MATTANZA TUNA FISHING VESSELS OF PORTOPALO, SICILY:

PHOTOGRAMMETRY AND 3D MODELING

A Thesis

by

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ABSTRACT

Tuna fishing has been a staple in the Sicilian economy from ancient times into the 20th century. Southern Sicily especially benefitted from the prosperity of the industry and built infrastructure known as *tonnare* for tuna processing and special *mattanza* vessels to exploit the fish during the warm summer months. Sicilians possessed a unique fishing method because of these boats, which contain distinctive construction features that aid specifically in the capture of tuna. Since the tuna-fishing economy of Sicily has largely diminished, many of the now derelict boats have fallen into disrepair. It is the goal of this thesis to record and study these cultural heritage objects to preserve their information for members of the southern Sicilian community and for the research of future scholars. In June of 2019, three of these *mattanza* boats were digitally recorded using photogrammetry, laser scanning, and a combined method of photogrammetry and laser scanning, known as photogrammetric texture mapping (PTM), which produced 3D models. These digital recording methods are beneficial in a number of ways, including a user-friendly platform for manipulation, great accuracy of details for measurements and analysis, and ease of data sharing and dissemination. One of the achieved goals of this project was to use the 3D PTM models to produce sections and hull lines, as well as an orthophotograph. This research project serves not only as an evaluation of 3D modeling for cultural heritage documentation, but also as the preliminary data for the planned conservation of these vessels. Digital preservation of the tuna fishing *mattanza* vessels will inform the social and economic history of southern Sicily.

DEDICATION

For Mom, Dad, Emma, and Anna.

To all my teachers, thank you.

And for Dr. George Bass, who inspired and guided us all.

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It is impossible to embark on such a project without immense support from multiple individuals. First of all, I would like to thank my committee chair, Dr. Christopher Dostal, as well as my committee members, Dr. Deborah Carlson and Dr. Lilia Campana for their relentless guidance, support, and patience. It is no mean task to support a graduate student while simultaneously juggling all other demands of academic life; I am beyond appreciative of your efforts.

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Contributors

This work was supervised by a thesis committee consisting of Professors Christopher Dostal and Deborah Carlson of the Department of Anthropology and Professor Lilia Campana of the Department of Architecture.

Contributions of the laser scan data analyzed in Chapters III and IV was provided courtesy of the Marzamemi Maritime Heritage Project with support from the Institute of Nautical Archaeology. The laser scans were produced by Dr. Leopoldo Repola of the Università degli Studi Suor Orsola Benincasa with the help of his team of students. Elizabeth Hoffer of Brock University was instrumental in the laser scanning process, especially with her work aligning the scans. Dr. Christopher Dostal assisted in photography, processing the photogrammetry scans, and aligning the photogrammetric texture models.

All other work conducted for the thesis was completed by the student independently.

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NOMENCLATURE

cm	centimeter
CMM	Coordinate Measuring Machine
DEM	Digital Elevation Model
GCP	Ground Control Point
GIS	Geographic Information Systems
ICCAT	The International Commission for the Conservation of Atlantic Tuna
INA	Institute of Nautical Archaeology
kg	kilogram
km	kilometer
m	meter
MMHP	Marzamemi Maritime Heritage Project
PTM	Photogrammetric Texture Mapping
t	ton

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CHAPTER I

INTRODUCTION: *LA MATTANZA* AND SICILIAN HERITAGE

During the summer of 2018, the research efforts of the Marzamemi Maritime Heritage Project (MMHP) widened to encompass several abandoned early 20th-century vernacular tuna-fishing boats in the Sicilian cities of Marzamemi and Portopalo di Capo Passero.[1] Since medieval times and perhaps even earlier, Sicilians practiced a strategy of tuna fishing that involved corralling fish in a series of net traps and culminated in a harvesting known as *la mattanza*. As these boats were integral to the development of the social and economic traditions of the region, Drs. Justin Leidwanger, Elizabeth Greene, and Leopoldo Repola of the MMHP realized the importance of documenting these cultural heritage projects as swiftly and accurately as possible.[2] Due to the rapid degradation of the timbers and the boats' exposed locations, thorough documentation was necessary to aid in the production of a conservation and construction report. This thesis aims to present the results of three 3D documentation techniques – photogrammetry, laser scanning, and photogrammetric texture mapping – with an evaluation of these methods for future use in archaeological conservation.

