawing in the target audience of many museums, children and their parents" (Huber 2014).

The changing nature of the way in which the public receives and interacts with information on a daily basis leaves archaeology and history at somewhat of a disadvantage. Due to the fragile nature of many historical artifacts, it is often impossible to allow untrained handlers, such as the average museum visitor, to touch and interact with artifacts. Additionally, many archaeological sites, particularly those that are submerged, are inaccessible to a large portion of the population. A site may be found in deep water, water with zero-visibility, or may be in extremely fragile condition, rendering it all but unavailable to the public. The use of 3D recording and modeling, as well as 3D printing, has the potential to change how the public has access to their cultural resources.

In their 2014 paper "3D Printing for Cultural Heritage: Preservation, Accessibility, Research and Education," Neümuller et al. state "We expect that 3D Printing will not only become vital in the field of reconstruction of objects, but also for research, documentation, preservation and educational purposes, and it has the potential to serve these purposes in an accessible and all-inclusive way" (Neümuller et al. 2014). Neümuller and his colleagues discuss several archaeological projects in which 3D printing is being used in some way. Harvard's Semitic Museum houses one of two ceramic lions that originally stood guard next to an image of the goddess Ishtar in a temple at Nuzi, Iraq. The lion stored at the Harvard Semitic Museum is in fragments, whereas the second lion, kept at the Pennsylvania Museum of Archaeology and Anthropology, is in a well-preserved state. The Semitic Museum hired an outside contractor, Learning Sites Inc., to reconstruct the lion using photogrammetric scans from both lions. It was then reproduced using 3D printing and CNC milling, and put on display so that museum visitors could experience the artifact as it was originally meant to look (Neümuller et al. 2014).

PhD student Fangjin Zhang of Loughborough University is currently working on the restoration of artifacts from the Forbidden City in Beijing. Zhang is utilizing both laser and optical scanners to capture the object, repairing the model, and then 3D printing a replica (Neümuller et al. 2014).

Cornell University is currently engaged in a project entitled "3D Printing of Cuneiform Tablets." Cornell houses a collection of approximately 10,000 Mesopotamian tablets, and is printing replicas of the tablets using powder-based ink to reproduce the texture of the original tablet. The project also seeks to explore methods in which the cuneiforms can be printed at higher resolutions to reproduce fine details (Neümuller et al. 2014).

The Virtual Curation Laboratory at Virginia Commonwealth University seeks to "create digital models of artifacts and ecofacts from historic and prehistoric sites for research, teaching, and, increasingly, outreach efforts…" (Means 2014). The Virtual Curation Laboratory partners with museums and other sites of cultural significance, including George Washington's Ferry Farm and Historic Jamestown to digitally preserve and 3D print their collections. 3D printed replicas of artifacts have allowed museum and archaeological site visitors to interact with artifacts in ways that would otherwise not be possible. Among these artifacts is a replica of an ivory compass, used in educational outreach efforts at Historic Jamestown. The replica was printed in plastic and then painted to closely resemble the original. The Virtual Curation Laboratory plans to continue their work with 3D printing and education, particularly concerning school-aged children in an effort to expand archaeological education to younger generations.

The largest use of 3D data and 3D printing in an archaeological museum setting is currently by the Smithsonian Institution. In 2013, the Smithsonian launched "Smithsonian X 3D," a digitization project for cultural and scientific heritage.

> "Smithsonian X 3D launches a set of use cases which apply various 3D capture methods to iconic collection objects, as well as scientific missions. These projects indicate that this new

> technology has the potential not only to support the Smithsonian mission, but to transform museum core functions. Researchers working in the field may not come back with specimens, but with 3D data documenting a site or a find. Curators and educators can use 3D data as the scaffolding to tell stories or send students on a quest of discovery. Conservators can benchmark today's condition state of a collection item against a past state – a deviation analysis of 3D data will tell them exactly what changes have occurred. All of these uses cases are accessible through the Beta Smithsonian X 3D Explorer…" (Smithsonian Institution).

The Smithsonian Institution is home to a collection of 137 million artifacts, including objects, artwork, biological specimens, and remains. Although the Institution as a whole is made up of twenty-two different museums and galleries, as well as the National Zoo and research institutes, only 1% of the entire collection can be displayed at any one time. The Smithsonian's Digitization Program hopes that the Smithsonian X 3D project will make more of the Institution's collections available to the public at any given time. Because digitizing every piece at the Smithsonian would take 260 years of 24/7 work, approximately 10% of the collection has been prioritized for digitization (Smithsonian Institution).

Currently, the Beta Smithsonian X 3D Explorer interface is home to only a small selection of artifacts from across the members of the Smithsonian Institution. The selection includes such artifacts as a model of a Greek slave from the American Art Museum, incense burners and ritual ewers from the Freer Gallery of Art, fossilized dolphin skulls from the Smithsonian Tropical Research Institute, and Amelia Earhart's Flight Suit from the National Postal Museum. Additionally, the Smithsonian has included 3D models of entire archaeological sites and architectural elements, such as the Jamestown Chancel Burial Excavation, the gunboat *Philadelphia*, and the Qorikancha Wall.

The webpage of the Smithsonian X 3D project also includes a section in which K-12 educators can find materials for their classrooms. While the creators of Smithsonian X 3D state that they are working on new resources for education programs, there is currently an e-book, "The Mind behind the Mask: 3D Technology and the Portrayal of Abraham Lincoln," available for use involving 3D data and printing using digitized copies of casts made of Abraham Lincoln's face. The lesson discusses using photogrammetry to create 3D models, as well as an interactive history component using primary sources and digital data to teach a lesson about both Abraham Lincoln and how people are portrayed in history (Smithsonian Institution).

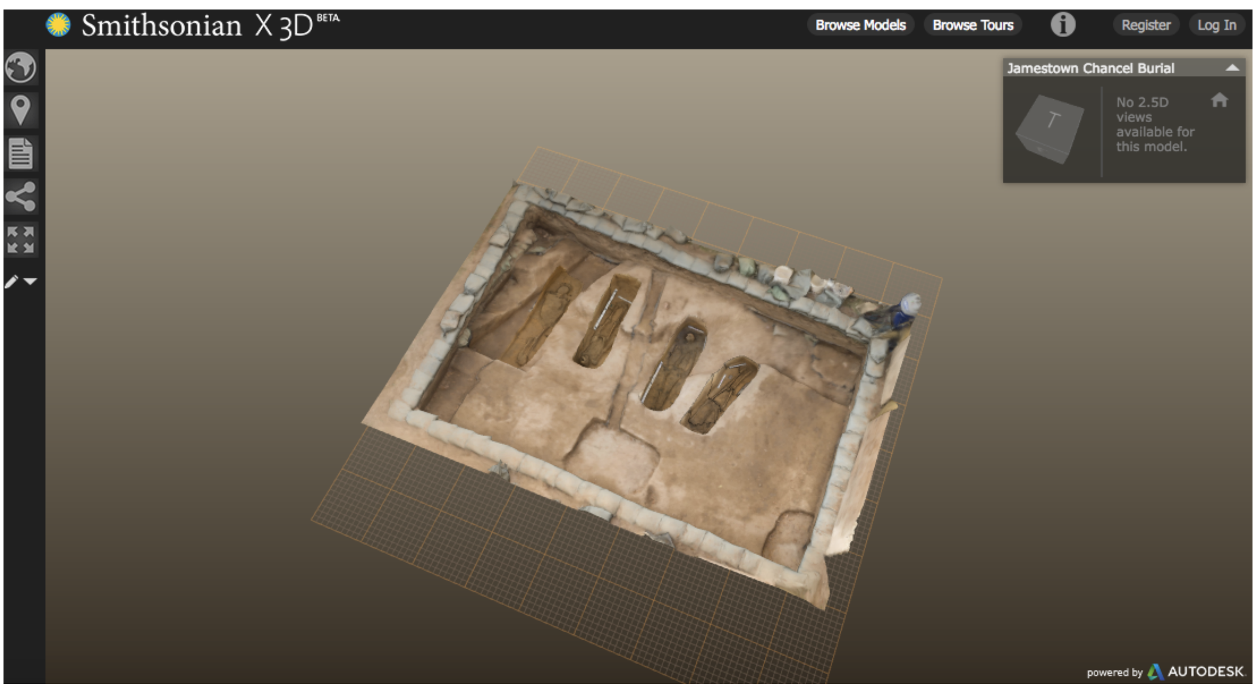


Figure 10. Beta Smithsonian X 3D Explorer representation of the Jamestown Chancel Burial excavation project (Smithsonian 2017).

The Smithsonian X 3D project is an excellent example of the ways in which historical, archaeological, and digital data can be combined to create an exciting and engaging way to present information to younger generations.

At the Calvert Marine Museum, Collections Manager and paleontologist John Nance is using 3D printed replicas of fragile dinosaur fossils in educational programs for students at an early elementary age through high school. When the museum began incorporating 3D printing into their educational programming, Nance noted that it was well received by students, as they had the chance to physically put their hands on and interact with an object. While the museum is currently using 3D prints only for educational programs, they plan to expand to incorporate 3D printed materials into exhibits in the near future. The museum hopes that putting 3D printed artifacts on display will allow rare specimens to be seen and handled by the public, and that the incorporation of more technology will attract more visitors (John Nance per. comm. 2017).

The past decade has seen a great deal of technological advancement in the potential to expand the public's access to cultural resources through digital media. Many museums and programs, such as the Smithsonian Institution, see value in incorporating 3D documentation and 3D printing into their education and interpretive material.

3.3 Current Research in 3D Modeling and Photogrammetry for Maritime Archaeology

While there are many examples of the use of 3D documentation and 3D printing in terrestrial archaeology and history, its use in maritime archaeology is relatively new. Circumstances such as the need for water-proofing cameras and scanners, as well as drawbacks such as attempting to document submerged sites and artifacts in poor water clarity has caused the technology to progress more slowly.

The concept of photogrammetry itself for maritime archaeology is not new. The first use of photogrammetry in underwater archaeology was by George Bass in 1963 to record the *Yassi*

Ada 2 wreck, using the submarine *Ashera*. Bass and his team created a photomosaic with the collected photos, and were able to measure the shipwreck and create a 3D model of the upper layer of the wreck (Drap et al. 2015). Archaeologists and divers alike continue to use photomosaics as a tool for recording shipwreck sites. However, as technology has developed, photogrammetry, or the creation of a three-dimensional model using photos digitally stitched together, has increasingly gained in popularity.

Numerous projects in recent years have focused on developing photogrammetry as a tool for maritime archaeology. In 2014, John McCarthy and Jonathan Benjamin conducted a study entitled "Multi-Image Photogrammetry for Underwater Archaeological Site Recording: An Accessible, Diver-Based Approach." The authors discuss the potential for using photogrammetry as a low-cost solution for recording underwater sites in 3D, using case studies in Denmark and Scotland. McCarthy and Benjamin were able to produce accurate 3D models of the sites from photosets captured in a mere 20 minutes. They were also able to create additional products with the 3D models, including animated fly-throughs of the wrecks and projected reconstructions of parts of artifacts missing from the site (McCarthy and Benjamin 2014).

A 2014 study conducted by Massimo Martorelli, Claudio Pensa, and Domenico Speranza investigated the possibility of using photogrammetry to generate lines drawings of historic vessels. The authors used three case studies (*Tomahawk, Refola,* and *Nada)* to test using photogrammetry and the iterative method to analyze vessel shape. This procedure produced three accurate lines drawings, and was compared for accuracy with the actual vessel using an RE laser scanner. The authors suggest this work as a methodological basis for creating an archive of lines drawings of historic vessels (Martorelli et al. 2014).

A group of researchers from the University of Venice (Balletti et al.) conducted a study in 2015 using photogrammetry and 3D reconstruction to document and measure cargos of marble on two Roman shipwrecks. Photogrammetric and topographical surveys were conducted, and 3D reconstructions of the wreck sites were created using Agisoft Photoscan. The authors conclude that photogrammetry is an inexpensive and accurate method for rapidly documenting underwater archaeological sites. Additionally, they suggest that the creation of 3D models has the potential to expand the options for management and exploration of wreck sites, particularly to the non-diving public, using display systems such as virtual reality headsets (Balletti et al. 2015).

In "The ROV 3D Project: Deep-Sea Underwater Survey Using Photogrammetry: Applications for Underwater Archaeology," Drap et al. present a methodology for surveying underwater archaeological sites in deep water using remotely operated underwater vehicles. The authors found that using an ROV for photogrammetric survey allowed for real-time results, as well as providing uniform coverage of the site. This process also allows for zero disturbance to the site, as well as removing the need to put a diver in the water. Drap et al. surveyed the site of the *Cap Bénat 4*, found at 328 meters below the surface with a single dive. The authors found that the use of this method allowed for the survey of complex structures and produced more complex and detailed results than traditional survey methods (Drap et al. 2015).

> "Graphic representations of archaeological sites such as drawings, sketches, watercolors, photographs, topographies, and photogrammetries are an essential phase when talking about surveys… In a certain way, this sets the foundation for the further development of this work: surveys are both a metric representation of the site and an interpretation of the same site by the archaeologist" (Drap et al. 2015).

In 2015, T. Van Damme of the University of Southern Denmark produced a study using photogrammetry to create 3D models of underwater archaeological sites in low-visibility environments. Using the Straatvaarder wreck as a case study, Van Damme discusses the use of

Agisoft Photoscan to process data collected using a GoPro HERO3 Black edition camera in visibility conditions ranging from one meter to 50cm. Video collected using the GoPro had to be taken very close to the wreck, often only 20cm away, so as to ensure that all necessary data was obtained in a way that Agisoft Photoscan could detect sharp features. In order to collect the data this way, 15 dives were conducted over the course of four days, and 181 short videos were recorded. Approximately 40% of this data was used to create the actual 3D model. A full photogrammetric model of the wreck site was produced by modeling 11 separate chunks, and then aligning the individual chunks to create one model. The model was also used to produce a lines plan, profile drawings, a digital elevation model, and an enhanced mesh. Van Damme concludes that due to the progression of photogrammetric technology and software, photogrammetry is a viable option for producing accurate 3D models and 2D representations of underwater archaeological sites in low visibility conditions. Additionally, Van Damme conducted a literature survey of the use of photogrammetry in underwater and maritime archaeology since the basic technology was made available in the 1960s. He found that while it was popular in its beginning stages, use of photogrammetry in the discipline decreased until recent years due to the benefits of photogrammetry not outweighing the advantages until the technology became more affordable and more accessible (Van Damme 2015). The author states that, "The overall result is that today, using Computer Vision Photogrammetry software such as Photoscan, photogrammetry is easier to use, more flexible, more reliable and more affordable than ever before, while at the same time producing more accurate and more complete results than those attainable at any time in the past" (Van Damme 2015).

In 2012, Fabio Menna and Erica Nocerino presented a methodology for "Hybrid survey method for 3D digital recording and documentation of maritime heritage." The authors propose a hybrid multi-technique approach for maritime heritage preservation, using the 3D documentation of a scale model warship, *Indomito* as a case study. The authors also discuss the use of the case study as part of a digital documentation preservation effort to the Parthenope University of Naples maritime museum. Menna and Nocerino argue that the use of 3D documentation as a means of preservation has been vastly underutilized in the field of maritime archaeology. They propose using a combination of photogrammetry and laser scanning to create highly-detailed, accurate representations of artifacts, such as scale model. The authors conclude that using the photogrammetry laser-scanning hybrid method is a low-cost procedure for 3D modeling complex objects, and can be used for creating both a 3D model for physical replicas or technical analysis, or for creating online databases to document significant elements such as hulls, weapons, life boats, etc. (Menna and Nocerino 2012).

Yamafune, Torres, and Castro's 2016 paper "Multi-Image Photogrammetry to Record and Reconstruct Underwater Shipwreck Sites," presents photogrammetric methodology used to reconstruct a 19th century shipwreck in southern Brazil, the Lagoa do Peixe site, and the 16th century Gnalic wreck in Croatia. The authors present both the methodology used and other potential uses for the 3D model. These include using photogrammetry to produce orthophotos, data collection and storage, two-dimensional maps, profile sections, lines drawings, artifact catalogues, timber catalogues, virtual tours, hull analysis, and site analysis (Yamafune et al. 2016). Yamafune's work, including his 2016 PhD dissertation, "Using Computer Vision Photogrammetry (Agisoft Photoscan) to Record and Analyze Underwater Shipwreck Sites," provides the most detailed methodological framework for using Agisoft Photoscan, commonly the most accepted software within the archaeological community for photogrammetric modeling.

3.3 Utilization of 3D Modeling and 3D Data in Maritime Archaeology and History Outreach

The use of 3D modeling in underwater and maritime archaeology and maritime history outreach has also progressed more slowly than its terrestrial counterparts for the same reasons outlined above in addition to complications such as the need for water-proofing, therefore making equipment more expensive, delays in technological developments as makers of 3D software adapt it to an underwater environment, and training professionals to use 3D modeling and scanning equipment underwater. However, as technology has developed and adapted to the underwater environment, archaeologists have begun using 3D modeling products from underwater sites in a variety of different ways.

The Smithsonian Institution, as previously discussed, uses 3D data through their Beta Smithsonian X 3D Explorer program. Through this platform, the Smithsonian hopes to provide the public with better access to their collection including maritime-related objects. The Calvert Marine Museum, also as previously discussed, has plans to expand use into the maritime history department.

The Antique Boat Museum in New York utilized CAD documentation for lines from several boats in their collection as part of a documentation grant, but otherwise does not use 3D data in exhibits or programming (Claire E. Wakefield 2017, elec. comm).

The U.S. Brig *Niagra* has an exhibit kiosk in the museum which uses an animated 3D reconstruction of the vessel to demonstrate sailing maneuvers. While this is currently the museum ship's only use of 3D data in an exhibit or educational setting, they have also used 3D modeling to aid in redesigning the ship as part of a mid-life rebuild project. The marine architect in charge of this project used CAD as the primary medium (Joseph T. Lengieza 2017, elec. comm).

For the first time, the Lake Champlain Maritime Museum integrated the use of photogrammetry into their summer maritime archaeology field school. The museum's outreach and education coordinator, Allyson Ropp, integrated photogrammetry models into the LCMM educational curriculum (Allyson Ropp 2017, elec. comm).

Nauticus, a maritime museum located in Norfolk, Virginia, is also home to the battleship *Wisconsin*. At the entrance to the ship, the museum has placed a 3D interior model of the battleship. The museum intends for the 3D model to be used by patrons with disabilities to increase accessibility and exploration for all. Additionally, the museum plays 3D films on a large viewing screen in the museum. The film rotates, but is always on a maritime subject. Nauticus continues to explore the potential of 3D technology. The museum is currently in the planning stages of a 3D virtual reality experience that involves the feeding of sharks from the museum's third floor shark cage.

The Smithsonian Institution has educational materials for children involving 3D printing available on the Smithsonian X 3D Explorer program website. In addition, the Smithsonian is also using 3D printing to craft select exhibits. In 2016, the Smithsonian partnered with Miller 3D, Alfred University, and artist Walter McConnell to create an exhibit entitled "Chinamania." The exhibit, displayed at the Smithsonian's Arthur M. Sackler Gallery, focused on porcelain-based blue and white pottery from China's Kangxi period. 3D printing was used to create replica pieces for display. The Smithsonian used photogrammetry to record the ceramics. McConnell corrected shadows and color variations in the models. Then, the models were transferred to

Miller 3D, where they were scaled down to 40% of the original size (Millsaps 2016). This is illustrated in FIGURE 2.3.

Figure 11. "Chinamania" 3D Printed Ceramics at the Arthur M. Sackler Gallery (Photo: Arthur M. Sackler Gallery, 2016).

The ceramic replicas are displayed in the Arthur M. Sackler Gallery. The planned exhibit will last from July 9, 2016, to June 4, 2017.

The Calvert Marine Museum, while already using 3D printing for educational programming for children in their paleontology department, is currently making plans to expand their 3D printing program to include the maritime history division. The museum is home to a rare, antique boat motor, that is displayed in the "Maritime Patuxent: A River and Its People" exhibit. In the past, the museum has had problems with collectors of antique boats and/or motors taking parts directly from the displayed motor, as the parts are difficult to come by elsewhere. The museum plans to 3D print a replica of the motor for display to discourage museum patrons from stealing from the exhibit (John Nance per. comm).

The National Park Service's Submerged Resources Center (SRC) regularly uses various 3D data collection systems to record archaeological sites found within the nation's National Parks system (Brett Seymour 2017, pers. comm). In 2014, SRC, in partnership with Autodesk, used photogrammetry and 3D printing to record the *USS Arizona* at Pearl Harbor. The Autodesk team used their Recap software, which stitches photographs together to form models of section of the ship, as well as selected artifacts found on the deck. The result produces a textured 3D representation of the artifact. A 3D printed bottle found on deck of *USS Arizona*, made using photogrammetry, is shown in Figure 2.4.

Figure 12. 3D printed bottle from *USS Arizona*. (3DPrint.com 2015)

The models were created in Autodesk Recap and touched up for 3D printing in Autodesk Mudbox. In addition to the bottle, a 3D model of a cooking pot found on *USS Arizona* was also printed (Krassenstein 2014). Finally, small models of the battleship were 3D printed to give to survivors of the attack on Memorial Day 2014, presented by members of the combined Submerged Resources Center and Autodesk team (Brett Seymour 2017, pers. comm). Survivor

Don Stratton was present that day. "When presented with the 3D print of the cooking pot for the first time, Stratton said, 'That is amazing. I don't know anybody in the galley that survived that day. At the time of the explosion, it was self-preservation. After that, it was extremely hard to return. Now, when I go back and remember, it's a little easier. I think it [3D artifacts] will make an impression on a lot of people, I really do'" (Hurley 2014).

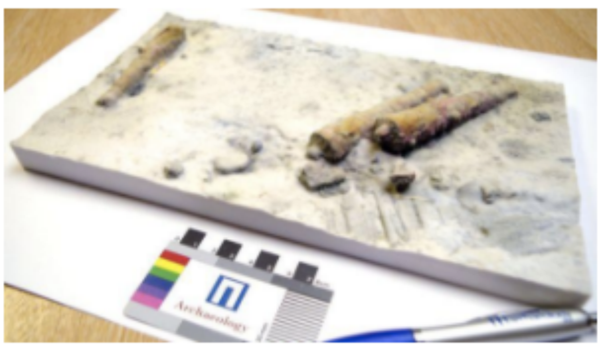
In addition to the work at the Valor in the Pacific National Monument, the National Park Service's Submerged Resources Center has recorded underwater archaeological sites in Biscayne National Park and Dry Tortugas National Park, both in Florida. An animated 3D GIF of a Cuban chug vessel was created for outreach purposes at Biscayne National Park. At Dry Tortugas, imaging specialists from the SRC took 3D video for use in a 3D interpretative film for visitors, available in the park's visitor's center (Jeneva Wright 2017, elec. comm). The Submerged Resources Center oversees all the underwater cultural resources found within the National Park system. As the purpose of the National Parks is to provide natural and cultural resources experiences for visitors, they are constantly seeking new ways, including 3D, to interpret and engage with the public (Jessica Keller 2017, elec. comm).

At Louisiana State University, the Digital Imaging and Visualization in Archaeology (DIVA) lab is creating 3D images and prints of fragile, waterlogged artifacts from the Underwater Maya Project in Belize. This project began in 2004 when a collection of wooden Mayan buildings, as well as the only known Mayan canoe paddle were found in a peat bog beneath the seafloor. Over 4,000 wooden posts and 105 individual buildings were mapped out between 2005 and 2009, and determined to be a collection of salt-works buildings. The site became submerged due to sea-level rise, and was protected by peat for thousands of years formed from red mangroves. Perishable items that were protected by the peat and water became susceptible to quick deterioration once they were removed from the site, and researchers became interested in using 3D recording and 3D printing as a form of conservation. In 2012, LSU and the Underwater Maya Project opened two permanent exhibits in Belize using 3D printed artifact replicas. One exhibit is in Punta Gorda, and the other is in Paynes Creek National Park, and is accessible only by boat. Both exhibits use 3D printed artifact replicas, as well accompanying posters and texts to interpret the sites to visitors (McKillop and Sills 2013). “Exhibits using 3D replicas of artifacts integrate the Underwater Maya Archaeology project with local tourism in southern Belize and inform descendant Maya communities about their heritage, thereby helping to protect the ancient sites by ‘sustainable archaeological tourism’” (McKillop and Sills 2013). The Underwater Maya Project’s exhibits are an excellent example of the ways in which 3D printing can be used to interact with the public, as artifact loans and security are not a necessary part of the exhibits.

In 2016, Wessex Archaeology conducted two projects resulting in two of the world’s first fully 3D printed underwater archaeological sites. The first of these sites, the Drumbeg shipwreck in Scotland, lies in 12 meters of water in Eddrachillis Bay. The site consists of three cannon, two anchors, and partial hull remains. The site was located in the 1990s by two local scallop divers. Wessex archaeology is still conducting research on the identity of the vessel, but believe it may be the *Crowned Raven*, a Dutch ship that sank in the winter of 1690 or 1691 while sailing from the Baltic Sea to Portugal, carrying timber and hemp (McKenzie 2016). The Drumbeg shipwreck site was first surveyed in 2012, and has undergone several surveys since then, using sonar, magnetometer, and photogrammetry. The 3D model was created using a combination of these data sets (Wessex Archaeology 2016).

The second site Wessex Archaeology 3D printed, *HMHS Anglia*, is much larger than the Drumbeg site. Archaeologists used multibeam sonar to capture the shape of the wreck, and 3D printed the sonar data as a tangible topographic map (Wessex Archaeology 2016). The ship, a floating hospital, was sunk in 1915 after hitting a mine laid by a German U-Boat.

Wessex Archaeology hopes that 3D printing will be able "to show the wider community what it's like to visit the site without having to learn to dive or even get your feet wet! We hope that future surveys by our team can result in more models which can be used in local and national museum displays and at talks and open days" (Wessex Archaeology 2016).



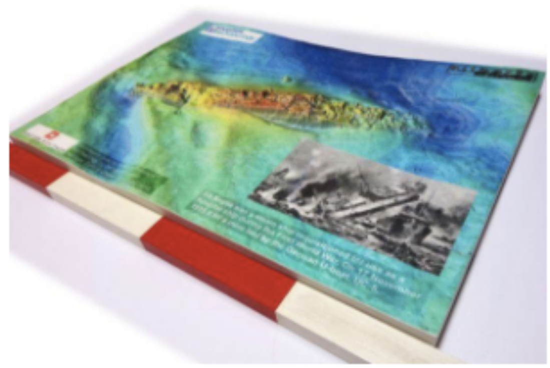


Figure 13. 3D Prints of Drumbeg shipwreck site and *HMHS Anglia* shipwreck site. (Photo: Wessex Archaeology, 2015)

The i-Mare Culture project is a collaborative project based out of Europe that includes several European universities and research institutions. The first objective of the project is, broadly, to study classical and Hellenistic maritime culture through the spatial analysis of GIS maritime data, oceanic, and weather data. Additionally, the project seeks to create a digital 3D library of ships, amphorae, and anchors. Each artifact displayed in the 3D library will also have a digital narrative, media content, and a storytelling component to accompany it. The creation of this 3D library is in an effort to study and analyze wreck site formation processes in order to create virtual reality applications. Additionally, there is a public outreach component to the i-Mare Culture project. The collaborators hope to create both a seafaring game and an underwater exaction game in which the public can explore both ancient trade routes and the work of a maritime archaeologist (i-Mare Culture 2017).

While the i-Mare Culture project has not yet produced their desired deliverables, this kind of contribution would potentially allow anyone with access to the internet to interact with maritime history and underwater archaeology via a 3D platform.

Discussion and Conclusion

3D printing offers a new direction for traditional history museums. Instead of simply allowing visitors to stare at artifacts inside glass boxes, 3D printing allows museums to "…reintegrate touch, and other non-retinal senses into our cultural experiences" (Neumuller et al. 2014). Using 3D printing also allows for greater accessibility to cultural heritage for all, but offers great benefit to those with learning disabilities and visual impairments, as well as to children. Neumuller et al. discuss Katherine J. Kuchenbecker's study on haptography, or the recording of tactile experiences, which found that a sense of touch is often extremely important for comprehension. The authors also suggest the use of a "Design for All" approach, which takes into account two simple principles: "to make the use of products and services easier for everyone, and to ensure that the needs, wishes, and expectations of users are taken into consideration in the design and evaluation processes of products or services" (Neumuller et al. 2014). The authors suggest this as a way to standardize 3D printing methodology to increase inclusivity in access to cultural heritage. Handicapped and visually impaired accessibility to cultural heritage is a poorly discussed topic in the world of archaeology. Some museums, such as Nauticus, state that their use of 3D technology, such as the interior model of the Battleship

Wisconsin, is intended to promote handicapped accessibility and exploration (Dustin Uhl 2017, elec. comm). The Design for All approach offers a solution and guidelines to continue working towards inclusivity in cultural heritage.

The 2001 UNESCO Convention on the Protection of Underwater Cultural Heritage cites *in situ* preservation as the recommended first option for the preservation of underwater cultural heritage. “The *in situ* preservation of underwater cultural heritage (i.e. in its original location on the seafloor) should be considered as the first option before allowing or engaging in any further activities. The recovery of objects may, however, be authorized for the purpose of making a significant contribution to the protection or knowledge of underwater cultural heritage” (UNESCO). The use of 3D documentation and 3D printing has great potential to uphold UNESCO’s recommendations for *in situ* preservation, as well as to bring better public access to these *in situ* sites. With 3D printing, archaeologists can document wrecks on the seafloor without disturbing the site, print the artifacts and/or topography, and allow the public to interact with underwater cultural heritage without ever having to set foot (or fin) on the site.

3D data and 3D printing has the capacity to record inaccessible underwater archaeological sites and sites at risk, uphold UNESCO’s recommendations for *in situ* preservation, and provide greater access to underwater cultural heritage to the public.

4 Archaeology, Accessibility, and the Design for All Approach

4.1 Accessibility and Archaeology, including Maritime Archaeology

The idea of the shipwreck has always captivated the minds of the public. Archaeologists and cultural resource managers have tried a variety of strategies to provide access to an intrigued public. These strategies include underwater shipwreck trails for divers and snorkelers, walkable maritime heritage trails, underwater preserve systems, traditional museum interpretation, glass bottom boat tours, and increasingly, web-based access to resources. Several challenges arise when providing public access to cultural resources such as shipwrecks. Questions arise including "Who should have access to underwater cultural resources?" "How do managers provide access without damaging the integrity of archaeological sites?" and "How can these resources be shared with those who cannot dive or snorkel?" The following chapter provides a discussion of some of the issues presented by common accessibility strategies and proposes using a Design for All approach to maritime cultural heritage interpretive and education programs.

Some strategies used in an attempt to provide access to submerged cultural resources have included shipwreck trails and preserves, traditional interpretive museums, glass bottom boat tours, and guided dives and snorkels on shipwreck sites. However, all of these strategies present the same issue. They require a large amount of mobility, and many are not suited for visitors with hearing, vision, or learning impairments.

4.2 The Design for All Approach

The Design for All Foundation (DFAF) defines Design for All, also referred to as universal design, as “the intervention into environments, products and services which aims to ensure that anyone, including future generations, regardless of age, gender, capacities or cultural background, can participate in social, economic, cultural and leisure activities with equal opportunities” (Design for All Foundation). The DFAF lays out a specific set of criteria that encompasses several sentiments. These include respectfulness, safety, health, functionality, comprehensibility, sustainability, affordability, and level of appeal. Table 4.1 displays the specific requirements laid out by the Design for All Foundation for product design.

TABLE 4.1 Design for All Criteria, Design for All Foundation.

Respectful	"It should respect the diversity of users. Nobody should feel marginalized and everybody should be able to access it"
Safe	"It should be free of risks to all users. This means that all elements forming part of an environment have to be designed with safety in mind."
Healthy	"It should not constitute a health risk or cause problems to those who suffer from certain illnesses or allergies. In addition, it should promote healthy use of spaces and products."
Functional	"It should be designed in such a way that it can carry out the function for which it was intended without any problems or difficulties."
Comprehensible	"All users should be able to orient themselves without difficulty within a given space, and therefore the following are essential: - Clear information: use of icons that are common to different countries, avoiding the use of words or abbreviations from the local language which may lead to confusion. - Spatial distribution: this should be coherent and functional, avoiding disorientation and confusion."
Sustainable	"Misuse of natural resources should be avoided to guarantee that future generations will have the same opportunities as us to preserve the planet."

Affordable	"Anyone should have the opportunity to enjoy what is provided."
Appealing	"The result should be emotional and socially acceptable but always bearing in mind the seven precedent criteria."

These criteria suggest the ideal characteristics of a product using the Design for All approach. The Design for All Foundation recognizes that it is impossible for developers to meet the needs of every person on the planet when creating a product. To aid in this dilemma, the DFAF offers seven strategies to develop a product or service that uses Design for All, so that creators may adapt them to suit a large range of audiences. These strategies are exhibited in Table 4.2

TABLE 4.2 Strategies to Develop a Product or Service for All, Design for All Foundation

Strategy	**Explanation**
To Everyone	"A single solution suitable for all potential users."
Adjustable	"A single product that meets the different dimensional or functional requirement of people by means of devices or mechanisms."
Products or services range	"A range of products and services among which the person chooses the one best fits."
Compatible with commonly used accessories	"Adaptations or not marginalizing alternative solutions can be provided to guarantee the compatibility with accessories that a person must wear or use."

Premises/Product and complementary service	"Not always it will be possible to meet the needs of users only via a product, a complementary service will then be necessary."
Use an alternative solution to the mainly used offering similar benefits"	"Sometimes the characteristics of some individuals prevent them from using products or services in the usual way. A non-discriminating alternative offering equivalent results is then advisable."
Customized product or service	"As is the case for most services provided by liberal professionals such as doctors or lawyers."

The concept of Design for All arose in 1987 when a group of Irish designers presented and passed a resolution at the World Design Congress that disability and aging should be taken into account by product designers across the world. This concept was taken further by American architect Ron Mace of North Carolina State University, who first used the term "universal design." Mace encouraged designers to create and produce every product to be as usable to all to the greatest extent possible (Institute for Human Centered Design).

While Design for All has been most commonly used in architecture, city planning, and product design, it has also been used in the interpretation of cultural heritage. In their 2015 paper "Accessibility to Culture and Heritage: Designing for All," a group of researchers from the Department of Planning and Regional Development, University of Thessaly present a theoretical and practical approach to the accessibility of cultural heritage. The authors break the concept of accessibility down into three stages.

> “Accessibility to culture and heritage…involves a physical moment of material access to infrastructures and sites, a perceptual moment involving an understanding of the symbolic meanings inherent in cultural products and activities, and a culminant appropriational moment when such meanings are appropriated, consciously accepted or represented and re-worked by those in contact with them” (Deffner et al. 2015:2).

Deffner et al. state that the application of Design for All principles minimizes the use of assistive technologies and creates products that are compatible with assistive technologies but that can be used by all people, not only people with disabilities (Deffner et al. 2015).

In the first phase of accessibility, physical accessibility, the visitor or receiver of a cultural product uses their body and functions to experience it in its original manifestation or reproduction. The user utilizes their five senses to interact with cultural heritage. It is at this time that people with disabilities first face an issue with accessibility. Deffner et al. also make note that when the discussion arises about using one’s body to interact with cultural heritage, an exclusion of people also occurs due to economic reasons of inaccessibility, i.e. some people may be incapable of purchasing a ticket to a museum, going on a boat tour to a shipwreck site etc. (Deffner et al. 2015).

The second phase of accessibility is perceptual accessibility. This phase involves the understanding of culture and heritage. The authors state that “The levels of mental accessibility and perceptiveness are closely linked to the receiver’s educational background, way of living and habitual mode of intellectual operation” (Deffner et al. 2015:4). Deffner et al. suggest that those who are indifferent to accessing cultural heritage and people with mental and learning disabilities may be excluded from the second phase (Deffner et al. 2015).

Appropriational accessibility is the third phase of accessibility. This phase combines the previously mentioned phases of physical and perceptual accessibility. In the appropriational phase, the visitor or receiver establishes an emotional connection to the cultural heritage presented to them, and intertwines their own story. "This final moment represents the apex of accessibility, the ultimate goal to be aimed for by policy makers in the field, if accessibility to culture and heritage is perceived generically" (Deffner et al. 2015:4).

The authors use Pierre Bourdieu's syllogism to illustrate this three-tiered approach to accessibility. Physical accessibility can be described as practical access, and mental accessibility as practice theory, resulting in an exercise of praxis through the combination of practical and conceptual accessibility (Deffner et al. 2015:4).

In the second part of their article, Deffner et al. explain how Design for All can be used as a means to expand accessibility. In the physical stage, the authors suggest using disability friendly public transport networks and road signage, full physical access within a space containing cultural heritage, and offering free or low-cost entry. In the perceptual stage, the authors suggest ensuring the proper spread of information, providing audiovisual information in all relevant languages, and providing a variety of material types for different audiences. In the final appropriational stage, the authors suggest developing interactive initiatives that involve the visitor/user of cultural heritage (Deffner et al. 2015:13). The authors provide simple, adaptive suggestions that could be bent to fit many different types of cultural heritage sites. Additionally, they break down the phases of accessibility into a format that creators of Design for All products can adapt to suit specific needs and ideas for public presentation of cultural heritage.

While no specific exhibit has been developed for maritime cultural heritage using Design for All, there are other examples in related fields. At the Prado Museum in Madrid, Spain, a small exhibit of six paintings was created in 2015 using 3D layout and texture. Visitors to the exhibit, with and without visual impairments, were invited to touch and interact with the art in a way usually uncommon in museums. Tour guides describe the paintings, as visitors are invited to touch and interact with the art, allowing those who cannot see them to complete the pictures in their minds. The paint used in these paintings reacts to ultraviolet light and rises, creating volume and texture (Frayer 2015). Frayer cites a woman, Guadelupe Iglesias, who used to visit the Prado Museum often, until she lost her vision to retinal disease in 2001. Since then, she had only visited a museum twice, until the opening of the Prado exhibit, due to feeling like she could not access the resources like other visitors.

Figure 14. A visitor with a visual impairment feels a 3D copy of the *Mona Lisa* (Photo: Prado Museum)

A comparison can be drawn between visitors with impairments to art museums and to those who visit maritime cultural heritage sites. Visitors with impairments to a traditional museum may find it difficult to see, hear, or maneuver around an exhibit. Many maritime cultural heritage sites present as many, if not more, roadblocks to accessibility for all. With the application of the Design for All approach, heritage managers can move towards providing access to resources for many populations.

4.4 National Park Service Interpretive Guidelines and the Design for All Approach

National Park Service interpretive and educational programs are designed to "enrich lives and enhance learning, nurturing people's appreciation for parks and other special places, therefore helping to preserve America's heritage" (NPS 2005). These programs are created using a list of principles established specifically for the purpose of designing educational and interpretive programs for presentation within National Parks. A full transcription of these principles can be seen in Appendix E. However, these require that all educational and interpretive programs presented within the parks be place-based, learner-centered, widely accessible, and based on sound scholarship, content methods and audience analysis. Additionally, they must help people understand and participate in civil democratic society, incorporate ongoing evaluation for continual program improvement and effectiveness, and, when appropriate, be collaborative with other agencies and institutions (NPS 2005).

Perhaps the most relevant of these principles to the Design For All philosophy is the requirement that National Park Service programming must be widely accessible. The principle states, "NPS programs are widely accessible. Programs provide learning opportunities, reflect and embrace different cultural backgrounds, ages, languages, abilities, and needs. Programs are delivered through a variety of means, including distance learning, to increase opportunities to connect with and learn from the resources" (NPS 2005). The guiding principles of Design For All require that products be widely accessible to a variety of backgrounds, levels of ability, and languages. The principles of Design For All and the guidelines for NPS interpretive and educational programming align well with one another.

Figure 15. Example display at Biscayne National Park's Dante Fascell Visitor Center (Florida Adventuring, 2011).

The Dante Fascell Visitor Center at Biscayne National Park, opened in 2002, has been used largely as an art gallery space. The park states that "Artists have always played a crucial role in increasing awareness and inspiring stewardship of national parks" (NPS 2017). Art shows hosted by the park have included photography, oil, acrylic, pastel, and watercolor painting, drawing, fiber, ceramics, collage, and sculpture shows, an generally include a "meet the artist" reception (NPS 2017).

Additionally, the visitor center houses traditional interpretive information that includes signage, photos and pictures, and display cases containing artifacts and replicas of coral reefs and animals found in the park. However, many of these displays are not accessible to visitors with visual impairments or potential learning disabilities.

In May 2012, the National Park Service formed the Accessibility Task Force in hopes of improving "organizational approach to ensuring that national parks can be enjoyed by individuals with disabilities" (NPS 2012). A five year strategic plan was produced entitled "All In! Accessibility in the National Park Service, 2015-2020," which is built around three goals. These goals include creating "a welcoming environment for visitors with disabilities," ensuring that "new facilities and programs are accessible," and upgrading "existing facilities to improve accessibility" (NPS 2012). The task force sought feedback from stakeholders for the plan, including the National Leadership Council, Deputy Regional Directors, Communication Council, Denver Service Center, Harper's Ferry Center, National Council for Interpretation, Volunteers, Park Facility Management Division, Planning Leadership Group, Servicewide Accessibility Coordinating Committee, Servicewide Maintenance Advisory Committee, and the Web Council, but does not list engaging with any park visitors with disabilities (NPS 2015).

The National Park Service does acknowledge the current state of accessibility at the parks.

> "From a programmatic perspective, few parks have printed publications, such as brochures, in alternative formats. Most exhibits are in cases, behind barriers, or are graphic in nature, rather than including reproductions and tactile exhibits in the designs. Maps, whether in brochures or as exhibits, are not in a tactile medium. Often, audio elements of programs and exhibits are not accessible to people who have hearing loss or are deaf. Frequently, content posted on National Park Service websites is not made accessible. All of these issues limit visitors with physical, sensory, learning, and intellectual disabilities.
> In some cases, staff and volunteers are not properly trained on how to interact with people with disabilities, and how to provide services in an appropriate manner. As a result, they may have inappropriately denied visitors access to programs, facilities, and outdoor areas. In particular, visitors with service animals have been denied their rights to access" (NPS 2015).

The National Park Service also acknowledges the challenges to incorporating additional accessibility strategies to NPS facilities. In particular, the economic cost of such an endeavor is noted as greatly exceeding $120 million. This estimate includes only updates to physical facilities, such as buildings, trails, and campgrounds. It does not include the cost of making interpretive programs accessible, including audio and tactile components of exhibits, alternate formats for interpretive signage, sign language translation, or the addition of braille signage (NPS 2015).

In the plan, NPS lays out a strategy for incorporating change. The main components of the strategy include developing an external communication plan to improve information presented to the public, developing a training plan aimed at encouraging cultural change in NPS staff, improve web accessibility, building park and regional capacity to budget for facility and program improvements, and to partner with national advocacy groups to ensure that new projects are universally designed (NPS 2015).

Figure 16. Tactile map from All In! Accessibility in the National Park Service (Image: NPS, 2015).

At Biscayne National Park, the Dante Fascell Visitor Center and park headquarters are fully accessible to those with mobility challenges. Visitor center exhibits are available in English and Spanish, including the exhibit along the Jetty Trail within the park. Haitian Creole translations for this exhibit are available upon request. Any audiovisual material in the exhibits are closed-captioned and available in English, Spanish, and Haitian Creole. Park brochures and junior ranger program books are also available in these three languages. Few of the islands within the park have accessible facilities beyond park restrooms. Boca Chita Key has sidewalks around the harbor, though the rest of the island is either grass or rock.

Incorporating principles of Design for All into the National Park Service interpretive guidelines has the potential to improve the accessibility strategy presented in the interpretive and educational guidelines. The National Park Service website states that "The National Park Service cares for special places saved by the American people so that all may experience our heritage (NPS 2017). However, making heritage accessible to all requires a reassessment of the ways in which maritime heritage cultural heritage is presented to the public. Incorporating Design for All into the 2015 NPS accessibility plan could dramatically increase the results of the action plan and successful provide access to visitors of all abilities.

Applying a Design for All Approach to the interpretation of maritime cultural heritage creates better access for more audiences. This thesis does not seek to lessen the importance of in-water access to resources through shipwreck trails, marine preserves, and boat tours. The ability to visit real shipwreck sites remains an important part of accessibility strategy. This thesis does, however, seek to draw attention to the lack of resources available to people with mobility, visual, and learning impairments, as well as to those with economic impairments that prevent them from experiencing a shipwreck site. The Design for All Approach allows heritage managers to better create interpretive products that accommodate a wide range of needs and audiences, providing better access to resources to more people. The strategies and criteria laid out by the Design for

All Foundation offer helpful guidelines for creating products of all kinds. When these are applied to cultural heritage, interpretive products are more likely to be accessible to a wide range of audiences.

5 Methodology

This thesis utilized various methodological approaches to creating an exhibit using 3D deliverables using a Design for All Approach. This chapter first discusses the methodology for collecting photogrammetric data, both on the site of the Pillar Dollar Wreck, and in a controlled environment for small artifact photogrammetry. Second, the approach used to create a high-quality, full color 3D printed site plan is examined. Following is a discussion of the methodology used to draw ship's lines from the photogrammetry model, as well as a discussion on creating the exhibit.

5.1 Photogrammetry in the Field: Photogrammetric recording of the Pillar Dollar Wreck

The photogrammetry process used to collect data on the Pillar Dollar Wreck site is described in great detail in Kotaro Yamafune's dissertation *Using Computer Vision Photogrammetry to Record and Analyze Underwater Shipwreck Sites* (2016).

Photographs were collected on site using an Olympus Tough digital camera and a GoPro Hero 4 camera. While Yamafune recommends a higher quality, DSLR camera, the team was limited by availability of resources, and had to use either the Olympus Tough camera or the GoPro.

Prior to collecting photographs, divers placed coded targets around the site. These coded targets allow the processing software, Agisoft Photoscan, to recognize the area being recorded, and increase the accuracy of the resulting 3D model (Yamafune 2016). These coded targets are generated by Agisoft Photoscan, and can be printed directly from the program. The targets were fixed to ceramic tiles, available at any hardware store, so that they could be placed around the site.

Proper alignment of photos is the most important part in photogrammetry processing. Yamafune developed an ideal flight pattern, illustrated in Figure 5.1, for maximizing the numbers of photos aligned. The combination of utilizing coded targets and an overlapping flight pattern produces the highest probability of producing a successful model.