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[1] This thesis follows the style of the *American Journal of Archaeology*.

Justin Leidwanger and Christopher Dostal, personal communications, 2019.
[2] Justin Leidwanger is an Associate Professor of Classics at Stanford University, Elizabeth Greene is an Associate Professor of Classics at Brock University, and Leopoldo Repola is an instructor and researcher at Università degli Studi Suor Orsola Benincasa.

Historical and Economic Significance

Since ancient times, fishing of the Atlantic Bluefin Tuna (*Thunnus thynnus*) played a central role in economic prosperity and growth in Sicily.[3] Tuna can live to be 30 years old, with an average length between 1 and 3 m and between 500 and 650 kg in weight.[4] Every year, the Atlantic Bluefin migrates into the Mediterranean, traveling along the coasts to warmer waters to find food and mates. When coastal villages took advantage of the then-plentiful resources of the Mediterranean by instituting centralized tuna processing factories in the early ninth century, they helped spur the medieval economy of southern Sicily. These traditions remained stable until the tuna's recent scarcity in the early 20th century.[5]

Early fishermen observed the migration patterns of tuna and attempted to capture these gigantic fish. Aristotle wrote about the migrations of the bluefin tuna in his *Historia animalium* during the fourth century B.C.E.[6] A clear continuum exists between ancient and modern traditional Sicilian fishing practices, which will be elaborated upon in Chapter II. As in ancient times, modern fishermen use nets to aid in the capture of fish.[7] Then, the fisherman clubbed or stabbed the fish to death in a bloody ritual that became known as *la mattanza*. The Italian word *mattanza* comes from the Spanish verb *matar*, which means "to kill" and the Latin *mactare* meaning "slaughter."[8] The entire

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[3] Longo 2007, 1; Scariano 2015, vi.
[4] Maggio 2000, 10, 135; Ottolenghi et al. 2004, 107-8; van Ginkel 2005, 74; Longo 2007, 7.
[5] Collet 1987, 47-8; Mather et al. 1995; van Ginkel 2005, 75-6; Longo 2007, 1. All dates are C.E. unless otherwise stated.
[6] Peck, 1965, Hereafter Arist. Arist. *Hist. Am*. VII(VIII) XIX, 164; Consolo 1986, 15; Maggio 2000, 56.
[7] van Ginkel 2005, 74; Longo 2007, 8.
[8] Maggio 2000, 11; van Ginkel 2005, 76, 94 n. 6; Longo 2007, 20 n. 1.

fishing process is called *tonnara*, which is also the name for the building complex where the fish are processed for market.[9] It is interesting to note that certain parts of Spain practiced a similar tuna fishing ritual known as *almadraba*, perhaps stemming from Sicily and Spain's ancient ties to the Roman Empire, but more likely because of the influence of the Muslim control over both regions.[10]

Location

The MMHP's study of the *mattanza* boats begins at the *tonnara* complex of Portopalo di Capo Passero, which offers a lens through which to focus the discussion of the maritime history and socio-economic development of fishing in Sicily. The city of Portopalo is situated on a projection of land called Capo Passero, the southeastern most peninsula of Sicily, approximately 92 km south of Catania (Figure 1).

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[9] Longo 2007, 20 n. 1 and 4. *Tonnara* translates to 'tuna capture' with *tonnare* being the plural. The *tonnara* buildings when associated with a store are also sometimes known as a *marfaraggio* or *malfaraggio*.
[10] van Ginkel 2005, 94 n. 6.