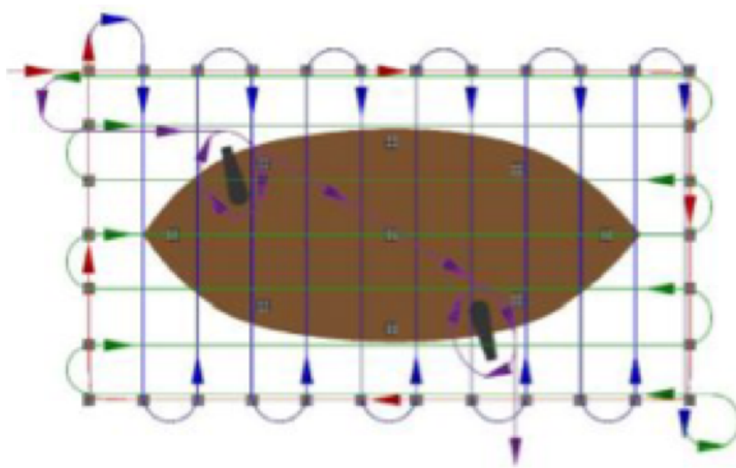


Figure 17. Dive “flight” pattern for photogrammetric recording. Red arrows indicate locking path, blue arrows indicate transversal path, green arrows indicate longitudinal path, and purple arrows indicate auxiliary path (Yamafune 2016).

In a team of three, divers swam across the site in the pattern illustrated in Figure 5.1. Each diver took as many photos as possible. These photos included overhead shots, shots in between timbers, and shots of the coded targets. Each diver averaged approximately 550 photos.

After recording the site in the field, the photos were processed using Agisoft Photoscan, following the parameters laid out by Yamafune.

When using Photoscan, the first step in creating a 3D model is to upload the photos into the program. This can be done by clicking on the “Workflow” tab, found at the top of the screen.

Under the drop-down menu, click the tab entitled "Add Photos." This should pull up a file selector. Add all desired photos. Click "Open." This will upload all photos in the program.

The next step in the process is to align the photos. Under the Workflow tab, select "Align Photos." This brings up a menu with several options, including "Accuracy," "Pair Selection," and "Advanced," which include the "key point limit" and the "tie limit." For archaeology, Yamafune recommends setting the Accuracy at "high," the Pair Selection at "generic," the key point limit at 40,000, and the tie point limit at 1,000 (Yamafune pers. comm 2016). Then, click "OK" to align photos.

Once the photos have aligned, the next step in the process is to correct the bounding box so that any outside data not necessary to the desired photogrammetric model is outside the box. This can be done by clicking and dragging the edges of the box. All data found outside the lines will be ignored.

Next, a dense cloud must be built. Select "Workflow," then "Build Dense Cloud." A dialogue box will appear. There are several options that must be changed within this dialogue box. The first of these is the quality setting. For the purposes of archaeology, it is best to use either a medium or low quality setting for building a dense cloud, as the higher the quality setting, the longer the processing time will be, with relatively little effect on the final product (Yamafune 2016). For the purpose of the Pillar Dollar Wreck, the "low" quality setting was used. However, several million data points were still generated, and there was no visible degradation to the final model produced. Then, the depth filtering setting must be changed to "Mild." Then, click 'OK" (Yamafune 2016).

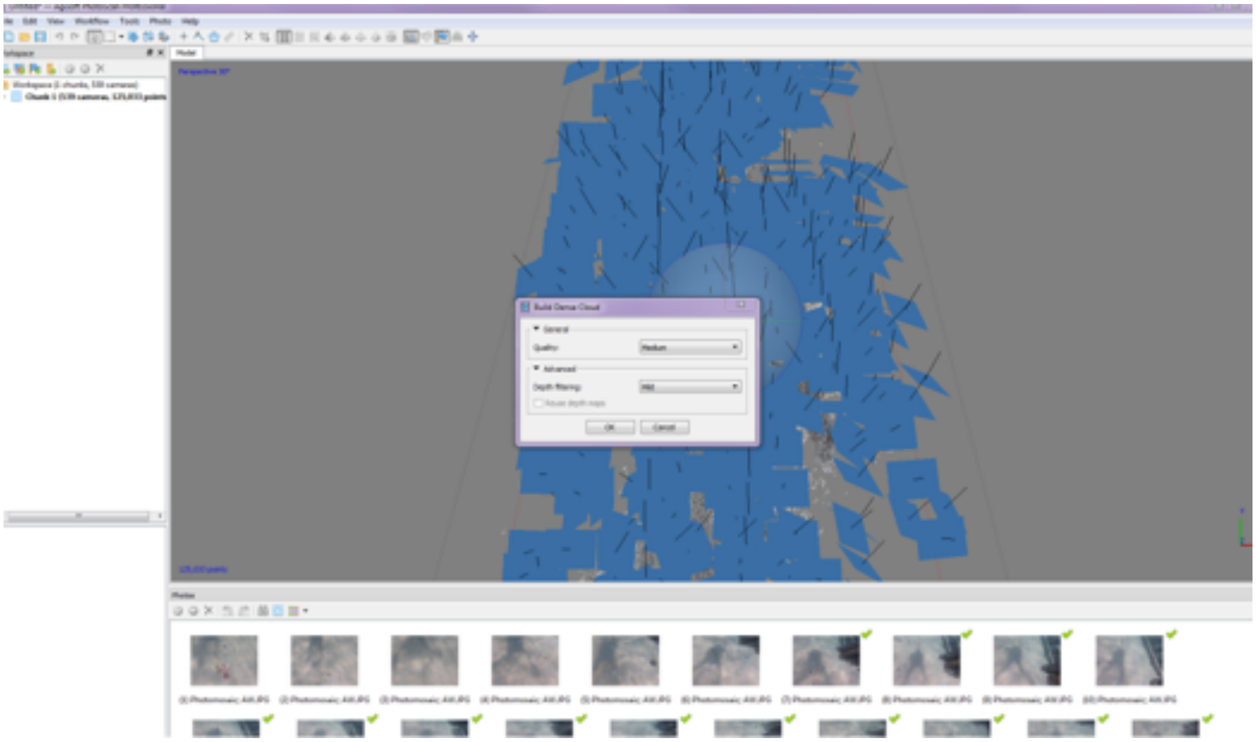


Figure 18. Build Dense Cloud settings in Agisoft Photoscan with example dialogue box (Image: Author 2017).

Once the dense cloud has been generated, a mesh must be built. Select “Workflow,” then “Build Mesh.” Another dialogue box will appear. Several settings must be changed. Change the “Surface Type” to “Arbitrary,” “Source Data” to “Dense Cloud,” “Face Count” to “High,” “Interpolation” to “Enabled.” Click “OK.” Arbitrary surface type is recommended for any structure with three dimensions. The Dense Cloud source data setting allows for the re-creation of small details, often important for archaeological purposes,. The enabled interpolation setting will allow Agisoft Photoscan to repair some of the small holes it may find within the mesh (Yamafune 2016).

The final step of creating a photogrammetry model in Photoscan is to build texture. Building an accurate texture is one of the most important steps for creating a life-like 3D print of a photogrammetry model. Select “Workflow,” then “Build Texture.” Another dialogue box will appear. For the settings, under “Mapping Mode,” select “Generic,” under “Blending Mode,” select “Mosaic (default)” and check the box next to “Enable hole filling.” These settings are shown in Figure 19.

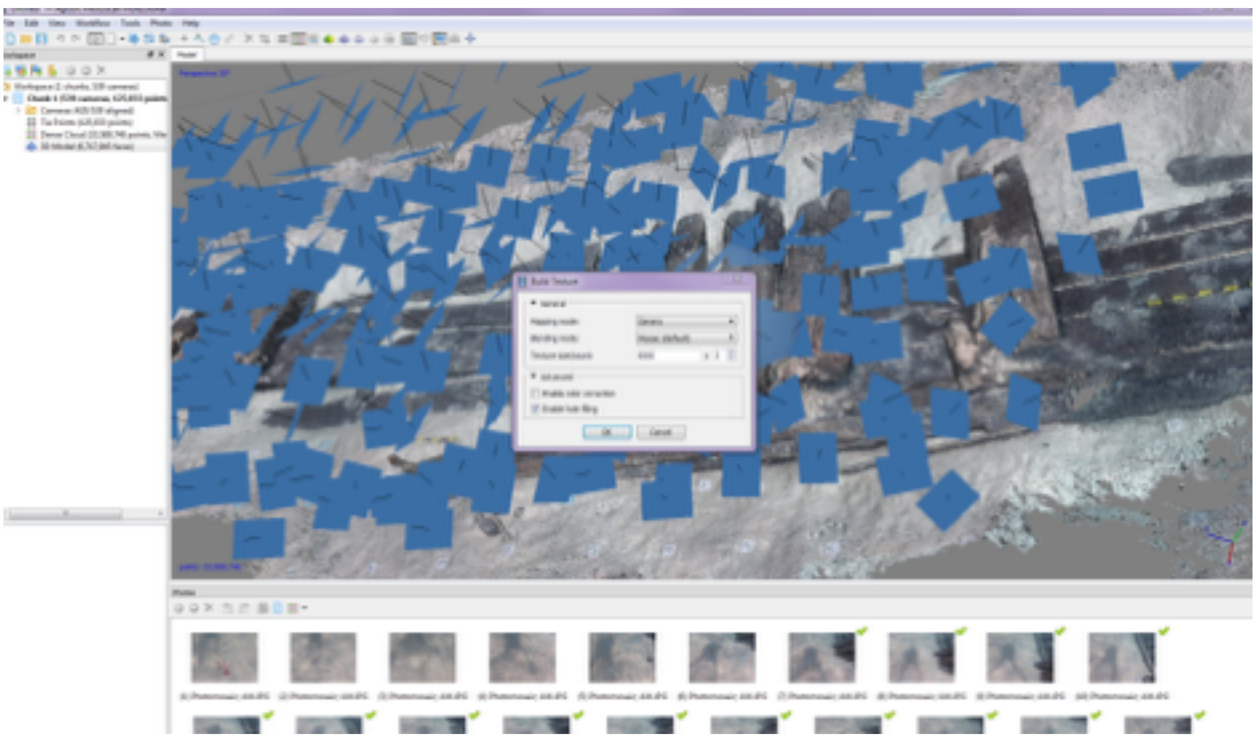


Figure 19. Build texture settings in Agisoft Photoscan with example dialogue box. (Author 2017).

Once these steps are complete, a high-quality, photorealistic photogrammetry model should be the end result. The final step is to scale-constrain the model to ensure that the model is properly scaled and can be accurately used for archaeological purposes. To do this, one must use the scale bar created in 3D in the model. Select an end of the scale bar and use the tool “Create

Marker." Do this for both ends of the scale bar. Then, select both markers in the Reference pane at the bottom of the screen, then choose "Create Scale Bar." You can then enter the numeric value of the scale. In the case of the Pillar Dollar Wreck, this was one meter. Once this process is complete, specific measurements can be taken from the photogrammetric model.

5.2 3D Printing Workflow: Site Plan 3D Printing

The workflow for preparing a photogrammetry model created in Agisoft Photoscan for 3D printing requires the use of three different programs, as well as the software particular to the 3D printer used. For the Pillar Dollar Wreck model, Autodesk Meshmixer, Autodesk Maya, Blender, and ZCorporation softwares were used to prepare the model for printing.

The first step in the workflow is to import your scale-constrained Photoscan .obj into Autodesk Meshmixer. Meshmixer is a free 3D CAD software, available for download from Autodesk's website. Once the model has been imported into Meshmixer, the first step in the preparation process is to clean up any additional polygons outside of what you wish to print. Fixing the bounding box within Photoscan may have taken care of much of this, but it is important to double check. Using the select and delete function, visually inspect and delete any "extras" that may be surrounding the model. Once your model seems like one object to the eye, export the model from Meshmixer as an .obj file. Create a new folder during this process from which to work with. This is a very important step in the process, as many of the programs require files to be placed in the correct folder. Give the folder a name. For the Pillar Dollar Wreck, the folder was named PDW_Materials.

The next step in the process is to fill any holes left by Photoscan in the mesh. Even if there are no holes visible to the eye, it is likely that there are tiny holes that only the software can detect. To do this, first import the .obj file into Autodesk Maya. Maya is a computer animation software available for download from Autodesk's website. For the particular 3D printer used for this project, it was necessary to use Maya 2015 software. However, this will vary based on the 3D printer used. While this program costs $50 per month, it is possible to receive a free educational license for three years.

Once the .obj has been uploaded into Maya, press the "6" button on the keyboard to convert the view from wireframe to textured. The textures and colors of the model should appear. If they do not, this can be troubleshot by manually browsing to the correct files using the Hypershade render window. To find Hypershade, select "Windows," then "Rendering Editors," then "Hypershade." Texture files can be selected by pressing the file folder icon next to "Color" in Hypershade.

Once textures have appeared, select "Mesh," then "Cleanup." Select the boxes next to "Faces with holes" and "Non-manifold faces." Then select "Cleanup." Once the model is clean, the polygon count must be reduced to a number useable by the 3D printer. For the Pillar Dollar Wreck, the model was reduced by 80%. This did not change any characteristics visible to the eye. To do so in Maya, select "Mesh," then "Reduce," clicking on the box next to "Reduce" to bring up the Reduce options menu. In this box, adjust the reduction to the desired reduction percentage, then click "Reduce."

The model must now be exported from Maya into another software, called Blender. Blender is a free, open source 3D software that can be downloaded from the software's website. In Maya, export the file as an .obj. Open Blender, and instead of merely opening the .obj file, it must be imported into the program. Click "File," then "Import," then browse to the correct .obj file. Click "Import." The model should load onto the build platform. The next step is to extrude the bottom of the model. This is an important step. In order for a model to be 3D printed, there must be a flat base upon which it sits. When photogrammetry models of archaeological sites are produced in Agisoft Photoscan, there is often not a solid underside to them. This is perfectly normal. However, it causes an issue with 3D printing, so a base must be created for the model to be printed on. This is done by extruded the bottom of the model. In Blender, select the model by right clicking on it. Press the "Tab" button on the keyboard to move into edit mode within the software. Then, select the faces of the model that need to be extruded. This will likely be the entire bottom of the model. Then, click "Mesh," then "Extrude," then "Extrude Region." This process will extrude the model downwards, adding depth. This may take a moment for the computer to complete. Once the extruding process is complete, the model should once more be saved as a .obj file.

The next step in the process requires using Meshmixer again. After ensuring that the extruded version of the model has been saved in Blender, open Meshmixer once again and import the extruded version into the program. The extruded model should appear on the build platform. The next step in the process is to cut off the unnecessary part of the extruded model. Select the "Edit" menu on the left side of the screen, then select "Plane Cut." In the options box, select "Cut (Discard Half) and "Remeshed Fill," as shown in Figure 20.

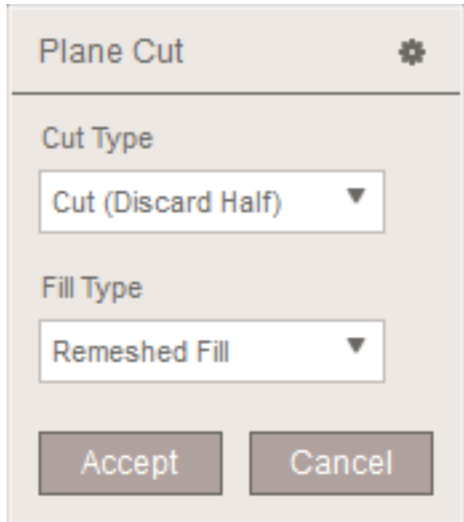


Figure 20. Plane Cut settings in Meshmixer. (Meshmixer Manual 2017).

These settings allow the unwanted part of the extrusion to be deleted, and the remaining part to retain an even triangle distribution. Then, either use the colored arrows to adjust the desired cut, or drag and drop a red cut line using the mouse. Click “Accept.” This may take the computer a moment to complete. After completing this step, the model should appear to be a single solid piece with a flat base.

In order to ensure that that there are no remaining holes in the model, “Inspector,” must be run in Meshmixer. If all of the previous steps were followed correctly, this should not pose an issue. Save the final Meshmixer as an .obj file in the *same* folder as all of the other modeling files. This step is *crucial*.

If the final 3D printed site plan is desired to be printed on a printer that does not have the capability to print in full color, the final Meshmixer .obj file can be opened in the printer’s corresponding software and printed. However, if the desired deliverable to be printed is on a full color, Z Corp powder printer, there is an additional step to ensure that the colors and textures of the model are retained and placed in the correct position.

The final step requires the use of Python, as well as a Python tool called Image Packer. The use of Python and Image Packer is necessary because the software used by Z Corp powder printers, ZEdit, ZEdit Pro, and ZPrint is out of date. In 2011, Z Corp was purchased by another 3D printing company, called 3D Systems (Brown 2011). Unfortunately, the software has not been updated to keep up with changes in 3D modeling softwares, even though Z Corp printers are still widely used by 3D manufacturing and prototyping businesses and other organizations. Due to this issue, the author found that ZEdit could only read one texture map at a time. Due to the size of the photogrammetry model produced, it required three texture maps. Therefore, when the final Meshmixer .obj file was opened in ZPrint, only part of the texture was visible on the model. By using Python and Image Packer, it is possible to combine multiple texture files into a single file. Image Packer can be downloaded from GitHub, a web-based hosting service for git programs. Git is a control system for tracking changes in computer files (GitHub 2018).

Once Image Packer has been installed, you can run the program to compress the files. Using Python, drag and drop your .obj file onto objuvpacker.py. This should result in a "packed" texture map. The output file should be found in a folder entitled the original name and ending in _packed. Inspect this file to make sure all of the desired texture maps are packed (GitHub 2018).

Finally, because ZEdit and ZPrint cannot read files greater than 4096 in resolution, reopen the packed texture map in Adobe Photostop, and resize the image resolution to 4096. Save this in the packed folder. Then, open up the packed .obj in Maya, and export it as a .wrl file, which is the preferred file type of ZPrint. Open up the .wrl file in ZPrint and ensure that all textures are mapped correctly on the file. If so, then the model is ready to print and can be sent to the printer.

5.3 Ships Lines Using Photogrammetry

Yamafune (2016) developed a methodology to take hull lines from a photogrammetry model of a shipwreck. He states that curvature of a ship's hull is perhaps one of the most important pieces of information that archaeologists can acquire from a shipwreck (Yamafune 2016). His methodology uses a combination of Autodesk Maya and Rhinoceros 3D modeling software to extract section profiles and hull lines from photogrammetry models of shipwrecks created in Agisoft Photoscan. This thesis follows a similar, but slightly different methodology to extract hull lines. Yamafune's methodology was not followed exactly due to the depth of the sand around the Pillar Dollar Wreck causing issues with the archaeological "CT scan" (Yamafune 2016:119) that Yamafune proposes. This issue is further discussed in the Limitations section of this chapter. The methodology used in this thesis uses a combination of Autodesk Meshmixer and Rhinoceros 3D modeling software to extract section profiles and hull lines from the photogrammetry model of the Pillar Dollar Wreck created in Agisoft Photoscan, which allows an approximation of the original hull to be reconstructed in Rhinoceros 3D.

The first step in this workflow is to import a copy of the clean, scale-constrained 3D model created in Agisoft Photoscan into Autodesk Meshmixer. If a large model is being used, it may be necessary to also use the reduced polygon count version to eliminate some of the computer processing time, as was the case with the Pillar Dollar Wreck. Using the reduced polygon count version of the model should not create any issues with creating section profiles. For the Pillar Dollar Wreck, a slicing tool was used to cut off sections of the model at the frames, which allowed the computer-generated underside of the frames to be shown. Once the model has been imported into Meshmixer, select the "Edit" button on the left side of the screen, then "Plane

Cut” from the sub-menu. Another sub-menu will appear. Under “Cut Type,” select “Cut (Discard Half), and under “Fill Type” select “No Fill.

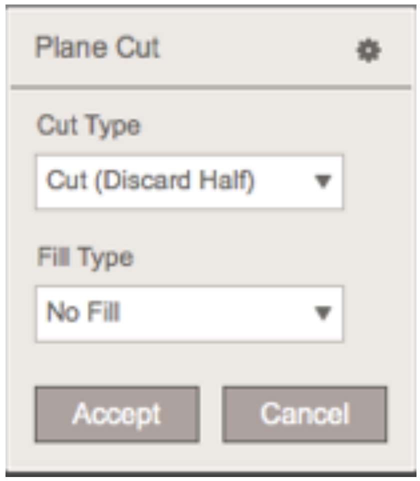


Figure 21. Plane Cut settings in Meshmixer. (Meshmixer Manual 2017).

Once these settings are selected, click and drag across the frame. A red line will appear that depicts the selected cut. Once the cut is positioned appropriately, click “Accept” on the “Plane Cut” menu. To scale, hold down the hotkey “C” until the camera snaps to the desired position. This ensures that the camera is in the same position and equidistant from all section profiles each time. Then, use the snipping tool to capture the section profile and save as a .jpg.

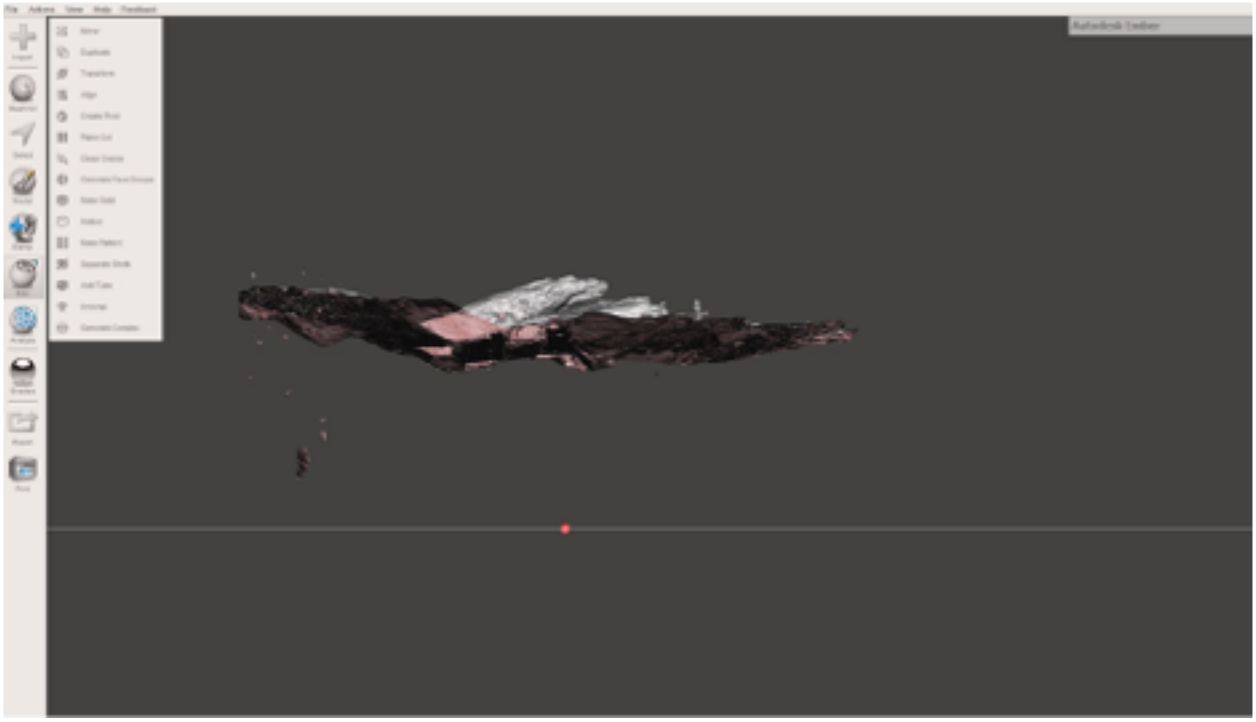


Figure 22. Model with first section profile removed (Author, 2017).

This process was repeated for the remaining thirteen frames of the Pillar Dollar Wreck. Section profiles of each frame are found in Appendix H.

Once all section profiles were captured, they were combined into one document, along with the site plan of the Pillar Dollar Wreck into one file, so that they could be used as a Background Bitmap in Rhinoceros 3D. A Background Bitmap allows 2D objects to be traced into 3D.