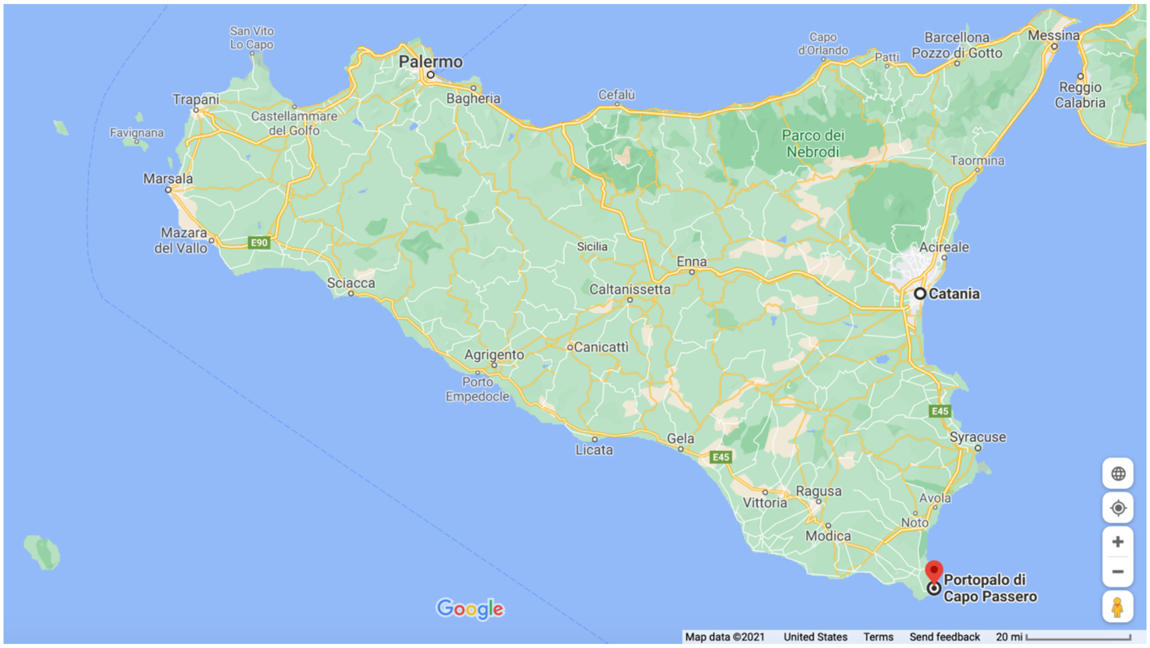

Figure 1: Map of Sicily with the city of Portopalo di Capo Passero. Image courtesy of Google Maps, 2021.

Three *mattanza* boats from the early 20th century are proudly featured in the central piazza, overlooking the water and a small island known as the Isola di Capo Passero, approximately 300 m away from the mainland (Figure 2). On the island are two buildings meant to house additional *mattanza* boats, store fishing equipment, and provide extra workspace. To the north of the piazza is the *tonnara* complex, where most of the tuna processing occurred until the mid-1960s, when frequent tuna fishing halted.[11]

[11] Capodicasa 2016, 33.

Figure 2: The three *mattanza* boats in the piazza of Portopalo di Capo Passero. Image courtesy of Google Maps satellite imagery, 2020, modified by the author.

MMHP Involvement

The overarching goal of the MMHP is the widespread preservation of Sicily's heritage of migration and connection with the sea. This heritage relationship stretches from the Neolithic times to the more recent modern migration of Syrian refugees.[12] The MMHP members are simultaneously engaged in several projects in conjunction with the

[12] Marzamemi Maritime Heritage Project, https://marzamemi.stanford.edu

office of the Soprintendenza del Mare of Sicily, along the coastline of the Marzamemi region from Vendicari in the north to Portopalo di Capo Passero in the south. Current projects include a survey along the coast of Vendicari, the excavation of a Byzantine shipwreck carrying a marble shipment for the construction of a church, digital recording of refugee migrant boats, and the conservation of *mattanza* tuna fishing vessels.[13]

The MMHP project concerning the *mattanza* fishing vessels involves evaluating the most desirable method of digital recording to accomplish the team's research goals, which are twofold: (1) to preserve an aspect of Sicilian cultural heritage, and (2) to conduct a pre-conservation evaluation of three *mattanza* vessels from the early 20th century. The conservation of the tuna fishing vessels can be used to enhance the narrative of southern Sicily's maritime landscape, which has remained a consistent epicenter of connection and exchange over two millennia. The conservation evaluation through the digital recording presented here serves as the preliminary work for an ethnography and conservation project conducted by the MMHP, which aims to record the stories of fisherman who participated in *la mattanza* and preserve the vessels as symbols of local history and cultural significance.

In a country bursting with cultural wealth, the everyday history and local traditions of Sicilians are overshadowed by the larger historical narrative that tends to focus on the glory of the distant past. Nevertheless, tuna fishing is as significant to coastal Sicilians in the construction of southern Sicilian history as is the role of ancient

[13] Leidwanger 2018, 341; Leidwanger, 2019, personal communication.

Rome. The demise of traditional tuna fishing in the Mediterranean culminated at the end of the 20th century, yet there has not been any formal study on the construction of the *mattanza* tuna fishing vessels. However, the subject has inspired several anthologies and ethnographies.[14] Still, most of these accounts focus on the social organization of the fishermen and their techniques, rather than on their vessels specifically. The *mattanza* vessels contain highly specialized technological adaptions that are designed to aid in the capture of tuna and stand out among other vernacular fishing boats of southern Italy. The *mattanza* and tuna fishing deserve to be documented and studied through both cultural ethnographic interviews with fishermen and archaeological recording of the vessels before the primary sources are lost to time and memory.

Role of 3D Digitization in Recording Cultural Heritage

Recognizing in the early 2000s that preservationists were quickly adopting digital platforms for data recording and presentation, Franco Niccolucci, Richard Beacham, Sorin Hermon, and Hugh Denard established a document that would serve as a standard of computer-based research methods.[15] The *London Charter for the Computer-based Visualisation of Cultural Heritage* was first published in 2009 following recommendations set forth in a 2006 symposium entitled *Making 3D Visual Research Outcomes Transparent* at the British Academy in London.[16] There is little

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[14] Danzuso and Zinna 1987; Giarelli 1998; Maggio 2000; Longo 2009; Scariano 2015. Longo's dissertation is particularly comprehensive regarding the historical social and economic impact of Sicilian tuna fishing.
[15] Denard, The London Charter 2009. History of the London Charter: https://www.londoncharter.org/history.html
[16] Denard, The London Charter 2009.

doubt that this document has been highly influential globally, having been translated into nearly a dozen languages and adopted by the Italian Ministry of Culture as the standard of digital visualization of cultural heritage.[17] The most recent edition introduces the *London Charter* as the benchmark assessment for all projects involving heritage visualization.[18] This document has allowed for researchers to make great strides in the field of preservation and conservation by outlining a standard for the digital preservation of 3D modeling, suggesting methodologies for the recording of cultural heritage, advocating for the proper communication of digitized materials, and discussing other widespread practices concerning visual platforms of cultural heritage. This thesis aims to uphold such standards of academic and technical rigor by producing models in an accessible and understandable format, by responsibly storing data, and by sharing information with collaborating researchers in the MMHP.

Recently in archaeology, there has been an immense shift towards digital 3D documentation and modeling, largely influenced by the fields of conservation and cultural preservation studies. Advocates for 3D digitization note that these models are user friendly, easily disseminatable to diverse audiences, and communicate more information than is possible in a 2D format.[19] Still, traditional methods of recording like ship's lines drawings and sketches of archaeological material continue to present significant value. For example, 2D recording on paper is preserved in a tangible format

[17] Denard 2012, 58.
[18] Denard 2012, 58.
[19] Dostal 2017, 5.

that will not change with technology, encourages a “hands-on” relationship between the archaeologists and the material, and allows for an ease of comparison with previous research. Additionally, these formats might be better for the dissemination of information with populations that may not have reliable digital technologies such as updated computers, stable internet access, and costly software platforms.[20] The debate in archaeology is still occurring over the long term viability of digital recording, data storage, and modeling over more traditional methods.[21] While digital modeling certainly does not serve as a complete replacement of these traditional and trusted methods, 3D digitization can greatly aid in producing lines drawings and plans, enhancing the data’s accuracy and ease of manipulation.

When an artifact is under stress from environmental factors, 3D digitization and modeling ensure preservation of information that may otherwise rapidly disappear. While the three vessels in the Portopalo piazza are not under immediate threat, there are at least six other *mattanza* vessels on the nearby Isola di Capo Passero, located in a work shed with a collapsed roof. The roof significantly damaged most of the vessels and the resulting exposure to weather has also played a role in their degradation (Figure 3). In cases such as this, 3D digitization can play a role in quickly documenting and thereby preserving precious data particularly where the future of such vessels is uncertain.

[20] Drap et al. 2019, 143.
[21] The virtual conference for the European Association of Archaeologists in 2020 included Sessions 318 and 319 entitled “Archaeology in 3D – New Technologies for Old Questions,” featuring continued arguments for and against 3D technologies in addition to methods of data storage and preservation. These abstracts and papers of this session are available to the public through the EAA Repository. https://submissions.e-a-a.org/eaa2020/repository/

Moreover, this method of documentation allows scholars from all over the world to use the data without the added expense and complication of traveling to the site of the object itself. This allows for international collaboration and data sharing, as well as input of different scholarly interpretations in the future.