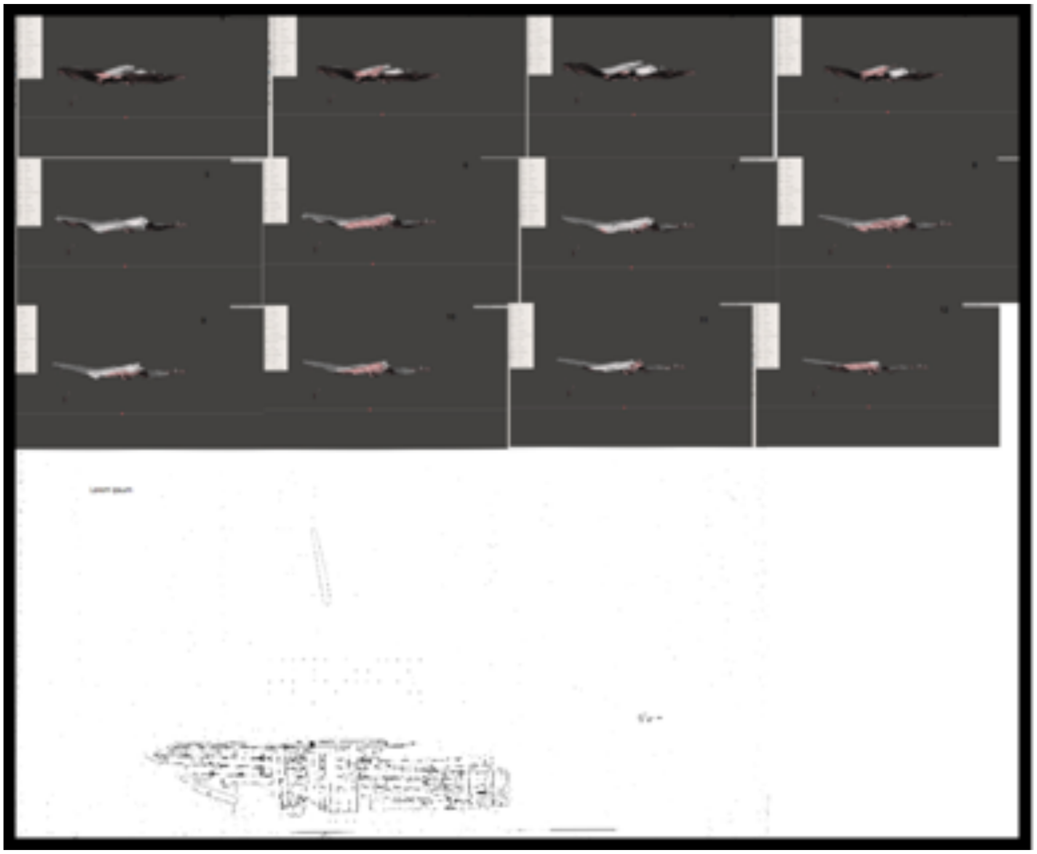


Figure 23. Combined section profiles for Background Bitmap. (Author, 2017).

Once the Background Bitmap has been imported into Rhino, it must be scaled. Using the scale bar on the Pillar Dollar Wreck site plan, the “2D Scale” tool was used. A ten meter section was selected along the baseline. This distance was entered in the 2D scale tool. Individual scaling was used to double check the correct scale for each individual frame.

Then, the outline of the frames were traced using the “polyline” tool. Once all of the frames were traced, they were dragged to their appropriate position on the site plan using the “grid” view frame in Rhinoceros 3D. Once frames were placed, the view frame was switched to “perspective view” to see the current hull shape. The frames were then faired using the curve tool.

Once faired, a surface was lofted onto the hull shape, giving an approximate reconstruction of the hull of the Pillar Dollar Wreck.

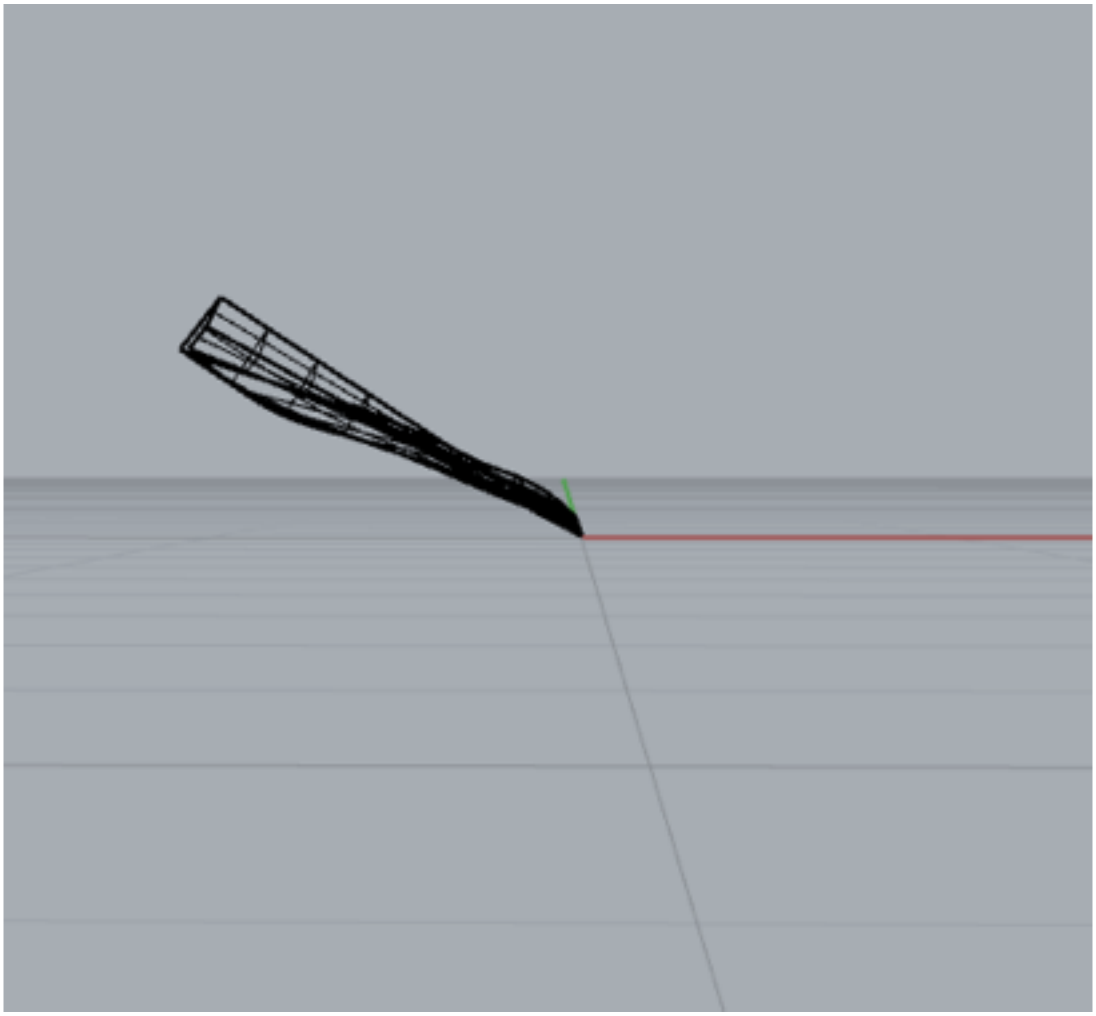


Figure 24. Approximate reconstruction of Pillar Dollar Wreck hull shape using photogrammetry (Author, 2017).

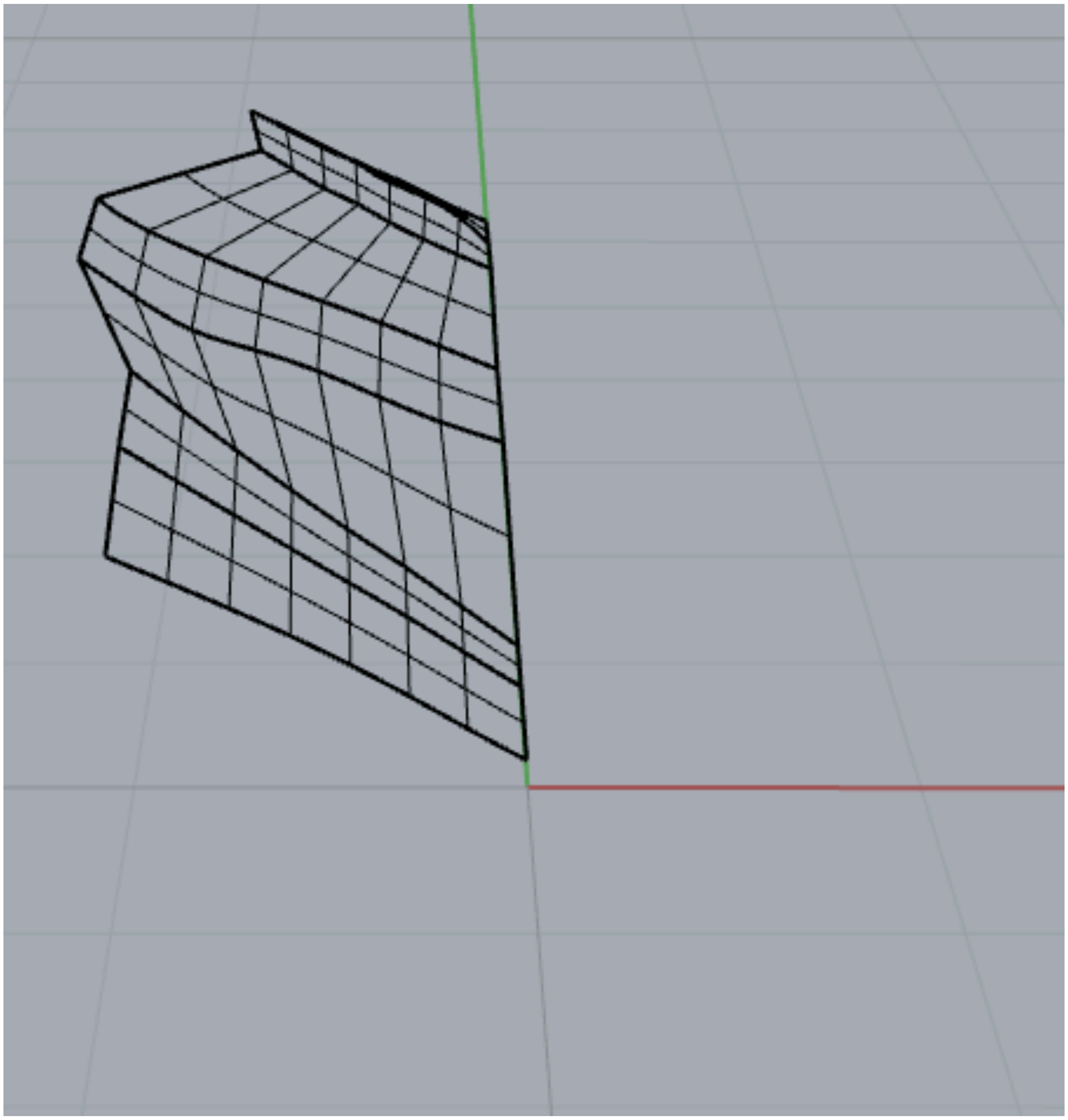


Figure 25. Lofted surface on hull shape. (Author, 2017).

Figure 26. Lines of ship using photogrammetry. (Author, 2017).

5.4 Creating the Exhibit

The methodologies presented in this chapter describe the steps used to create the variety of 3D products displayed in the exhibit. Each product was used as a separate but complementary piece of the exhibit.

Traditional interpretive signage was printed on foam core poster board. Copies of the interpretive signage can be found in Appendix I. Identical copies of these posters, though lacking their text, were printed to which braille writing was attached. Braille labels were created using an online 3D printing application called "TouchSee." TouchSee is a free, easy to use service that allows users to input information and have the text reproduced as a 3D model of the information in braille. It can then be printed from any compatible 3D printer (TouchSee 2018).

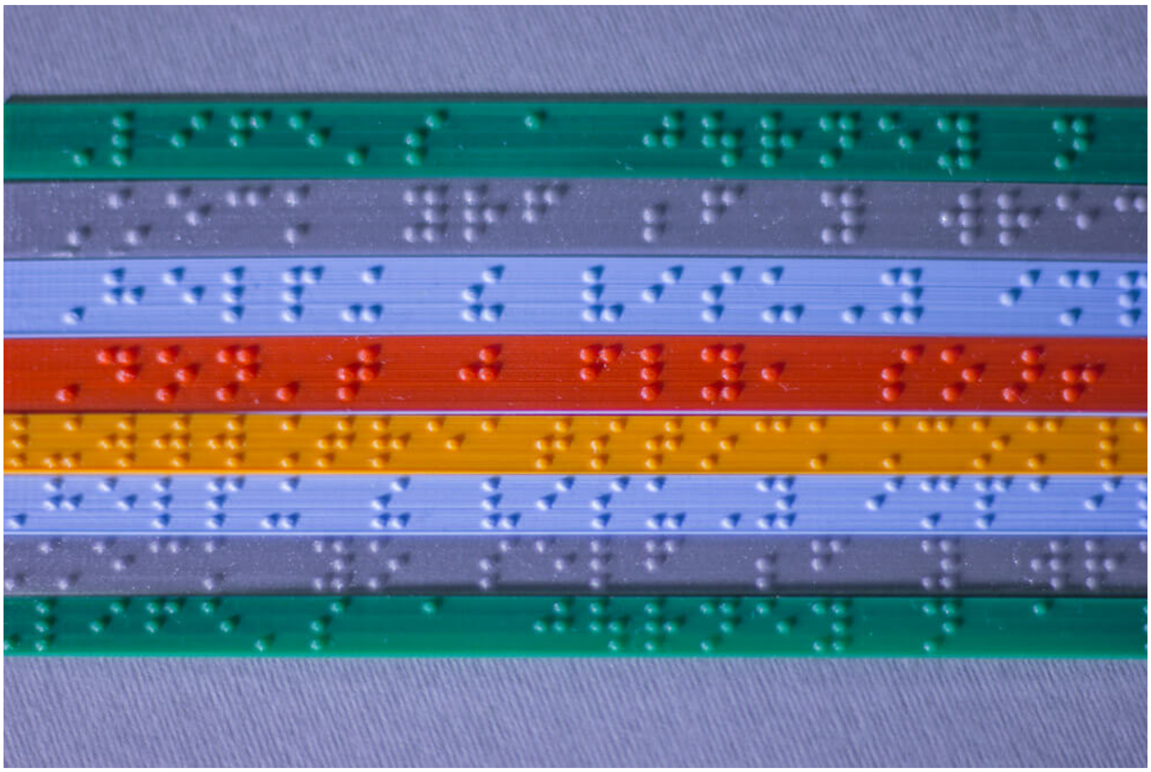


Figure 27. Sample 3D printed braille (TouchSee, 2018).

Braille labels were created using this application and printed using a MakerBot 3D printer in plastic. They were then fixed to the text-less versions of the interpretive signage in the same order as the versions containing text.

The 3D printed site plan was placed in an open-top, wooden display case, filled with sand to create as similar an experience as possible to what one would experience when visiting the archaeological site. A rope guard was attached to the edges of the display case to protect users' hands and arms from any splintering wood. This was in an effort to meet the Design for All criteria that products pose no danger to users.

An audio "touch tour" was written that guided users on a tour of the site using the 3D printed site plan. It provides information about the Pillar Dollar Wreck, associated artifacts found during excavation, and information about construction of the ship. A transcript of the audio tour in both English and Spanish can be found in Appendix J and K, respectively.

For the "virtual dive" component of the exhibit, the original, unreduced version of the 3D model of the site created using photogrammetry was uploaded to Sketchfab. Sketchfab is an online platform that allows users to upload, host, view, and share their 3D models with the public.

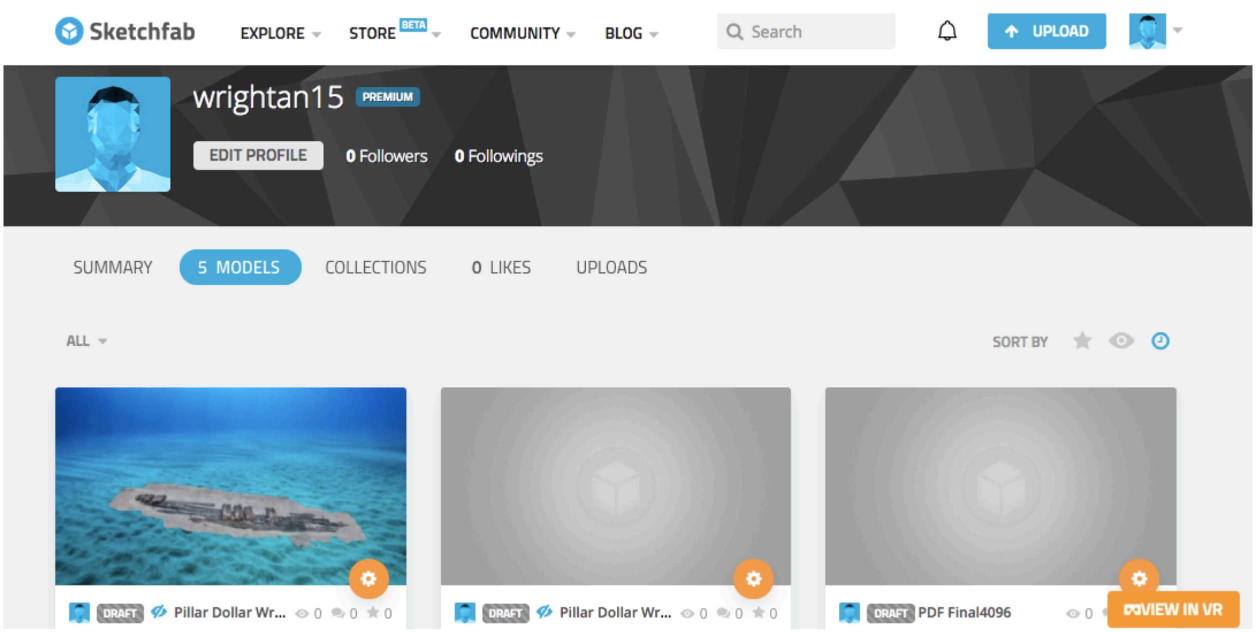


Figure 28. Sketchfab 3D model hosting platform. (Author, 2017).

The model was then displayed on Sketchfab during the exhibit, allowing users to interact with the site.

5.5 Limitations in Methodology

A limitation specific to the Pillar Dollar Wreck was encountered in creating the photogrammetry model, and consequently in using it to create hull section profiles. This limitation was caused by the depth of the sand encountered during excavation and the positioning of the frames in relation to one another.

When reconstructing the site, Agisoft Photoscan did not have data points for in between and underneath many of the frames, and therefore interpolated a curvature to the frames when being used to create hull section profiles. This can be seen in Figure 30. The pink section of the image displays data points not created from photos in Agisoft Photosan. While the basic curvature of the frames is correct, there is the presence of interpolated data that may or may not be true to the site itself.

During the 2016 excavation of the Pillar Dollar Wreck, frame curvature data was taken using a goniometer. Using this method, full curvature data was acquired by taking measurements of the front side of a frame, and the back side of the corresponding futtock. A comparison of the reconstructed hull generated through this method and the reconstructed hull generated through photogrammetry is presented in Chapter 6.

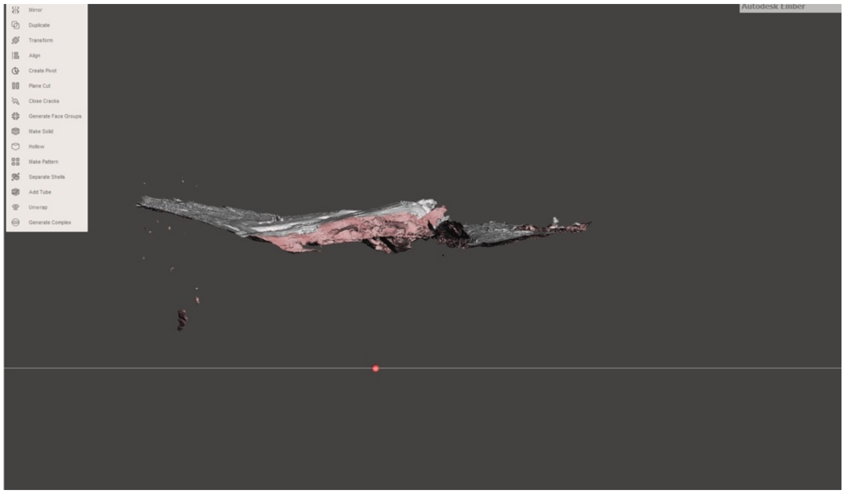


Figure 29. Interpolated data from Agisoft Photoscan, shown in MeshMixer. (Author, 2017).

The methodology developed by Yamafune in his 2016 dissertation for extracting hull section profiles works remarkably well for shipwrecks with greater spacing distance between frames than the Pillar Dollar Wreck. His method of shipwreck “CT scans” allows the camera angles to be brought in between frames and to view interior data. However, because frames were stacked next to each other with little space for data collecting with a camera, some of this is lost on the Pillar Dollar Wreck. Therefore, the methodology was slightly modified to extract the greatest amount of data possible.

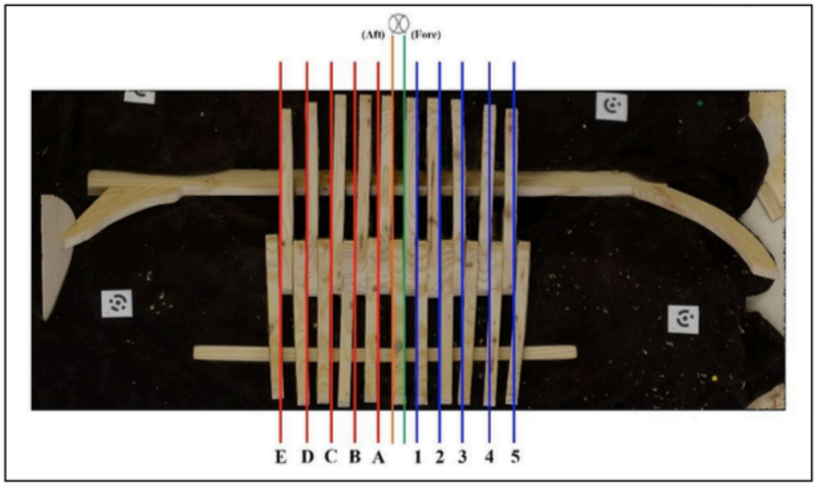


Figure 30. Extracted section profiles with spacing. (Image: Yamafune 2016).

6 Results

6.1 A Practical Application of the Design for All Approach to Maritime Cultural Heritage

The principle goal of the Design for All Approach is to create a single product that is accessible to as many people as possible. When translated to cultural heritage management, particularly to a maritime cultural heritage exhibit, the goal of heritage managers should be to design an interpretive product that provides the same information for all visitors, regardless of disability or impairment. Additionally, it should strive to provide an equal experience, allowing visitors to use products in a way that suits their particular needs in a non-discriminatory way.

In the past, many accessibility strategies for maritime heritage have failed to address how to provide access to sites for people that cannot visit them in conventional ways. Many visitors may not be able to interact with sites in the water, move freely throughout a museum exhibit, or see and understand interpretive signage. Applying several principles of the Design for All Approach may help submerged cultural resource managers address these issues.