Figure 3: Derelict *mattanza* boats on Isola di Capo Passero. Image by the author, 2019. © Claire Zak 2019.

History of Photogrammetry and Laser Scanning Technologies

The invention of photography in 1839 and the airplane in 1903 was quickly followed by the use of aerial photography in 1908.[22] During the World Wars, aerial photographs were used to take accurate distance measurements through a process known as stereogrammetry. When two photos are taken with at least 50 percent overlap and the distance between two landmarks is already established, additional measurements can be taken between other sets of objects.[23] Altogether, distances between objects and the height of objects produce digital elevation models (DEM), used for topographic maps. If airplane height and speed are known, other factors can be calculated, such as landmark height, parallax, and relief displacement.[24]

Relief displacement occurs when objects appear displaced outward from the principal point or central focus of the photograph. The height is then directly proportional to the elevation difference in the image between the top and bottom of an object. Parallax is a concept similar to relief displacement, where due to aircraft motion an object appears to change position from one image to the next. Since all displacement occurs along the x-axis, it is possible to measure the y-axis (height) to determine the amount of parallax. The height of an object (h_o) is equal to the height of the aircraft ($H - h$) multiplied by the parallax ($dp/(P + dp)$), as seen in the following equation.

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[22] Lillesand et al. 2015, 86-8. Kite and balloon photography predates airplane aerial photography by only a few years.
[23] Lillesand et al. 2015, 88.
[24] Lillesand et al. 2015, 147.

$$h_o = (H - h)[\frac{dp}{(P + dp)}]$$

By solving for parallax, two photographs taken within sequence from an airplane can be used within a stereoscopic pair to imitate depth.[25] However, photographs must be taken at relatively the same altitude or distance so that the principal point remains fairly constant.[26] These principles are central to the development of photogrammetry, which models an object within space using a coordinate system created by photograph overlap and calculated depth.[27] Software programs such as *Metashape* and *RealityCapture* are able to apply the Parallax principle and triangulation to sets of photographs in order to produce a digital model.[28]

Photogrammetry has been utilized in the field of remote sensing since the formation of the American Society for Photogrammetry in 1934.[29] Terrestrial and nautical archaeologists alike have utilized this technology.[30] Developments in software and technology continue to drive photogrammetry as one of the top methods to model objects in 3D both under water and on terrestrial sites.[31] The desire for greater detail, geometric depth, and accuracy has further fueled the development of new methodologies that combine the strengths of photogrammetry with those of laser scanning.

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[25] Lillesand et al. 2015, 78.
[26] Agisoft LLC 2021, 9.
[27] Lillesand et al. 2015, 148; Agisoft LLC 2021, 73.
[28] Agisoft LLC 2021, v.
[29] Lillesand et al. 2015, 88.
[30] Bass and Rosencrantz 1972 and Rosencrantz 1975 both provide early outlines of the uses of photogrammetry and methodologies for underwater contexts.
[31]Boehler and Marbs 2004; Artioli 2009; McCarthy 2014; Yamafune 2016.

Laser scanning has a long history comparable to that of photogrammetry within remote sensing. First used in technologies such as LiDAR and radar, lasers have been used to develop an active form of remote sensing as opposed to photography's passive recording.[32] The laser scanner used in this project operates through triangulation; the distance and angle between the laser and the sensor remain constant, while the distance between the sensor and the recorded object changes.[33] Laser scanners and Coordinate Measuring Machine (CMM) scan arms are known for their precision in creating more geometrically accurate data, though the resulting models fail to produce a high-resolution texture.[34] Nearly the opposite is occasionally true for photogrammetry: the textures produced can be visually appealing, even if the underlying mesh (or geometry) exhibits errors.[35]

Previously, researchers have demonstrated the ability to slightly improve laser scanned and photogrammetric models in *3ds Max* software during postprocessing, while others have attempted to improve the photogrammetry models with laser scan data measurements or by combining a 2D photograph with a 3D texture map.[36] Many of these methods are time consuming and each has disadvantages that fail to address fundamental inaccuracies of the underlying mesh. In 2018, researchers at Texas A&M University developed a process to align and replace a geometrically inaccurate photogrammetry