As a part of this thesis, a pop-up exhibit in East Carolina University's Joyner Library was created as a case study in the Design for All Approach for maritime heritage, focusing on Biscayne National Park's Pillar Dollar Wreck. This exhibit included several interpretive products, as well as supplemental products for different audiences. These include a 3D printed site model of the Pillar Dollar Wreck, several small 3D printed artifacts, a guided audio "touch tour" of the 3D printed site plan in both Spanish and English, braille labels for interpretive products, interpretive signage in both English and Spanish, and a virtual model that will allow users to “take a dive” on the site. Each of these interpretive products met a specific Design for All strategy. This is illustrated in Table 4.3.

TABLE 4.3 List of exhibit components and corresponding Design for All strategy.

Exhibit Components	**Design for All Strategy**
3D Printed Site Model	“To Everyone”
3D Printed Artifacts - Guadalajara Clay - Fasteners	“To Everyone”
Guided audio tour for touch tour of 3D printed site and artifacts	“Alternative solution”
Spanish language version of audio tour and signage	“Complementary service”
3D printed braille labels	“Alternative solution”
Interpretive signage	“Complementary service”
Virtual 3D model	“Product or services range” “Compatible with commonly used accessories”

The 3D printed site model served as the primary interpretive product for this exhibit. The site model, a tabletop likeness of the Pillar Dollar Wreck, will allow all audiences to view the site as it rests on the seabed. Since many visitors do not have the ability to dive or snorkel on the site itself, the 3D printed site model allows them to see what a shipwreck looks like underwater. If visitors had a visual impairment, they were invited to take a “touch tour” of the 3D printed site model. An audio guide was provided to them that describes the Pillar Dollar Wreck as they felt their way across the site. The 3D printed site model meets the Design for All strategy of “to everyone,” meeting “a single solution for all potential users” (DFAF). A product created using the strategy of “to everyone,” is the ideal solution for the Design for All Approach. The 3D printed site model allows multiple audiences to access it as it suits their needs, either through viewing or touch.

All labels found on the 3D printed site plan were also printed in braille, offering an “alternative solution” for visitors with visual impairments to reading traditional labels.

Similarly, the exhibit included 3D printed small artifacts. These were an iron fastener and a small piece of Guadalajara ceramic sherd found during excavation of the Pillar Dollar Wreck. Information about these artifacts were included in the audio “touch tour.”

The Guadalajara sherd has a daisy pattern on its surface. After the shape was 3D printed in plastic, the daisy pattern was created using clay and attached to the plastic piece, so that visitors with visual impairments can visualize the pattern of the artifact. It was sealed with spray acrylic to make it suitable for handling. In this way, visitors were able to touch small artifacts that would often be found behind glass in a traditional museum exhibit.

Traditional interpretive signage with information about the Pillar Dollar Wreck was placed around the exhibit. As previously mentioned, guided audio “touch tours” were provided for visitors with visual impairments. This audio guide included all information found on the interpretive signage, and vice versa, creating an equal informational experience for all visitors. The audio tour offered directions on where visitors should move their hands as they feel their way across the site. This component of the exhibit fulfills the “alternative solution” strategy of the Design for All Approach. Additionally, as there is a large Spanish-speaking population in south Florida near Biscayne National Park, the audio tour was also offered in Spanish, fulfilling the “complementary service” strategy.

Finally, a virtual 3D model of the Pillar Dollar Wreck was created using the same photogrammetry model used to create the 3D printed site model. During this the exhibit, this model was displayed via Sketchfab, a 3D model hosting platform, on a large monitor. Visitors were invited to interact with the site through the computer. Visitors could move around and through the model, zooming in and out. This provided an experience similar to diving or snorkeling on a shipwreck site for those that may be unable. While this component of the exhibit likely excluded visitors with visual impairments, it meets the criteria for “product or services range” and “compatible with commonly used accessories” strategies of the Design for All Approach. The virtual 3D model offers an additional experience to visitors beyond the primary interpretive product of the 3D printed model.

These interpretive products meet the Design for All Approach criteria of being respectful, safe, healthy, functional, comprehensible, sustainable, affordable, and appealing. The criteria of “respectful” ties into the Design for All Approach strategy of “to everyone,” as the respectful criteria states that “It should respect the diversity of users. Nobody should feel marginalized, and everybody should be able to access it." The primary goal of this exhibit is to demonstrate how to make maritime cultural heritage accessible to as many audiences as possible. The exhibit was both safe and healthy, as it used minimal space and no materials known to be toxic or cause allergic reactions were used to create interpretive products. In terms of functionality and comprehensibility, the information in the exhibit was clear and concise, and interpretive products were provided for all comprehension levels, from children to adults. While the 3D printed artifacts and site model have plastic components, the sustainability of these products is not in question as there was only one, reusable product made. The exhibit at the Joyner Library was free and open to the public, as it would be as if it were installed at Biscayne National Park. Finally, all interpretive products were visually appealing to a wide range of audiences, including children.

6.2 3D Printed Site Plan

The 3D printed site plan was the center piece of the exhibit presented as part of this thesis. As the center piece, it was imperative that the model meet the Design for All strategy of being accessible "to everyone." The principle goal of the Design for All approach is to create a single product that is accessible to as many people as possible. Visitors to the exhibit could either touch or view the 3D printed site plan, and use the audio touch tour along with the site model to access it.

Figure 31. 3D printed site plan of the Pillar Dollar Wreck. (Author, 2018).

The 3D printed site plan is a photo realistic model of the Pillar Dollar Wreck. While a few small details are lost due to the reduction in size, the model is a remarkable likeness of the shipwreck as it sits on the seafloor. The site model allows viewers to visualize and understand what a shipwreck looks like on the ocean floor after hundreds of years, and provides a supplementary experience to those who may not be able to dive or snorkel on an archaeological site.

Figure 32. Pillar Dollar Wreck model display case during exhibit. (Author, 2018).

As both an alternative solution and complementary service, as outlined in the Design for All strategies, a guided audio touch tour of the 3D printed site model was written to provide a tour of the site. The audio tour provides information about the site and its history, the excavation conducted by East Carolina University in 2016, and information about the construction of the ship. During the exhibit, headphones were provided for users to listen to the tour. Additionally, the audio tour was provided in both English and Spanish. A transcript of the audio tour in English can be found in Appendix J, and a transcript in Spanish can be found in Appendix K.

6.3 3D Printed Artifacts

Two artifacts found on the Pillar Dollar Wreck, a piece of Guadalajara clay and an iron fastener were modeled using Agisoft Photoscan and 3D printed in plastic, using a Makerbot 3D printer. The inclusion of 3D printed artifacts allows all users to interact with historic artifacts in an unusual way. In a traditional history museum or exhibit, one would be asked to view artifacts from behind glass, in a "look but don't touch approach." Using 3D printing to create replicas allows people to interact with heritage, rather than being separated from it by a physical barrier.

Figure 33. 3D printed iron fastener and Guadalajara clay during exhibit. (Author, 2018).

In the style of the Prado Museum exhibit discussed in Chapter 4, modeling clay was used to recreate the original floral pattern painted on the piece of Guadalajara clay. In this way, visitors to the exhibit with visual impairments could visualize the pattern of the artifact. Information about the artifacts was also included in the audio touch tour, providing information about the history of Guadalajara clay and the use of iron ship fasteners.

6.4 Textual and Braille Interpretive Signage

Traditional interpretive signage was created to accompany the exhibit. Copies of the signs can be found in Appendix I. Information displayed was created to be at an appropriate reading level for a variety of audiences, including children and adults. Topics discussed included the site, artifacts found on the site, archaeological excavation, the history of treasure hunting on the Pillar Dollar Wreck, and photogrammetry.

Copies of the interpretive signage were printed without text. The text-less versions of the signs were identical to the versions with text, in an effort to create equal access to resources. 3D printed braille, containing the same information as the textual signs, were attached to the text-less signs.

Figure 34. Braille interpretive signage during the exhibit (Author, 2018).

6.5 Using Design for All for a Maritime Cultural Heritage Exhibit

Each component of the Pillar Dollar Wreck exhibit combined to create a presentation of maritime cultural heritage that met the ideal Design for All strategy of "to everyone." These components included a 3D printed site model, individual 3D printed artifacts, a guided audio touch tour of the site and artifacts in both English and Spanish, traditional interpretive signage, braille versions of the interpretive signage, and a virtual dive using the photogrammetry model.

Figure 35. Exhibit set up in the lobby of Joyner Library (Author, 2018).

On January 25, 2018, the exhibit was presented to the public in the lobby of Joyner Library at East Carolina University. Interpretive signage, both written and in braille, were set up on easels. The virtual dive component of the exhibit was displayed on a large monitor. The only necessary skill required by users to access it was the ability to maneuver a computer mouse. Hosted on Sketchfab, the dive allowed users to view the Pillar Dollar Wreck on a sandy ocean floor, and virtually "swim" around the site, zoom in and out on areas of interest, and take ownership of their own exploration of the site.

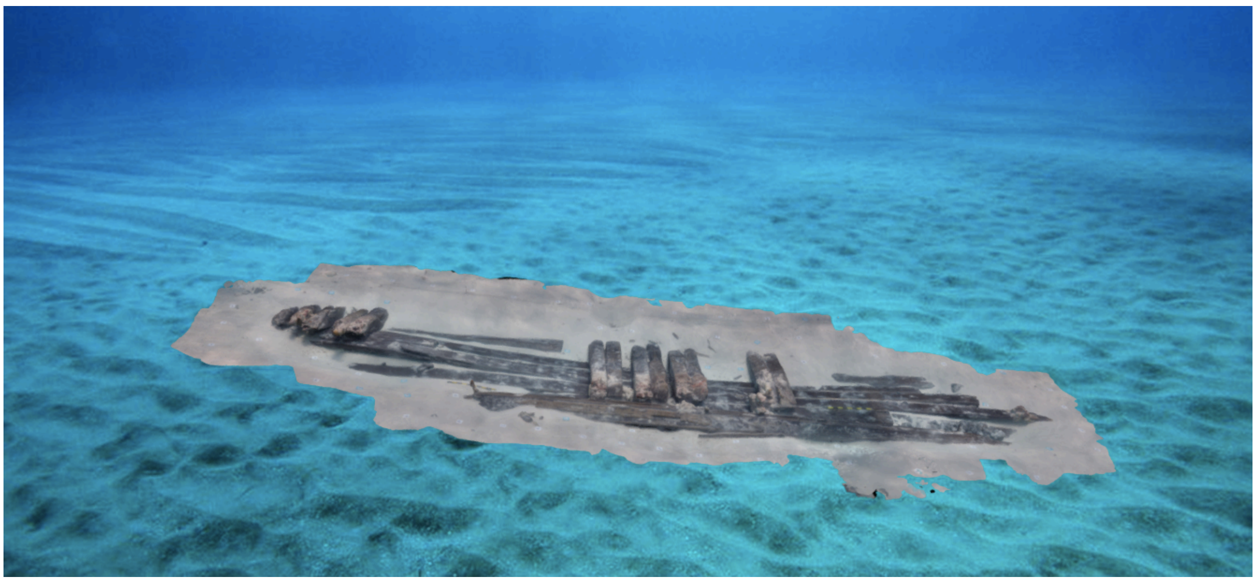


Figure 36. Sketchfab display of the virtual "take a dive." (Author, 2018).

Visitors to the exhibit were invited to explore the 3D printed site model and artifacts through the audio touch tour. Headphones were provided for those who wished to partake. Many, however, chose to simply view and touch these components of the exhibit.

Unfortunately, it was not disclosed to the author if there were any visitors attending the exhibit with visual or hearing impairments. Therefore, it is difficult to assess whether or not the exhibit as a whole, or individual components of the exhibit, provided greater accessibility to the archaeological site. However, the exhibit was carefully planned to the standards of the Design for All Foundation presented in Chapter Four.

The Pillar Dollar Wreck exhibit was the first application of a “design for all” approach to interpreting maritime heritage. While the general concept of “design for all” is broad, when narrowed and applied to cultural resource management, this approach presents a new way for the public to interact with archaeology that expands the types of audiences reached. By presenting material in a variety of ways that keeps the idea of “design for all” at the forefront, submerged archaeological sites can be accessible to all. The exhibit, and this thesis, draws attention to the lack of resources available to people with mobility, visual, and learning impairments, as well as to those with economic impairments that prevent them from visiting a shipwreck site. By using the “design for all” approach and the work of this thesis, heritage managers can create better interpretive products that accommodate a wide range of needs and audiences, providing better access to resources to more people. This thesis provides the tools, knowledge, and theoretical background to create cultural heritage exhibits and interpretive products that provide greater access to archaeological sites.

6.6 Comparison of Goniometer and Photogrammetric Ship Lines

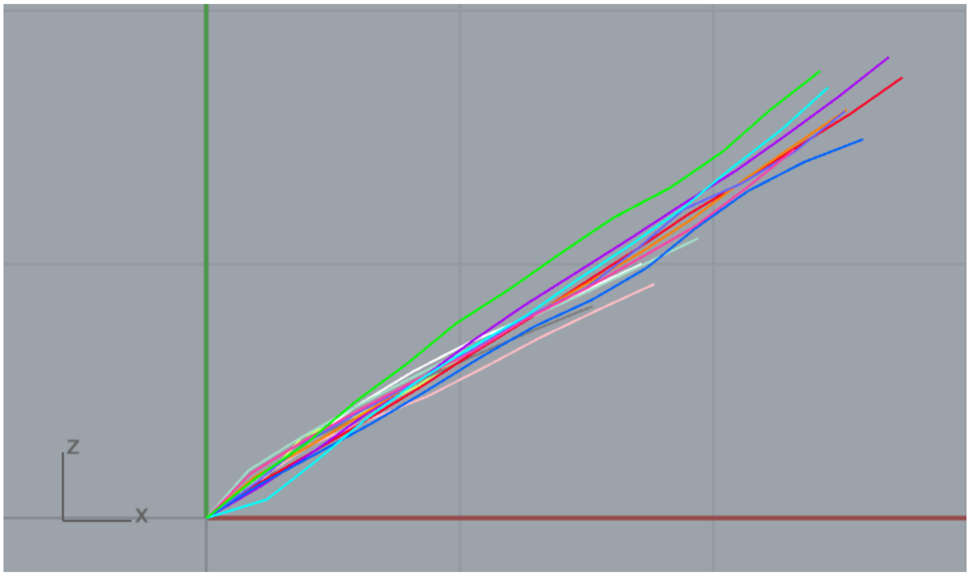


Figure 37. Ship lines created using goniometer (D. Sprague, 2016).

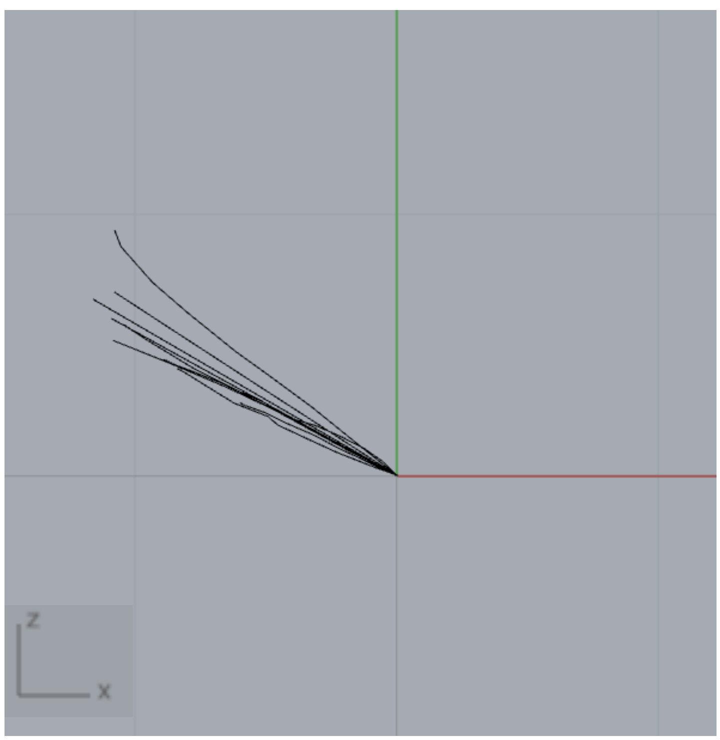


Figure 38. Ship lines created using photogrammetry. Scale: 1 box = 3 meters. (Author, 2017).

Figure 38 and Figure 39 show ship lines of the Pillar Dollar Wreck created by using a goniometer and photogrammetry, respectively. While similar, the curvature shown in the figures are two different interpretations of what the original ship that is now the Pillar Dollar Wreck may have looked like. The differences in interpretation were likely caused by varying ideas in what a "faired" curve looks like to different archaeologists. Archaeology is, after all, interpreting the past in the best way one see's fit.

In the case of the Pillar Dollar Wreck, the remaining parts of the frames are relatively short. In both instances of hull line reconstructions, the lengths of the timbers were controlled to make them of equal height.

As part of the 2016 excavation, a list of comparable available seventeenth and eighteenth century shipwreck sites used by the Spanish at the time of wrecking was created (McKinnon 2017). If ship planes are available for these ships, the goniometer and photogrammetric reconstructions could be used to compare similar ship construction patterns in hopes of coming closer to identifying the wreck.

6.7 Beyond Pictures: What Can Photogrammetry Tell Us About the Past?

Recent research has shown that there are many uses for photogrammetry beyond creating "pretty pictures." This critique of using photogrammetry for archaeology is addressed in Yamafune's 2016 dissertation. He proposes the use of photogrammetry as a tool for digital *in situ* preservation, stating that accurate photogrammetric recording can be used as an important tool for protecting cultural heritage against natural and conflict disasters. Additionally, he states that photogrammetry can be used as a tool to protect against treasure hunters in a similar manner. Once a site has been recorded in 3D, archaeological data can be recorded from the model. Yamafune also proposes the use of legacy photogrammetry or creating photogrammetry models from photos originally intended to create analog photo mosaics, taken before photogrammetry software, such as Agisoft Photoscan existed. Additionally, creating ship's lines from photogrammetry models allows archaeologists to better understand ship construction and learn new information about the past. Finally, he states that photogrammetry is an excellent tool for leaving data for future generations, allowing sites to remain intact for future archaeological study and interpretation (Yamafune 2016). Yamafune's methodology, as well as the methodology for creating 3D printed models presented in the previous chapter allows archaeologists to understand the past and preserve heritage for future generations of both archaeologists and the public.

However, there is still more to be learned from the use of photogrammetry about the past. In their 2017 article, "Regional Maritime Contexts and the *Maritorium*: A Latin American Perspective on Archaeological Land and Sea Integration," Herrera and Chapanoff present the idea of *maritorium*. The authors expand on Westerdahl's (1992) idea of the maritime cultural landscape, or the "human utilization (economy) of maritime space by boat, including settlement, fishing, hunting shipping, and its attendant sub-cultures, such as pilotage, lighthouse, and sea-mark maintenance" (Westerdahl 1992:5). The idea of *maritorium* seeks to expand the concept of the maritime cultural landscape to include the understanding of high-seas dynamics in the form of oceanic navigation and geologic features, routes, cartography, symbolic understanding, and senses such as visuals and smells. Additionally, *maritorium* seeks to incorporate modern technologies and traditional activities of those who live by the sea, while remaining close to a phenomenological approach. The authors briefly touch on the use of GIS, satellite images, and

LiDAR technology, stating that while they are enthusiasts of these tools, they have often been used to create an objectified and distanced perspective of maritime landscapes (Herrera and Chapanoff 2017). However, they later pose the question of "How far does the maritime landscape and its inhabitants reach?" (Herrera and Chapanoff 2017). From this perspective, one can argue that photogrammetry allows the *maritorium* of a location to extend globally to anyone who is able to interact with it in a virtual environment.

Additionally, because *maritorium* places an emphasis on the sensory experience of one attempting to understand the past, photogrammetry and virtual reality modeling allow archaeologists to better understand the reality of people living in the past. The authors state, "With the understand that objects, smells, experiences, and identities associated with the maritime environment may extend far beyond its geographical limits…what are the real limits, in terms of human experiences, of maritime landscapes…" (Herrera and Chapanoff 2017).

This is also exhibited in C. L. Ogleby's (1999) article "From Rubble to Virtual Reality: Photogrammetry and the Virtual World of Ancient Ayutthaya, Thailand." While some of the photogrammetric methodology used by Ogleby is outdated, the theoretical perspective proposed remains true. Using photogrammetry and 3D modeling to create models of animals, people, architecture, boats, and landscape, the author attempted to create a realistic virtual space that incorporated as many senses as possible so that viewers, archaeologists and the public unlike, could learn more about the experiences of people from the past, by taking heritage and presenting it in a more humanistic way. This experience ties into the concept of *maritorium*. "Moving around a maritime setting implies a particular sensorial relationship with the environment, involving the dynamics at play while moving around a landscape… The notion of *maritorium* implies negotiating the experience of exploring the temporality of moving around, and above….as a critical part of that ambulatory knowledge."

In the case of the Pillar Dollar Wreck, and shipwreck sites in general, archaeologists may be better able to understand the past by applying *maritorium*. By taking into account components of a seascape beyond the maritime cultural landscape, such as sensorial features and terrestrial navigational features, scientists may be better able to understand what caused a wrecking event. Photogrammetry and the creation of interactive or virtual reality models from 3D models allows a deeper connection to the past for scientists and the public alike.

As for the interpretation of shipwrecks through photogrammetry and the use of the "design for all" approach, the non-archaeologist public comes a step closer to experiencing *maritorium*. Understanding the past and interpreting it to others through material goods is the primary goal of archaeologists. However, in the past, people with disabilities have not had equal access to these tools or interpretive products, particularly for submerged archaeological sites. This thesis, as well as the exhibit presented on the Pillar Dollar Wreck provide cultural resource managers with the knowledge base to include broader audiences in maritime archaeological interpretation, so that the past can be shared with more people.

7 Conclusions

7.1 Revisiting the Research Questions

This study sought to examine the capabilities of 3D modeling regarding the accessibility of archaeological sites and to examine the use of a Design for All approach and its application to accessibility in maritime archaeology. Additionally, it created a methodology for creating 3D printed replicas of archaeological sites, and examined their potential for use in public interpretation of submerged archaeological sites.

- 1) Using the Pillar Dollar Wreck as a case study, how can the use of 3D models increase accessibility to inaccessible sites using a “design for all” approach for public interpretation and display?

Design for All is a broad concept that aims to “enable all people to have equal opportunities to participate in every aspect of society” (Neumuller 2014). When applied to the interpretation of maritime cultural heritage, this means looking past the traditional accessibility strategies of shipwreck preserves and museums, and implementing educational and interpretive programming that allows people of all abilities to interact.

Incorporating 3D modeling into education and interpretive programming for maritime archaeology provides greater access to all in a variety of ways. First, for many, interacting with a virtual model of a shipwreck site may be the closest that they ever come to diving or snorkeling on a shipwreck site. 3D models allow viewers to view and interact with an archaeological site as it sits *in situ* on the sea floor. Agisoft Photoscan allows archaeologists to produce high-quality, scaled, photo-realistic 3D models that accurately depict an archaeological site. Sharing these models provides access to many audiences. Protected shipwreck sites may not allow access to anyone besides archaeologists or cultural resource managers. Documenting a site using 3D modeling and 3D printing allows other to visit it. For those who may be excluded from diving or snorkeling activities due to economic impairments, 3D documentation allows them to view and interact with sites. For people with disabilities who prevent them from accessing a site in the water, or even from viewing a model of it, 3D printing and the principles of Design for All allow interaction.