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[32] Lillesand et al. 2015, 471.
[33] Boehler and Marbs 2002, 10; Ebrahim 2015, 327.
[34] Dostal and Yamafune 2018, 430.
[35] Radosevic 2010, 172; Dostal and Yamafune 2018, 430.
[36] Alshawabkeh and Haala 2004; Grammatikopoulos et al. 2004; Al-kheder et al. 2009; Radosevic 2010, 173-4; Dostal and Yamafune 2018, 431.

mesh with a higher-quality laser scan mesh.[37] Software companies like *CapturingReality* are advertising a similar solution for combining laser scans and photogrammetry.[38]

Organization and Presentation

This thesis focuses on the history of *la mattanza* and the ways it can be preserved and interpreted through 3D imaging techniques. The chapters of this thesis are organized as follows. Chapter II describes the history and legacy of *mattanza* fishing in Sicily, along with a brief history of the thesis project. The MMHP chose to evaluate several digital technologies for the recording of the *mattanza* vessels, including photogrammetry, laser scanning, and photogrammetric texture mapping. Chapter III covers the data collection procedures and creation of models using photogrammetry, laser scanning, and photogrammetric texture mapping (PTM). This is followed by details of the hull sections and the creation of orthophotographs. The results, promising features, and potential drawbacks of each method are discussed in Chapter IV, providing analysis of the 3D models and a discussion of the construction features specific to these *mattanza* vessels. Chapter V presents conclusions along with recommendations to the MMHP for refinements to the data collection process, data sharing, and plans for future direction for the project. This study only presents a brief look into the *mattanza* traditions and the vessels' construction elements. This preliminary work is a first step towards highlighting the importance of the mattanza boats as a precious and non-renewable cultural resource of Sicily.

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[37] Dostal and Yamafune 2018, 434.

[38] Dostal 2021, personal communication; www.CapturingReality.com

CHAPTER II

HISTORY OF TUNA FISHING IN SICILY

The origins of tuna fishing in Sicily can be traced back to the Neolithic period, dating from approximately 6000 – 3000 B.C.E.[39] However, it was not until after the Muslim Empire conquered Italy the seventh and eight centuries, that tuna fishing was sponsored and owned by the ruling state.[40] The *tonnara* at Favignana, one of the Egadi Islands off the northwestern coast of Sicily, was established in 807 C.E. to officially industrialize the production of captured fish. Similar commercial consolidation by the Muslim Empire occurred throughout Sicily, though some scholars argue that there must have already been systems in place for tuna capture, given the rich history of iconographic and archaeological evidence for tuna fishing.[41]

The ritualistic importance of *la mattanza* was perpetuated through the use of traditional songs, names that reference older times, and ancient religious ceremonies that involved the entire community and the Catholic Church.[42] Still today, the effects of the industry are pervasive in all aspects of Sicilian life, from place names, murals and artwork, to community centers. In the local Catholic church, a painting is displayed by a local artist of the resurrected Jesus Christ in front of a beach with fishing vessels and the local *tonnara* in the distance (Figure 4). It is difficult to overemphasize the extent to which fishing pervades all aspects of art, religion, and daily life in this part of Sicily.

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[39] Consolo 1986, 58-60.
[40] Finley 1979, 188-9.
[41] van Ginkel 2005, 75.
[42] van Ginkel 2005, 79.

Figure 4: The resurrected Jesus Christ above the altar of the Marzamemi Catholic church with a background of the town, a beach with fishing boats, and the *tonnara*. Artist unknown. Image by the author, 2019.

Early Archaeological and Literary Evidence

The first evidence for tuna in Sicily comes from a Neolithic cave painting at Levanzo, one of the Egadi Islands off the northwestern shore of Sicily.[43] The Grotta del Genovese at Levanzo was discovered in 1949, and has been studied by art historians, scientists, and archaeologists alike, even being recently recorded in 3D.[44] The cave paintings include depictions of ceramics, four human figures, and animals such as

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[43] Consolo 1986, 58-60; Maggio 2000, 9, 55; Longo 2007, 9.
[44] Tusa et al. 2013; di Maida 2016; di Maida et al. 2018; Lo Presti et al. 2019.

horses, cows, a deer, dolphin, and a tuna fish. The prehistoric representation of the fish indicates at least a human awareness of the species, if not the active capture and consumption of it.