Furthermore, the Design for All Foundation states that universal design is the "intervention into environments, products and services which aims to ensure that anyone, including future generations….can participate in social, economic, cultural and leisure activities with equal opportunities" (Design for All Foundation 2011). In its beginnings, maritime archaeology most often consisted of full scale excavation of shipwrecks, bringing as many artifacts as possible up from the ocean floor. This paradigm has shifted. It is becoming more and more common to document submerged wreckage and artifacts *in situ*, leaving them on the seafloor for further study and for the enjoyment of future generations. The 2001 UNESCO Convention of the Protection of Underwater Cultural Heritage cites *in situ* preservation as the recommended first option for the preservation of underwater cultural heritage, stating "The *in situ* preservation of underwater cultural heritage should be considered as the first option before allowing or engaging in any further activities, such as the recovery of objects" (UNESCO 2001). The use of 3D documentation and 3D printing has great potential to uphold UNESCO's recommendations for *in situ* preservation as well as to bring better public access to these *in situ* sites. With 3D printing, archaeologists can document wrecks on the seafloor without disturbing the site, print the wreck, artifacts, and topography, and allow the public to interact with underwater cultural heritage without ever having to set foot on the site.

1) What are the capabilities of 3D models in accessibility? What is the “design for all” approach and how can it be applied to the public interpretation of maritime cultural heritage?

3D models have the capability of bringing archaeological sites to the public who has no other way to access them. 99.7%, or greater of the population does not have immediate access to submerged cultural resources, and must rely on interpretive and educational programming for access to these resources. Most commonly, this takes the form of a museum or visitor center. However, the information presented to them often does not provide a realistic experience of visiting a shipwreck site. With the incorporation of 3D modeling and 3D printing, cultural heritage manners can better provide an experience that allows a person to understand and interact in greater depth with maritime cultural heritage.

The original concept of Design for All is broad, aiming to make the use of products and services easier for everyone, and to ensure that users with disabilities or impairments are accounted for in the design process. The Design for All approach requires that products be respectful, safe, healthy, functional, comprehensible, sustainable, affordable, and appealing (Design for All Foundation). These criteria are easily applicable to the use of 3D models and

3D printing, as they can be made readably accessible to all, are relatively inexpensive, and the materials used are safe for every day handling.

2) What historical and scientific narratives can be extracted from the Pillar Dollar Wreck in the interpretation and 3D display?

The creation of 3D models for the purpose of archaeological interpretation is still an undervalued tool. 3D models allow archaeologists to extract data from archaeological sites and artifacts without having to visit the site. This drastically cuts the cost and time commitment of field work for archaeologists. Mapping a site may have once taken an entire season of field work. Now, accurate site plans can be produced in a single dive for a small site with good visibility and conditions, such as the Pillar Dollar Wreck. Time needed to create an accurate 3D model may increase with the size of the site or other variables such as cloudy or murky water. However, it is still significantly smaller than traditional hand mapping. While hand mapping is still an important and valuable part of archaeological interpretation, if funds or time for investigation of a site are limited, photogrammetry offers an attractive alternative.

Additionally, documenting archaeological sites and artifacts in 3D helps mitigate the need for the expensive and time-consuming process of conservation. Once recorded *in situ*, artifacts can be reproduced through 3D printing. Due to the scaling feature in Agisoft Photoscan, it is possible to take measurements on photogrammetric models as if one were measuring the actual artifact.

As discussed in Chapter 5, it is also possible to extract hull section profiles and use them to reconstruct hull shapes in Rhinoceros 3D. Understanding ship construction is an important part of conducting maritime archaeology research, particularly on sites such as the Pillar Dollar Wreck, where there is no original context for artifacts and few artifacts remain. Understanding the origin of the ship construction may allow for better interpretation of the few other artifacts that remain.

7.2 Significance and Future Research

Few research studies have been conducted on 3D printing for archaeology, and even fewer regarding maritime archaeology in particular. The work presented here not only offers a theoretical explanation of the importance of expanding accessibility strategies for the interpretation of maritime cultural heritage, but offers the platform of Design for All as a way to ensure that maritime cultural resource managers reach as many audiences as possible. Additionally, it offers step by step guidance in producing 3D printed models of underwater archaeological sites. Other archaeologists and managers may follow this same methodology to reproduce and print virtually any other archaeological site. The ultimate goal of this study was to produce a methodology and theoretical basis for creating interpretive and educational products using 3D data that provide access to maritime cultural heritage for all. Research conducted during this study found that very little was being done to make 3D data and printing a part of maritime heritage interpretive products. The author hopes that the results presented here may pave a path towards incorporating 3D modeling and printing into the interpretive toolbox of cultural resource managers in order to provide an authentic shipwreck experience for all.

Opportunities for future research are bountiful as a result of this thesis. There is much to continue studying in the field of 3D printing and maritime archaeology. A study into the ability to recreate shipwreck sites underwater using 3D printing could provide resource managers with a complementary service to shipwreck trails and preserves. 3D printing entire sites may also reduce the risk of damage and looting to archaeological sites sometimes caused by divers and snorkelers. Furthermore, entire underwater archaeological sites could be recreated on land in a walkable shipwreck trail, accessible to more people than the underwater shipwreck trails of the past.

Continued research into methodology for creating hull section profiles could also benefit the study of ship construction. Limitations caused by the layout of the site created some issues, as described in Chapter 5, that could potentially be overcome with further research. Furthermore, additional research could be conducted on the Pillar Dollar Wreck itself from the hull lines created using photogrammetry by comparing Iberian and English ships from the eighteenth century with the generated lines.

Most importantly, a study with IRB approval could assess the reaction of visitors to an exhibit created with a Design for All approach, incorporating ideas and feedback from people who require different interpretive products. Unfortunately, there were no visitors to the exhibit in Joyner Library that disclosed that they had any kind of special need or impairment, so it is difficult to truly assess the effectiveness of the exhibit created for this thesis. Rather, the exhibit and its associated interpretive products serve as a prototype for interpreting maritime cultural heritage using Design for All. With IRB approval, creating a voluntary focus group made up of a variety of people with disabilities and impairments with the intention of assessing the usefulness, functionality, and methodology of creating a Design for

All based exhibit would contribute greatly to the knowledge-base of cultural heritage and accessibility, particularly in regards to using Design for All.

7.3 Conclusion

This thesis examined the capabilities of 3D modeling regarding the accessibility of archaeological sites and examined the use of a Design for All approach and its application in promoting accessibility in the field of maritime archaeology. Research was conducted on ways that 3D data was already being used in archaeology and public outreach, as well as ways in which 3D printing is being used in museum settings. Research was also conducted on the principles and criteria of the Design for All approach.

A methodology for creating scaled, photo realistic 3D printed models of archaeological sites using photogrammetry models created in Agisoft Photoscan was presented. This methodology allows heritage managers to create tactile exhibits that incorporate the needs of peoples of all abilities.

Providing a theoretical framework for the integration of 3D modeling and printing into maritime cultural heritage management was an important part of this thesis research. The results from this research better allow heritage managers to take into account the needs for people with certain disabilities and impairments who wish to access maritime cultural heritage.

Further, this thesis brings archaeologists one step closer to answering the question of "So what?," regarding 3D photogrammetry models. A common concern of using photogrammetry for archaeological purposes is that 3D models are often used as nothing more than a picture of an archaeological site, or a flashy tool to bring attention to a project, rather than a tool that serves a true analytic purpose. In using 3D models to bring realistic interpretations of shipwreck sites to the public in an inclusive and accessible way, this thesis provides a platform for using photogrammetry models for a real purpose.

Finally, this thesis promotes taking accessibility to maritime cultural heritage out of the water and the display case, and into the hands of people who also rightfully deserve access to it. Again, this thesis does not seek to take away from the importance of traditional museums and shipwreck trails and preserves. It seeks to draw attention to those that have been denied access to underwater cultural heritage, and promote greater access to maritime cultural heritage for all.

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Yamafune, K., R. Torres, and F. Castro
2017 Multi-Image Photogrammetry to Record and Reconstruct Underwater Shipwreck Sites. *Journal of Archaeological Method and Theory* 24(3) 703-725.

Appendix A: Excerpt From *Diving to a Flash of Gold*

Pillar Dollar Wreck

NW of Whistle Buoy No. 2

No sketch is needed to find this wreck. Refer to the master chart for the general location. You will see a large reef that is distinctive and shallow, easily found from a boat. The small shoal area just north of the wreck stands out sharply against white sand bottom. Locate it and you are a stone's throw away.

About 150 feet south of this ten-foot deep lies the main body of the wreck. It is all but buried, in fact could be covered at any time, by the sparkling white sand. Her timbers and ballast may conceal treasure still unfound. In 1963, she yielded two cannon and a quantity of Spanish pillar dollars (dates 1770 to 1778). She is a treasure galleon in every respect.

Artifacts have been recovered from cracks and pockets in the rock of the ten-foot deep shoal and along the offshore edge. From this, one can conjure up a mental image of the ship running before a fierce northeast blow. She struck hard upon the rocky rise and burst open, carrying onward only a few yards before sinking. Sand depth here is the big obstacle. It covers more cannon, and possibly treasure, along the trail of the wounded vessel. A patient searcher armed with a state lease and good detection gear might be reasonably well rewarded.

Among the objects recovered from the ten-foot shoal are iron spikes and hinges, some pewter, several spoons, pieces of pottery and glass, a pair of slave bracelets and a hoarding cutlass. The cutlass lay in plain view at the shallowest part of the rise. A chance discovery along the northeast edge was a matched pair of pewter candlestick holders concealed in sand.

Classification: Galleon

Appendix B: Excerpt from *Galleon Alley*

There was a shake-down cruise of sorts that found them digging holes on the "Pillar Dollar Wreck" site off Key Largo. Here was a wreck that had piled in over a moon-shaped reef, settling onto a sandy bottom twenty feet deep. That happened about 1768, the sand soon covering the entire site where she lay undetected until 1965. Art Sapp and Bobby Savage, operating off the salvage boat Norma found her with a magnetometer and salvaged her the best they could with four-inch airlifts. A number of pillar dollars dated 1760-64 were recovered, but nothing else of great artifactual value. Tom and his crew found nothing on the site at all, and headed further south, towards Marathon.

Appendix C: Excerpt from Shipwrecks of Florida: A Comprehensive Listing

El Nauva Victoriosa- Spanish nao, Captain Joseph Varan, had left Cadiz, Nov. 3, 1770, bound for Vera Cruz, wrecked in 1771, at the head of the Florida Keys. She hit a reef in ten feet of water. The crew, most of the treasure, and the small arms were taken off the next day by another ship of the fleet. She eventually came off the reef and settled in the sand to the west of the reef. She now lies in a sand pocket, in 25 feet of water, southeast of Caesars Creek at about Lat. 25-19-30, Long. 80-10-30. There is a shallow reef here, and the sand pocket is on the southwest corner of a shoal, just northeast of the reef. This wreck was salvaged in the 1960s and 1970s, and became known as the “Pillar Dollar Wreck.” Pillar dollars dated 1770 can still be found. Source: 54, 56, 100 (Frederick, Carl. “New Clues to the Pilar Dollar Wreck,” July 1977).

Appendix D: Design For All Criteria

Design for All criteria

- **Respectful:** it should respect the diversity of users. Nobody should feel marginalised and everybody should be able to access it.
- **Safe:** it should be free of risks to all users. This means that all elements forming part of an environment have to be designed with safety in mind.
- **Healthy:** it should not constitute a health risk or cause problems to those who suffer from certain illnesses or allergies. In addition, it should promote healthy use of spaces and products.
- **Functional:** it should be designed in such a way that it can carry out the function for which it was intended without any problems or difficulties.
- **Comprehensible:** all users should be able to orient themselves without difficulty within a given space, and therefore the following are essential:
    - Clear information: use of icons that are common to different countries, avoiding the use of words or abbreviations from the local language which may lead to confusion.
    - Spatial distribution: this should be coherent and functional, avoiding disorientation and confusion.
- **Sustainable:** misuse of natural resources should be avoided to guarantee that future generations will have the same opportunities as us to preserve the planet.
- **Affordable:** anyone should have the opportunity to enjoy what is provided.

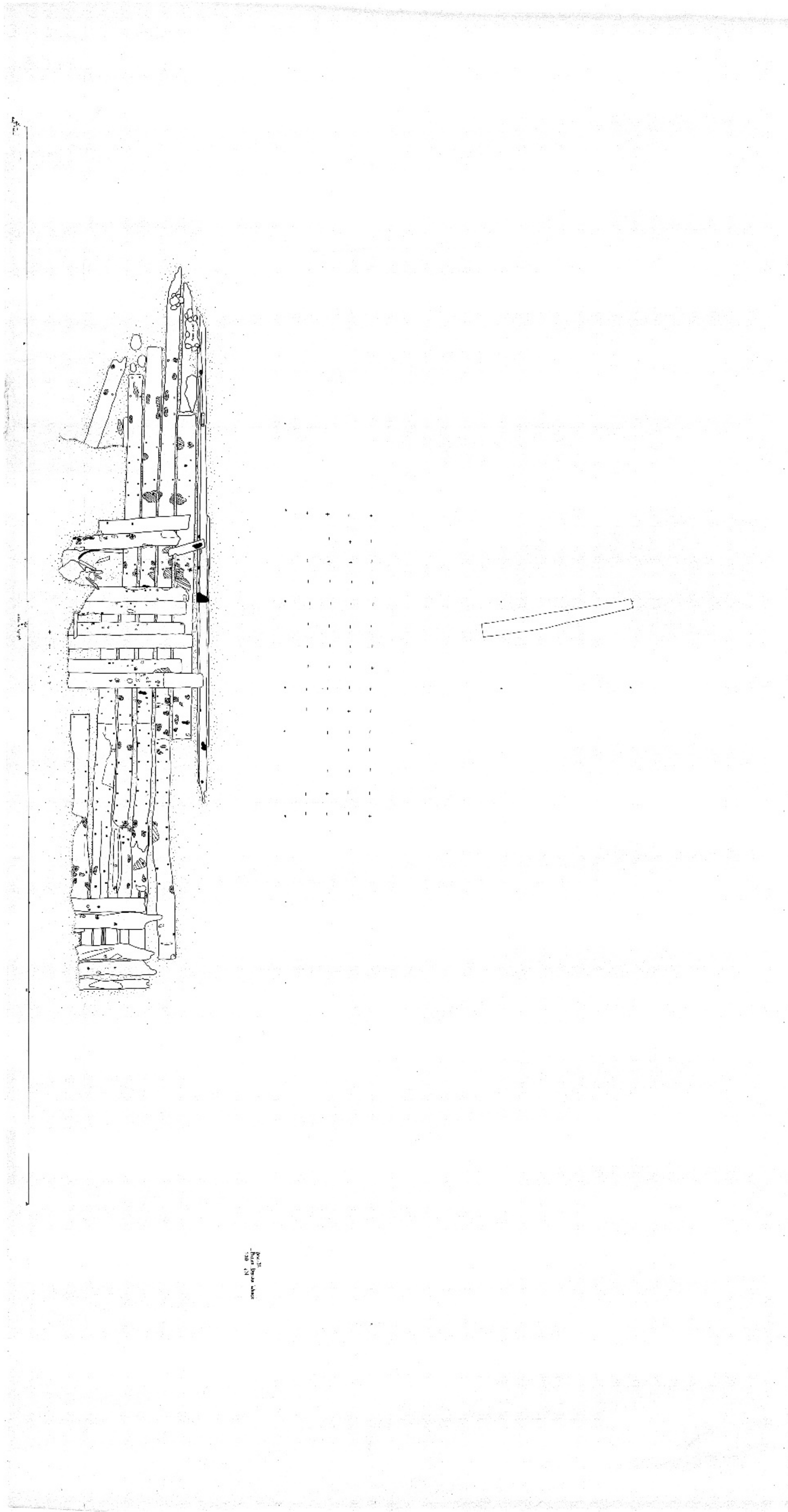
- **Appealing:** the result should be emotional and socially acceptable but always bearing in mind the seven precedent criteria.

Appendix E: National Park Service Interpretation and Education Principles

In accordance with Section 7.1 of Management Policies, effective interpretive and educational programs will include a variety of services such as informational and orientation programs, interpretive programs, educational programs, and interpretive media. NPS educational programs are designed to enrich lives and enhance learning, nurturing people's appreciation for parks and other special places, therefore helping to preserve America's heritage. To accomplish this, the NPS will develop interpretive and educational programs according to the following principles:

- NPS programs are place-based. Programs use national parks and other places as dynamic classrooms where people interact with real places, landscapes, historic structures, and other tangible resources that help them understand meaning, concepts, stories, and relationships.
- NPS programs are learner-centered. Programs honor personal freedom and interests through a menu of life-long learning opportunities that serve a wide variety of learning styles, encourage personal inquiry, and provoke thought.
- NPS programs are widely accessible. Programs provide learning opportunities, reflect and embrace different cultural backgrounds, ages, languages, abilities, and needs. Programs are delivered through a variety of means, including distance learning, to increase opportunities to connect with and learn from the resources.
- NPS programs are based on sound scholarship, content methods and audience analysis. Programs are informed by the latest research related to natural and cultural heritage and incorporate contemporary education research and scholarship on effective interpretive and educational methods.
- NPS programs help people understand and participate in our civil democratic society. Programs highlight the experiences, lessons, knowledge, and ideas embodied in America's national parks and other special places and provide life-long opportunities to engage in civic dialogue.
- NPS programs incorporate ongoing evaluation for continual program improvement and effectiveness. Programs are regularly evaluated and improved to ensure that they meet program goals and audience needs.
- NPS programs are collaborative. Where it furthers the NPS mission and is otherwise appropriate, programs are created in partnership with other agencies and institutions to achieve common goal.

Appendix F: Site Plan of the Pillar Dollar Wreck



Appendix G: Texture Maps

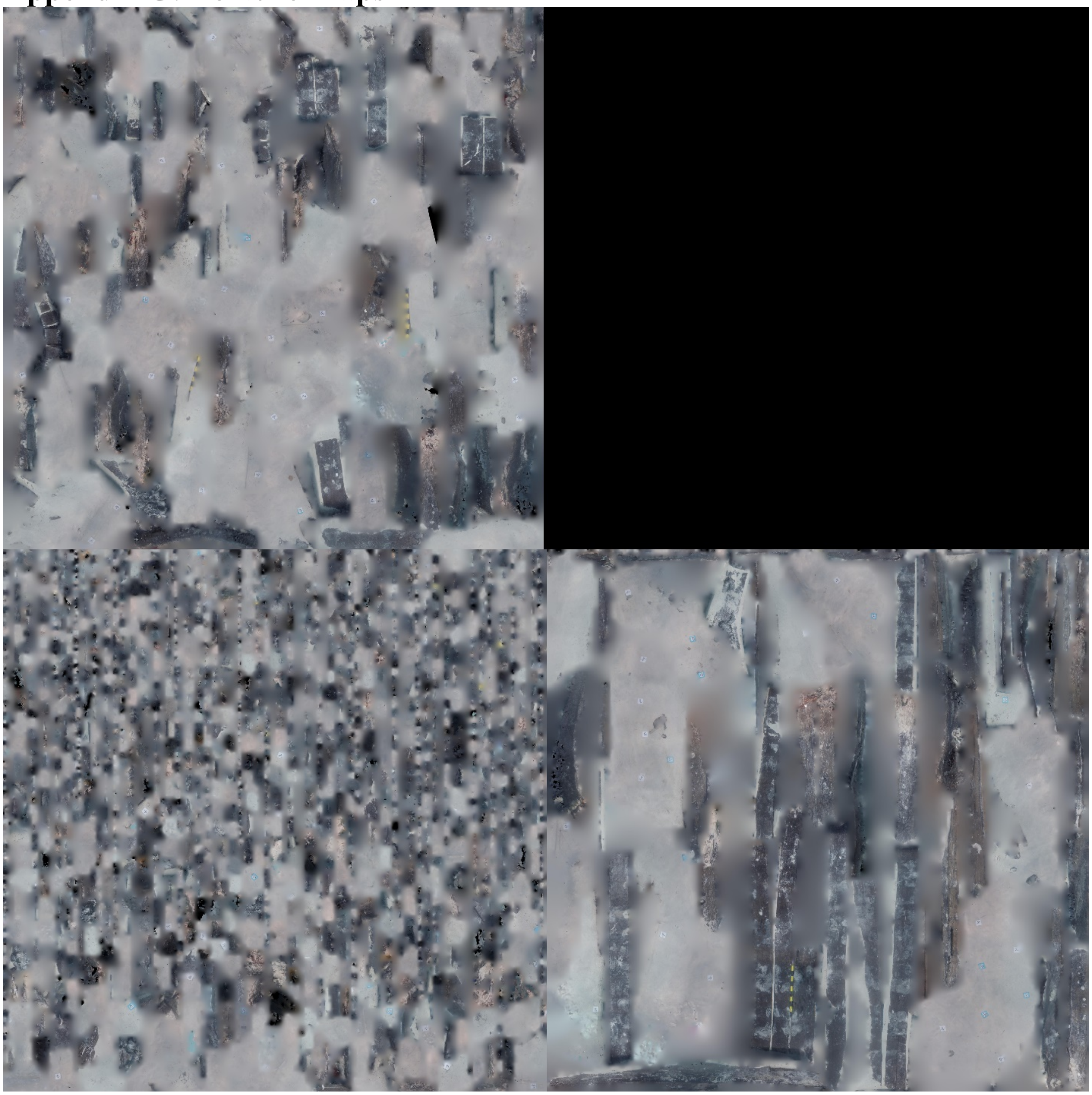


Figure 49. Texture maps produced by Agisoft Photoscan for the Pillar Dollar Wreck. These were later remapped onto the model for 3D printing using ZCorp software.

Appendix H: Hull Section Profiles

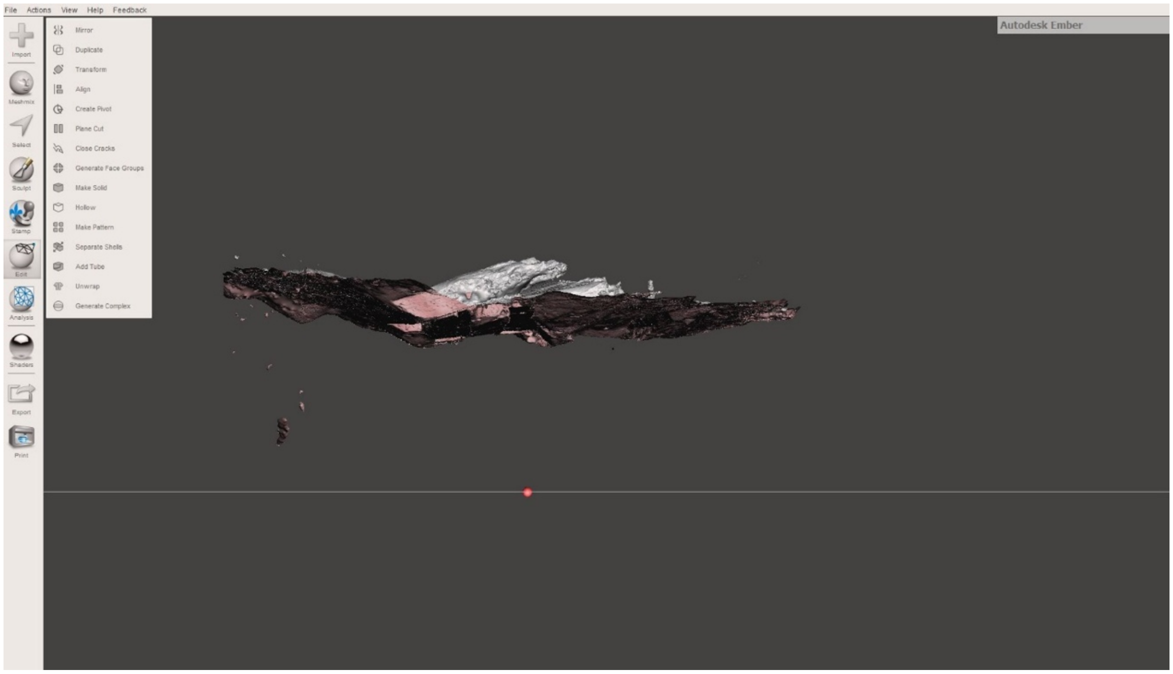


Figure 40. Section 1 hull profile (Author, 2017).

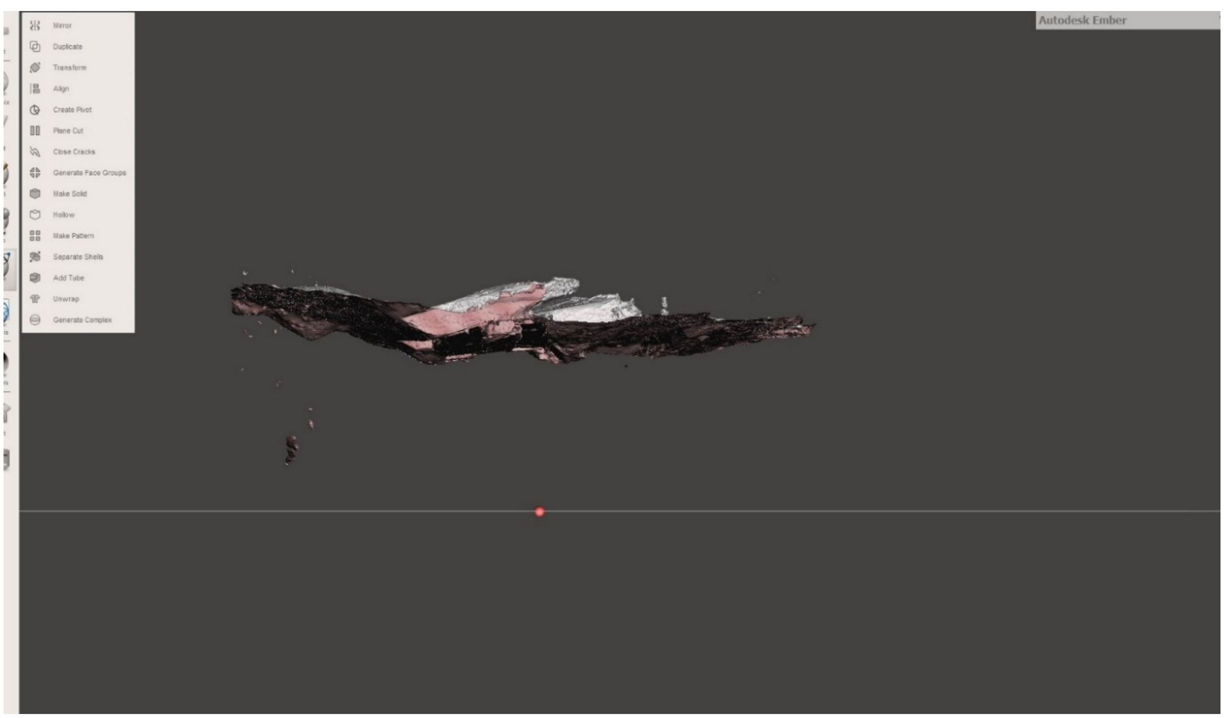


Figure 41. Section 2 hull profile (Author, 2017).

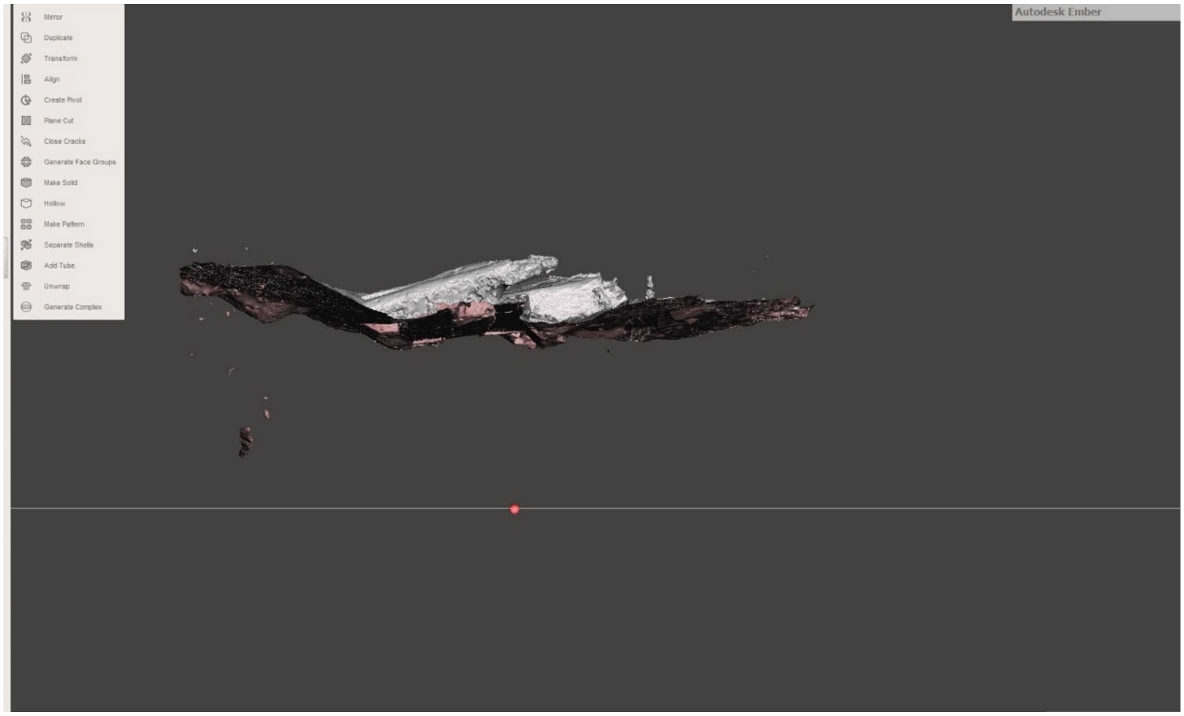


Figure 42. Section 3 hull profile (Author, 2017).

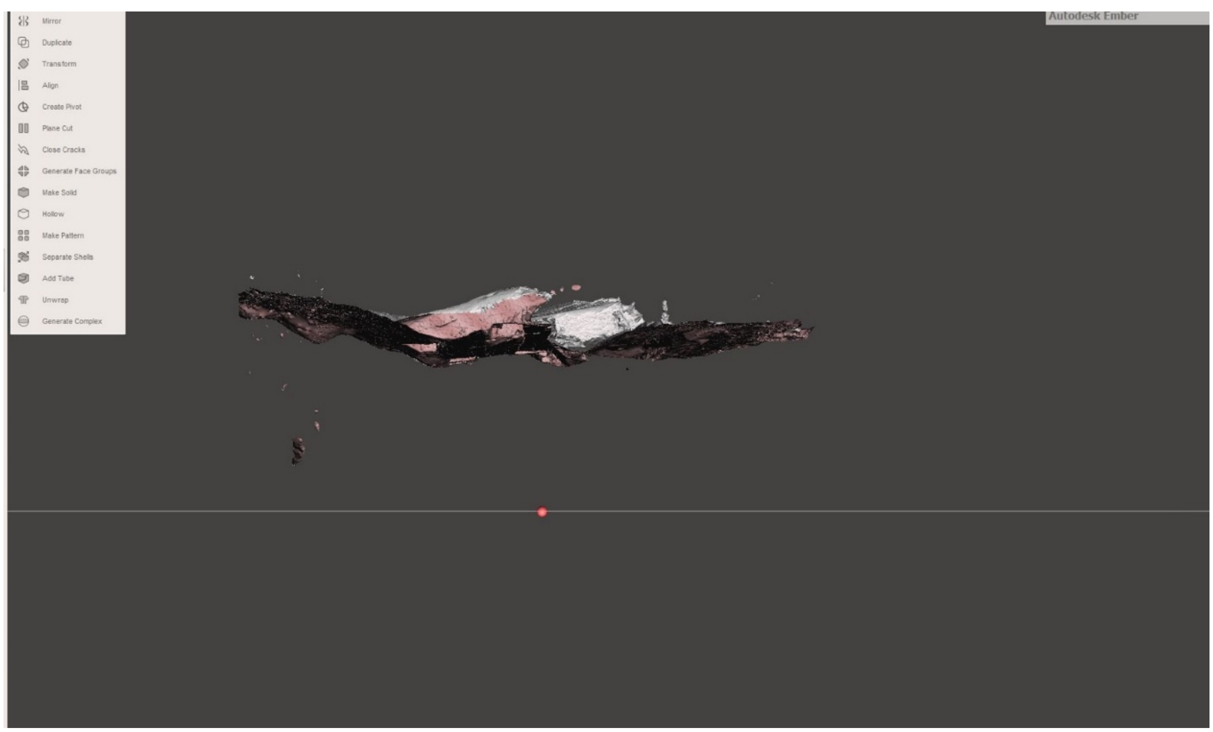


Figure 43. Section 4 hull profile (Author, 2017).

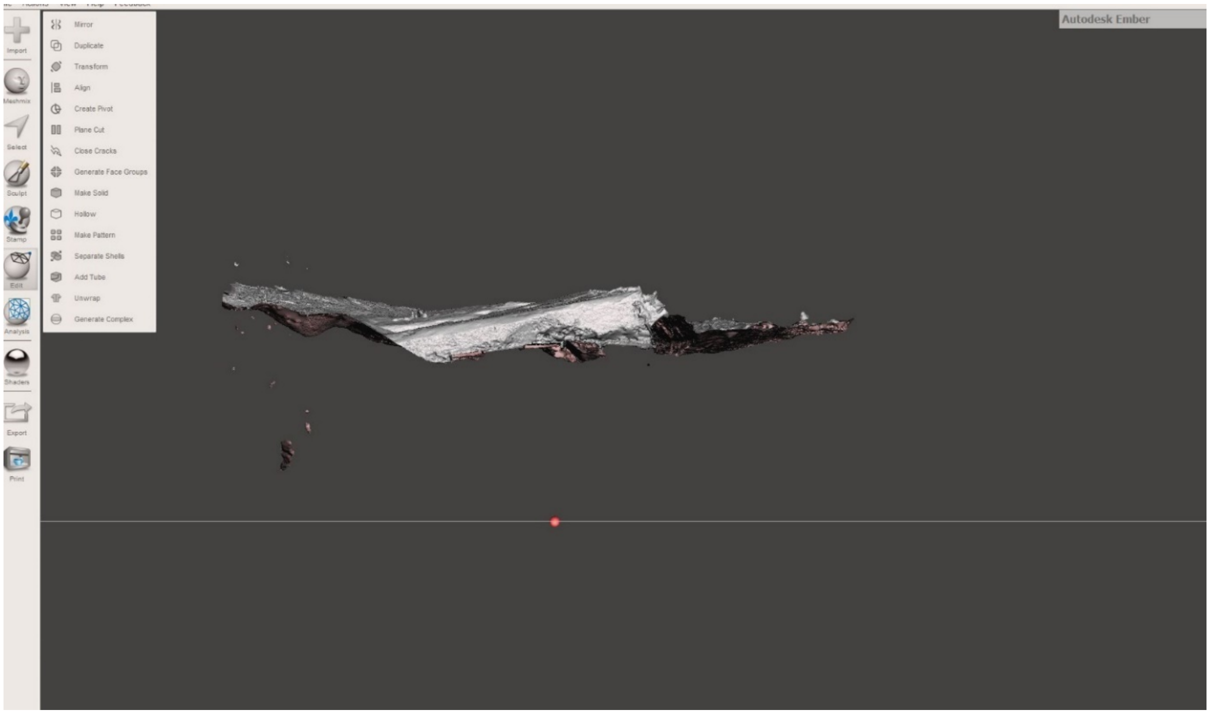


Figure 44. Section 5 hull profile (Author, 2017).

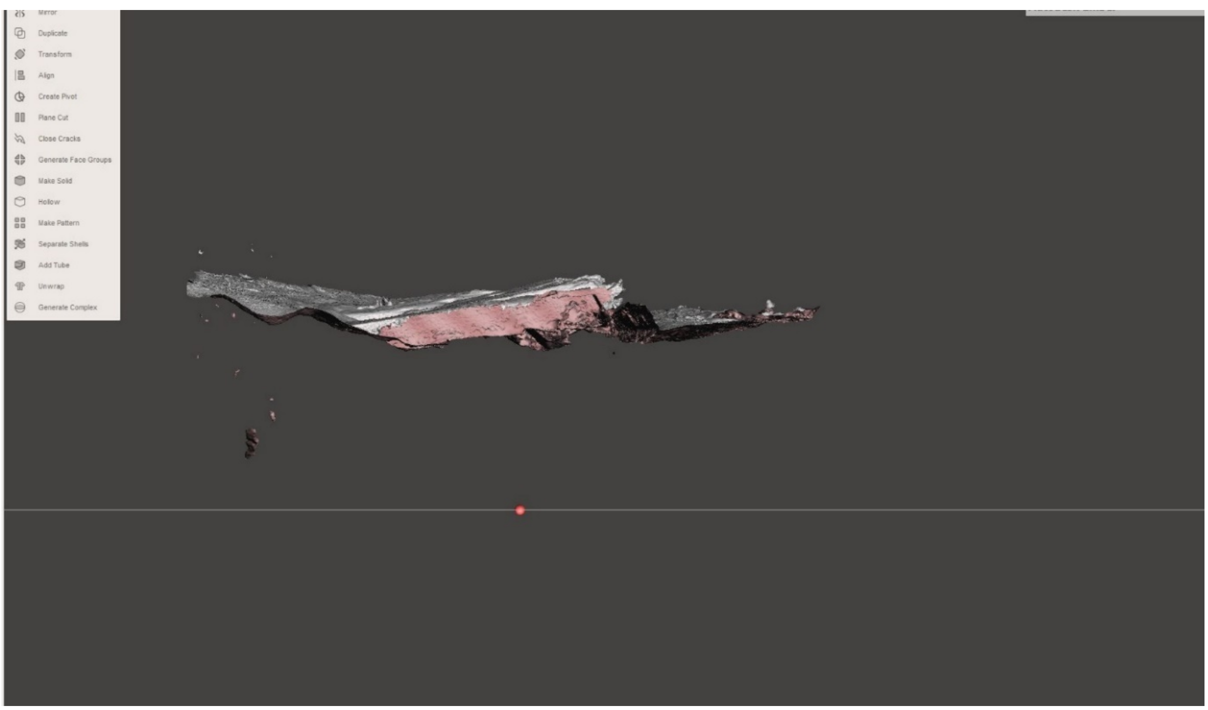


Figure 45. Section 6 hull profile (Author, 2017).

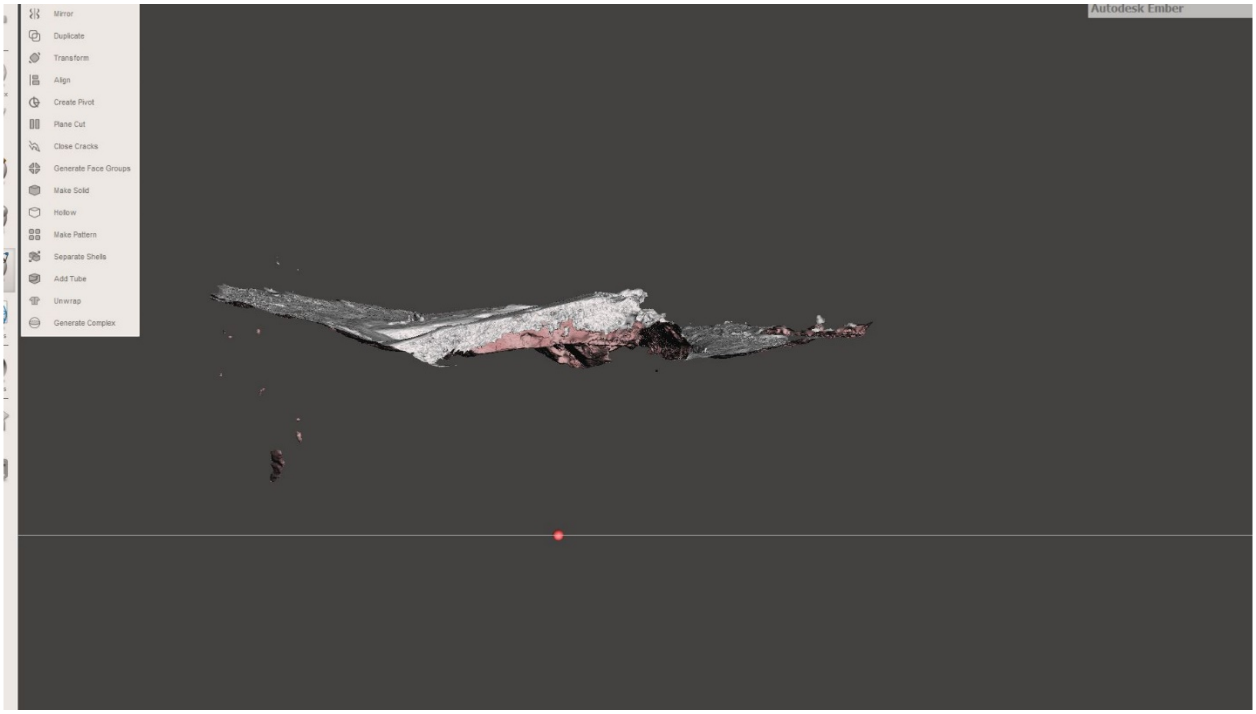


Figure 46. Section 7 hull profile (Author, 2017).

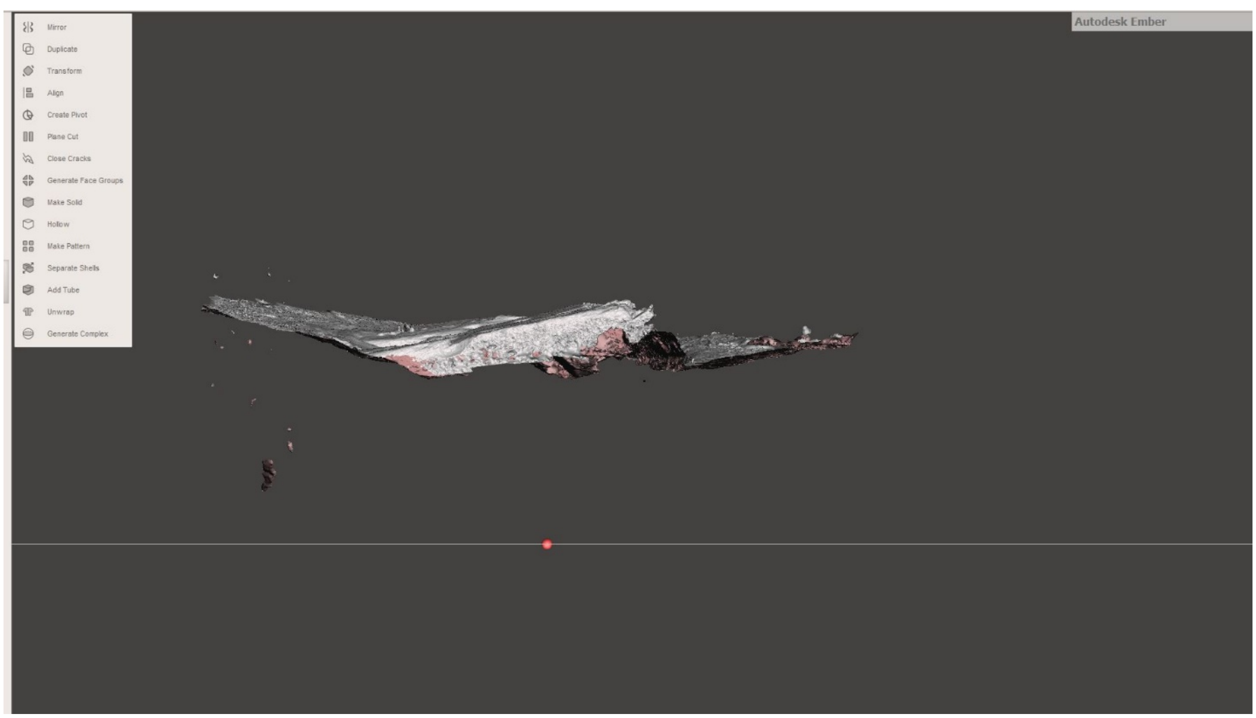


Figure 47. Section 8 hull profile (Author, 2017).

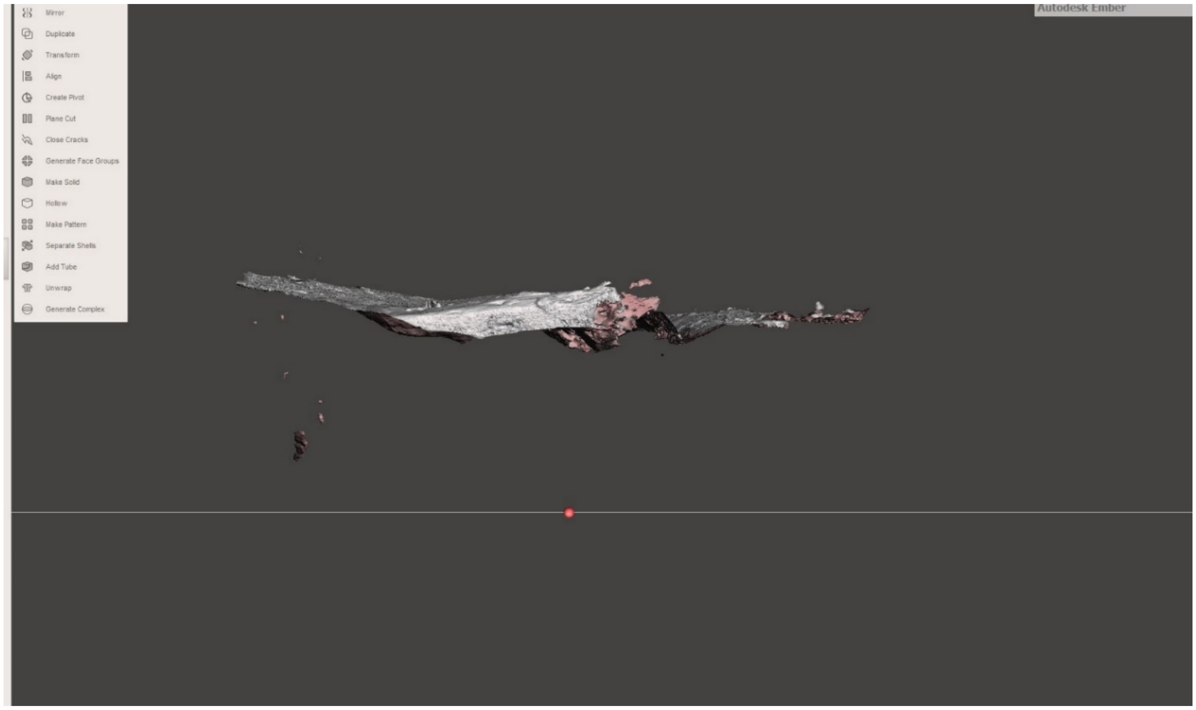


Figure 48. Section 9 hull profile (Author, 2017).