The ancient Greeks are well known to have colonized Italy and Sicily beginning in the eighth century B.C.E. and must have witnessed and taken advantage of the annual tuna migration events, which can be seen from land. A Greek bell krater (a large ceramic vessel used for wine) in the Mandralisca Museum in Cefalù depicts a scene of a tuna vendor. The pot was originally found in Lipari – an island just north of Sicily – by the Baron Mandralisca and brought into his private collection which is now a public museum.[45] Enormous fish nearly the size as the human subjects fill the scene of this fourth-century B.C.E. krater.

Ancient Roman accounts of fishing and of tuna in particular are plentiful in the form of iconography, literary references, and archaeological evidence. Literary evidence indicates that fishing was conducted by the rich and poor alike and seafood was a consistent source of protein by all levels of society.[46] Oppian, a Graeco-Roman poet, wrote *Halieutica* between 177 and 180 C.E. This work presents descriptions of productive fishing ventures: "Now when the fishermen behold them huddled together, they gladly enclose them with their hollow seine-nets and without trouble bring ashore abundant booty and fill with the fry all their vessels and their boats and on the deep

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[45] Consolo 1986, 15-17; Longo 2007, 9; Sorbello 2019, 9-10.
[46] Trakadas 2006, 259.

beaches pile up heaps, an infinite abundance of spoil."[47] Clearly, fishermen were able to capture great numbers of fish that fetched high prices at the markets. Of course, Roman authors such as Pliny, Martial, and Oppian report that certain types of fish were valued much more highly than others; the most esteemed included red and gray mullet, sea bass, tuna, eels, parrot-wrasse, and oysters.[48] These species of fish were typically only consumed by the wealthy, as they were the only ones who could afford such delicacies. The Roman historian Pliny the Elder recounts a story in which three red mullet sold for 30,000 sesterces and other stories exist where red mullet was sold anywhere between 1,000 and 8,000 sesterces.[49] The Roman poet Martial even compares sea bass to the price of perfume and jewels, when complaining that his girlfriend forced him to buy her expensive gifts.[50]

Preserved fish offered a more economic option for the majority of Romans purchasing and consuming fish. The ancient Roman production of fish commodities occurred throughout the Mediterranean and is represented archaeologically in sites along the Strait of Gibraltar, the Black Sea, and the Adriatic.[51] At these places, fish were salted and dried, or turned into an extremely popular fish sauce condiment known as *garum*. While high quality *garum* could be expensive, most dried fish and fish sauce lasted far

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[47] Mair, 1987, Hereafter Oppian. Oppian *Helieutica* 4.491-496 in Bekker-Nielsen, 2005, 92. Translation by A.W. Mair.
[48] Déry 1998, 100-104; Trakadas 2006, 263; Camacho 2017, 44.
[49] Jones, 1951, Hereafter Plin. *Nat.* 9.31.67; Déry 1998, 100.
[50] Bailey, 1993, Hereafter Mart. Mart. *Spect*. 11.50.9; Corcoran 1963, 99.
[51] Bernal-Casasola et al 2018, 329; Marzano 2018, 443. Interestingly, Marzano points out that there are more salt-processing workshops in the west than in the east, though epigraphic evidence of preserved fish is plentiful in the east and not in the west.

longer than fresh fish and was considerably more affordable to the average person in the Roman Empire.[52] Salted fish required infrastructure to gather and dry sea salt. At Vendicari, a *tonnara* site north of Marzamemi and Portopalo, salt flats can still be seen cut into the rocky shore (Figure 5).[53] The legacy of Roman fishing and fish processing can also be seen at other *tonnare* such as Portopalo, where pits were dug to make *garum* (Figure 6). Archaeologists found coins and tuna vertebrae in the tanks that confirm their date in the Hellenistic or Roman period and their function as receptacles for fish salting.[54] The salt flats and *garum* pits indicate an extensive history of fishing at both Vendicari and Portopalo lasting many centuries.

Figure 5: Salt dehydration flats on the coast of Vendicari, Sicily. Image by the author, 2019. © Claire Zak 2019.