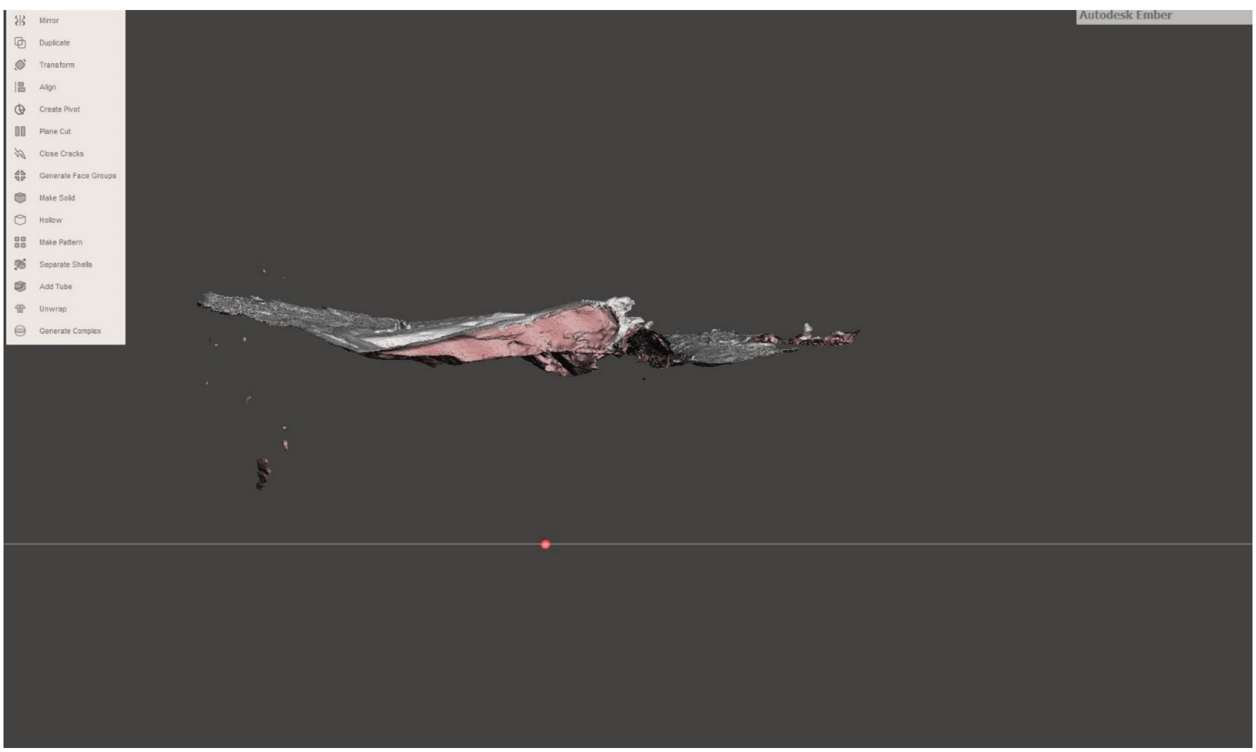


Figure 49. Section 10 hull profile (Author, 2017).

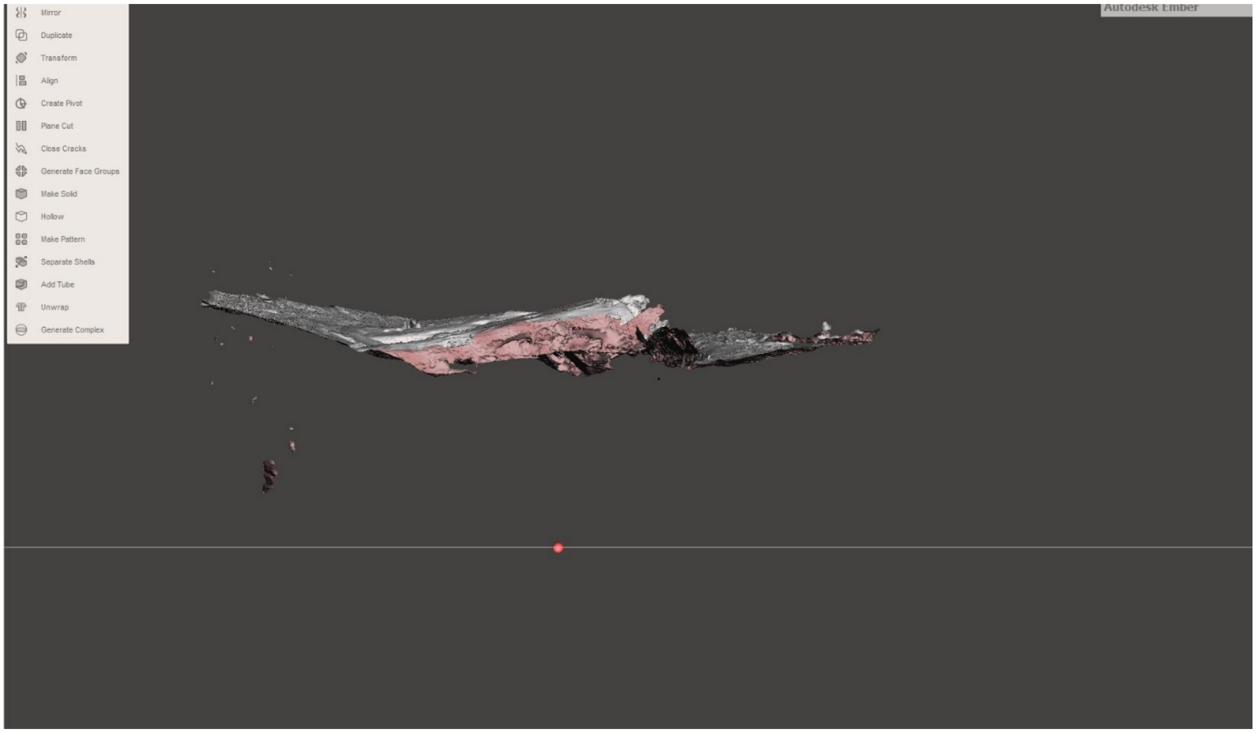


Figure 50. Section 11 hull profile (Author, 2017).

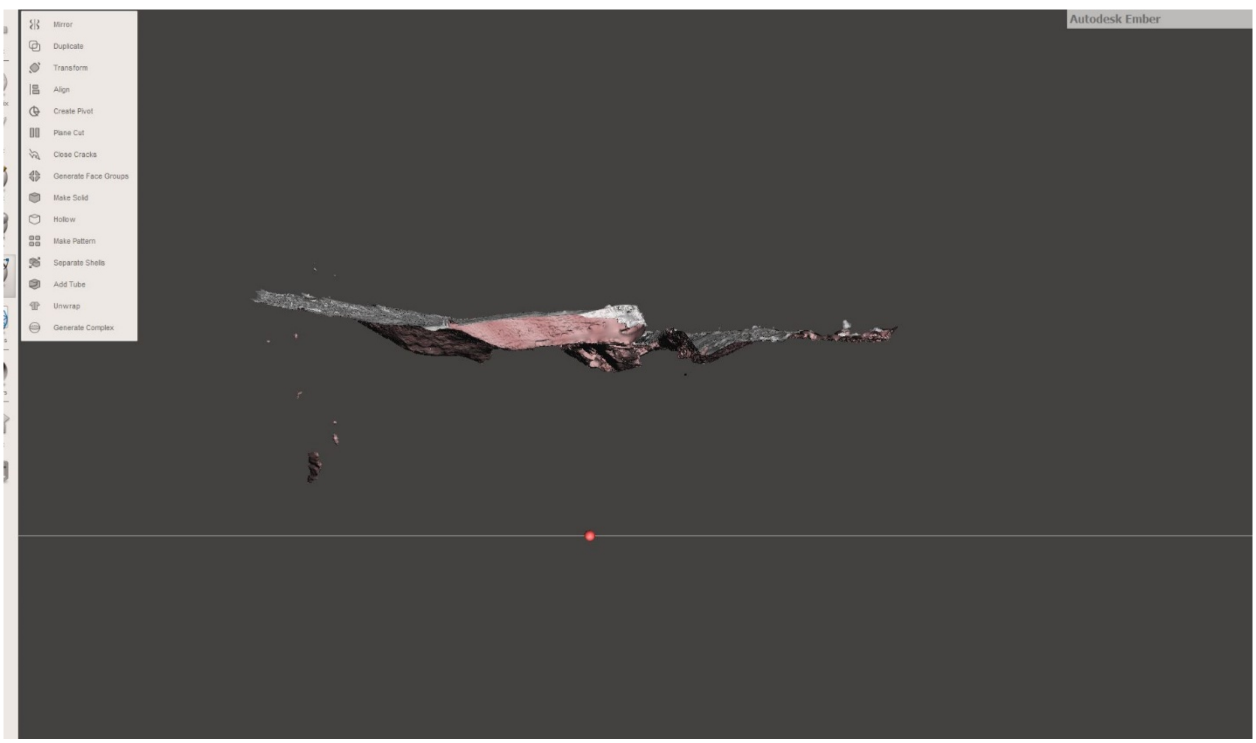


Figure 51. Section 12 hull profile (Author, 2017).

Appendix I: Exhibit Interpretive Signage

Accessing the Pillar Dollar Wreck: Exploring Maritime Heritage in 3D

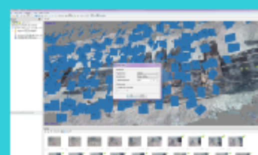
The Pillar Dollar Wreck, Biscayne National Park

What is the Pillar Dollar Wreck?

The Pillar Dollar Wreck is a shipwreck located in Biscayne National Park, near Miami. Likely a 17th century merchant vessel, the identity of the Pillar Dollar Wreck is unknown. Recent research suggests that it may be of either Spanish or British origin.

National Park Service and ECU Excavation Team Members in 2016

The Pillar Dollar wreck was excavated by a team of archaeologists and students from East Carolina University and the National Park Service in 2014, and again in 2016. The wreck site was recorded using a technique called photogrammetry, which allows a photo-realistic 3D model of an archaeological site to be reproduced digitally.



Using Agisoft Photoscan to model the Pillar Dollar Wreck

3D printed model of the Pillar Dollar Wreck using a powder printer

How does Photogrammetry work?

Using underwater cameras, archaeologists swam around the entirety of the site, taking as many photos as possible, from all angles. These photos were then stitched together using a specialized computer program, called Agisoft Photoscan. The end result is a photo-realistic model that can be scaled to take accurate measurements, used to allow non-divers to explore an archaeological site, or 3D printed.

How can an archaeological site be 3D printed?

Once the photogrammetry model is complete, a variety of 3D modeling, computer graphic and video game softwares can be used to create a printable version of the 3D model. The model of the Pillar Dollar Wreck was created using a powder-based 3D printer, which uses a combination of starch and plaster to create an object. The model is printed to scale, and once sealed with a spray sealent, can be touched.

NATIONAL PARK SERVICE

PROGRAM IN MARITIME STUDIES MARITIME HISTORY MARITIME ARCHAEOLOGY EAST CAROLINA UNIVERSITY

What kinds of artifacts were found on the Pillar Dollar Wreck?

Unfortunately, the Pillar Dollar Wreck was heavily looted in the 1960s and 1970s by treasure hunters. Reportedly, treasure hunters removed several canons, iron spikes and hinges, spoons, pieces of pottery and glass, a pair of slave bracelets, a boarding cutlass, a pair of pewter candlestick holders, and an unidentified amount of Spanish pillar dollars, from which the wreck received its name.

Guadalajara clay, manufactured between the years 1615 to 1810, is also known as native Aztec pottery. It would not have been uncommon for ships traveling from Spanish-held parts of the Americas tocarry vessels made from Guadalajara clay, as the clay was very valuable. The clay was believed to have cosmetic and medicinal properties when consumed. This was a popular habit among Spanish women. Many women also drank water from these vessels, hoping that water stored in Guadalajara clay would absorb its properties.

Many iron fasteners were found on the Pillar Dollar Wreck by both treasure hunters and archaeologists. Iron fasteners were used by shipbuilders to fasten different parts of the ship to one another. The fact that the Pillar Dollar Wreck uses iron fasteners instead of wooden ones supports the theory that the ship could be of Spanish origin. Iberian shipbuilders used iron in an effort to prevent degradation, whereas wood was more likely to rot.

Spanish Pillar Dollar, similar to what may have been found on the Pillar Dollar Wreck.

While looting of the site destroyed an enormous amount of valuable information, there is still much that archaeologists can learn from the Pillar Dollar Wreck. During excavations by East Carolina University and the National Park Service, several small artifacts were found, including iron ship fasteners and a piece of Guadalajara clay.

East Carolina University and National Park Service excavation of the Pillar Dollar Wreck.

Appendix J: Audio Tour Transcript, English

Welcome to the Pillar Dollar Wreck. This wreck is located in Biscayne National Park, just south of Miami, Florida. This model was 3D printed using a full-color powder printer, and represents a photo-realistic likeness of the shipwreck as it sits on the seafloor. Due to the capabilities of the resin printer, the 3D replica of the Pillar Dollar Wreck that you are about to interact with is an almost exact replica of the shipwreck itself. Small amounts of detail are lost due to the decrease in size, but many details, such as wood, sand, a large iron keel bolt, and ballast stones are both visible and touchable.

The Pillar Dollar Wreck is believed to have sunk in the late eighteenth century by running aground on a shallow patch of coral reef nearby. Currently, there has been no positive site identification for the wreck, but it is believed that it could have possibly been of either Spanish or British origin. Archaeologists are able to tell many of these details by the way in which the ship was constructed.

When you touch the 3D replica of the shipwreck, you may think to yourself, “This doesn’t feel like the shape of a boat!” This is because overtime, after a ship has wrecked, much of it disappears. Weather, animals and other biological surroundings, geographic location, and even people all contribute to what maritime archaeologists call the “site formation process.” What remains of the Pillar Dollar Wreck is mostly large pieces of wood of a single side of the ship, buried under sand for several hundred years.

Let’s begin the tour with the keel. Move your hand forward from the starting point until you feel the first piece of the ship, and move it in a straight line horizontally, until you come to the small protrusion from the end of this piece. This is the keel. The keel of a ship serves as the “backbone,” from which all other pieces are put together. The keel runs along the bottom of the vessel, and is always the deepest point of the ship in the water. It provides stability to a ship as it moves through the water, and is the first piece of a ship constructed. The protrusion at the end of the keel is the keel bolt. This bolt allows the keel to be attached to other parts of the ship.

From the keel bolt, move your hand forward until you reach another piece of the ship. It should feel slightly raised and flat. This is the hull planking. You can move your hand back and forth horizontally until you hit two frames on either side. Hull planking is located on the exterior of the ship, and makes up the wooden siding that you would see as you viewed a ship from a dock or on shore.

Now, move your hand to the right, until you feel the frame you felt while exploring the hull planking. Frames can be described as the “bones” of a ship. Frames determine what shape a vessel will have. Think of them as the metaphorical “rib cage” of the ship. Frames can be rounded, similar to the shape of a wine glass, more flat, like a barge, or somewhere in between. In the case of the Pillar Dollar Wreck, somewhere in between is likely the case. The frames were probably more rounded towards the middle, and evened out to a gentle curve to create the lines of an eighteenth century merchant ship.

Move your hand forward until you begin to feel the sand. You will notice that the shipwreck is located in what seems like a slightly deeper depth than the sand, like it were in a small hole. This is because archaeologists from the National Park Service and East Carolina University excavated the site to uncover the wooden pieces of the shipwreck. Before excavation, the ship was covered in sand, with only the top of its remaining frames visible on the ocean floor. Using a dredge, a tool that functions like an underwater vacuum, archaeologists carefully siphoned the sand off of the wreck, slowly exposing more and more pieces. While the site was heavily looted by treasure hunters in the 1960s, at which time many of the artifacts found on the shipwreck were taken, there were still some artifacts left to be found by maritime archaeologists and shared with the public.

Directly in front of you, there is a box containing two artifacts. These artifacts are replicas of artifacts found on the Pillar Dollar Wreck, but 3D printed in plastic. Place your hand in the box and pick up the smaller of the two artifacts. This artifact is a replica of a piece of ceramic, known as Guadalajara polychrome. This type of ceramic has an interesting history. Manufactured between the years 1650 and 1830, Guadalajara polychrome was believed to have cosmetic and medicinal properties when consumed by many Spanish women of the time. This means that some actually ate pieces of this pottery! For this reason, Guadalajara polychrome was a valuable trade good being transported from Spanish America to Spain. As you feel the 3D replica, you will notice that there is a raised area in the shape of a flower. The original artifact had a floral pattern painted on the clay. This flower you feel was created using modeling clay and fixed to the plastic, so that the pattern could be felt.

Pick up the other artifact in the box. This artifact is a 3D replica of an iron fastener. Iron fasteners were used to hold pieces of the ship together. The actual artifact is very heavy, and the iron is black in color. Maritime archaeologists can tell a lot of information about a ship based on the type of fasteners used, as well as the pattern in which the fasteners are placed on the wood. The fastener patterns found on the Pillar Dollar Wreck suggest that the ship may possibly be of Spanish origin, as Spanish shipbuilders often used iron fasteners in place of wooden ones in an effort to prevent degradation of the wood.

I hope you have enjoyed your tour of the Pillar Dollar Wreck. Take your time and continue exploring the shipwreck and the artifacts. Please feel free to ask any questions pertaining to the information that you have heard here, or about how maritime cultural heritage can be more accessible to more audiences.

Appendix K: Audio Tour Transcript, Spanish

Translation by Sophie Stuart, Fidel Guevara, and Emily Schwalbe

¡Bienvenidos al naufragio llamdo Pillar Dollar! Este naufragio está localizado en el parque nacional de Biscayne al sur de Miami. Este modelo 3D fue impreso usando una impresora de resina a color y representa la semejanza del naufragio sobre el suelo marino. Por las capacidades de la impresora de resina a color, esta réplica del naufragio del Pillar Dollar con la que vas a interactuar es lo más cercano una réplica exacta del naufragio mismo. Algunos detalles pequeños se han perdido por la disminución en el tamaño, pero muchos de los detalles pueden ser tocados, tales como: la madera, la arena, un perno de hierro de la quilla, y las piedras de lastre del barco.

Los expertos creen que el Pillar Dollar se hundió a finales del siglo XVIII cuando encallo en un arrecife de coral poco profundo cerca de donde el barco navegaba Actualmente no hay registros de la procedencia del naufragio, pero los expertos creen que el barco posiblemente provenga de España o Gran Bretaña. Los arqueólogos pueden llegar a estos detalles por la manera en que el barco fue construido.

Cuando tocas la réplica 3D del naufragio, es posible que pienses, “esto no siente como la forma de un barco.” Eso pasa porque, después de que un barco naufraga, gran parte del barco desaparece. EL clima, los animales, organismos biológicos cerca del naufragio, la locación, y a veces personas contribuyen a lo que los arqueólogos marinos llaman “El procesó de formación del sitio.” Lo que queda del naufragio del Pillar Dollar es principalmente grandes pedazos de madera de uno de los lados del barco, que estuvieron enterrados bajo la arena por cientos años.

Vamos a empezar nuestro recorrido con la quilla. Mueve tu mano hacia adelante del punto inicial hasta que puedas sentir la primer pieza del barco, y mueve en línea recta horizontalmente hasta que llegues a la pequeña elevación que sobresale al final de esta pieza. Esto es la quilla. La quilla de un barco sirve como la espina dorsal, de donde todas las piezas del barco se unen. La quilla corre por todo el piso del barco, y siempre es el punto más profundo de este en el agua. La quilla proveía estabilidad en el barco cuando este navegaba sobre el agua, y es la primera parte del barco que se construyó. La elevación que sobresale al final de la quilla es el perno de la quilla. Este perno permite que la quilla pueda ser sujetada a otras partes del barco.

Del perno de la quilla, mueve tu mano hacia adelante hasta que llegues a otra pieza del barco. Esta parte del barco se debe de sentir ligeramente elevada y plana. Estos son los tablones que hacen el casco del barco. Puedes mover tu mano horizontalmente hacia un lado y hacia el otro hasta que sientas dos armazones de cada lado. Los tablones del casco están en el exterior del barco y constituyen los costados de madera que podrías ver en un barco.

Ahora, mueve tu mano hacia la derecha, hasta que sientas el armazón que sentiste cuando estabas explorado el casco. Los armazones pueden ser descritos como los huesos del barco. Los armazones determinan la forma que el barco tendrá. Piensa en ellos metafóricamente como "la caja torácica" del barco. Los armazones pueden ser redondos, con la forma de una copa de vino pero más planos, como una barcaza, o algo intermedio. Para el caso del naufragado Pillar Dollar algo intermedio entre redondo y plano es el caso. Probablemente los armazones fueron más redondos hasta la mitad del barco pero nivelados a los lados para formar curvas graduales que representan las líneas de un barco mercante del siglo XVIII.

Mueve tu mano hacia adelante hasta que puedes sentir la arena. Notaras que el naufragio está ubicado en lo que parece una cavidad ligeramente más profunda que la arena, como si estuviera en un pequeño agujero. Esto paso porque arqueólogos al servicio del Parque Nacional y estudiantes de la Universidad de Carolina del Este han excavado en el sitio para destapar las piezas de madera del naufragio. Antes de la excavación, el barco estaba cubierto por la arena, y solo se podían ver las cimas de los armazones sobre el suelo marino. Usando una draga, una herramienta que funciona como una aspiradora debajo del agua, los arqueólogos cuidadosamente han quitado la arena del naufragio, exponiendo lentamente más y más piezas. Aunque el sitio fue extremadamente saqueado por cazadores de tesoros en los sesentas, en donde al momento los cazadores de tesoros tomaron muchos de los artefactos que se encontraban en el naufragio. Aun había algunos artefactos que los arqueólogos marinos buscaron y encontraron para posteriormente ser compartidos al público.

Frente a ti, hay una caja que contiene dos artefactos. Estos artefactos son réplicas de los artefactos encontrados en el naufragio del Pillar Dollar, pero impresos en 3D con plástico. Pon tu mano en la caja y recoge el más pequeño de los dos artefactos. Este artefacto es una réplica de un pedazo de cerámica, conocida como policromo de Guadalajara. Este tipo de cerámica tiene una historia interesante. Fabricada entre los años mil seiscientos cincuenta y mil ochocientos treinta, se creía que el policromo de Guadalajara tenía propiedades estéticas y medicinales siendo consumido por mujeres españolas de ese tiempo. ¿Te puedes imaginar comiendo pedazos de cerámica? Por estas razones el policromo de Guadalajara era un bien comerciable con mucho valor que era transportado de América del Sur a España. Cuando sientas la réplica de 3D, notaras qué hay un área elevada en forma de flor. El artefacto original tenía un patrón floral pintado en la arcilla. Esta flor que sientes fue creada usando plastilina para que el patrón se pueda sentir.

Ahora recoge el otro artefacto de la caja. Este artefacto es una réplica 3D de un encuadernador de hierro. Los encuadernadores de hierro fueron usados para mantener en unión piezas del barco. El artefacto real es muy pesado y el hierro es de color negro. Los Arqueólogos Marinos pueden dar mucha información del barco a partir del tipo de encuadernador usado, así como por la manera en que el encuadernador está colocado sobre la madera. El patrón de los encuadernados del Pillar Dollar sugiere que el origen del barco posiblemente es Español, pues los constructores de barcos Españoles usaban encuadernadores de hierro en lugar de los de madera en un esfuerzo de prevenir la degradación en la madera.

Espero que hayas disfrutado el recorrido del naufragio del Pillar Dollar. Toma tu tiempo y sigue explorando el barco y los artefactos. Por favor, siéntete libre de hacer cualquier pregunta relacionada con la información que has escuchado aquí, o acerca de cómo el patrimonio cultural marítimo puede ser accesible a más personas.