[52] Marzano 2018, 440.
[53] Basile 1992, 55.
[54] Basile 1992, 73-5; Sorbello 2019, 10.

Figure 6: At Portopalo, directly adjacent to the piazza of the *mattanza* vessels, is a Roman archaeological site. Here there are two circular pits that were most likely used in the production of *garum*. Image by the author, 2019. © Claire Zak 2019.

Despite earlier abundance, ancient sources such as Juvenal report that by the late second century C.E. the Tyrrhenian Sea had "become exhausted by fishermen's nets, preventing the fish from obtaining their full size," indicating overfishing became a prevalent and reoccurring issue while trying to sate the demands of the market.[55] Still, fishing remained a favored pastime of several Roman emperors; the Roman upper-class often kept fish as pets, and large and uncommon fish were featured as central dishes at sumptuous banquets. Throughout the mainland of Italy and nearby islands, members of the Roman Empire set up tuna watch towers and expanded their fishing practices.[56] A

[55] Braund 2004, Hearafter Juv. Juv. 5.92-96; Trakadas 2006, 264.
[56] Roesti 1966, 79.

lagoon at Cosa on the western coast of Italy hosted a large 100 m^2 commercial fishing complex, including fish holding ponds called *vivaria*, areas for drift netting, and tuna watch towers.[57] From these towers, fishermen could keep an eye out for large schools of migrating tuna approaching the coast.

Much of the early *tonnare* infrastructure present on Sicily today was influenced by the Muslim conquests. On the Egadi Island of Favignana, the *tonnara* was officially sponsored in 807 C.E. by the Caliphate representatives that controlled Sicily, though there is archaeological and literary evidence that tuna fishing with *tonnare* existed prior to this.[58] Muslim jurisdiction over the Sicilian *tonnare* set the precedent for state control, sponsoring local Sicilians to fish and process tuna. When the Norman kings conquered Sicily in the 11th century, they too took control over the island's *tonnare* to generate income for the monarchy.[59] Throughout the Norman, Spanish, and eventual Sicilian control of the island, additional *tonnare* were established, such as at Portopalo in 1792 and at Marzamemi in 1648.[60]

Comparable Tuna Fishing Traditions in the Mediterranean

For thousands of years, tuna fish have been caught along the Mediterranean coasts with the help of vertical nets placed along the shore. Ancient fishermen realized that a series of net partitions used to corral fish helped capture the tuna more easily.[61] In Sicily, this configuration of nets became known as *tonnara,* but these practices existed

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[57] Trakadas 2006, 263.
[58] Finley 1979, 188-9; Longo 2009, 101; van Ginkel 2005, 75.
[59] Finley 1979, 188-9; Maggio 2000, 57-8; van Ginkel 2005, 75; Longo 2009, 101.
[60] Lippi Guidi 1993, 54; Capodicasa 2016, 10, 36.
[61] Pitcher 2001, 603; Ravier and Fromentin 2001, 1300-1; van Ginkel 2005, 74.

throughout most of the Mediterranean, along the coasts of North Africa, Turkey, Spain, France, and Italy.[62] Reportedly, most of these traps disappeared from all coastal regions except for Sicily, which maintained about 80 such traps until the mid-20th century.[63] Archaeological and historical evidence point to a once-lucrative industry.

The earliest *tonnare*-type net fishing is credited to the Phoenicians along the Bosphorus.[64] Evidence for tuna fishing with nets has also been discovered in the Black Sea and at the Byzantine Theodosian harbor of Yenikapı in Istanbul.[65] Influence from the eastern Mediterranean on Sicilian tuna fishing can be seen in much of the language that is used to describe the process, the traditional songs, and place names. It has already been mentioned that *almadraba*, the word used to describe the *mattanza* in Spain comes from Arabic, perhaps meaning enclosure.[66] The term for the leader of the *tonnaroti*, the *rais*, is used prevalently within the Ottoman Empire naval organization, designating a "lord" or "captain." Even the town of Marzamemi likely comes from Arabic *Marsa el Hamen*, which translates to "Bay of the Turtledoves."

Traditional Tuna Fishing in Sicily

In the 18th and 19th centuries, the active tuna fishing season typically ran from mid-May to mid-June, aligning with the predictable migration schedule of the Atlantic Bluefin Tuna.[67] Though the season is only two to three months, it was preceded by

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[62] van Ginkel 2005, 74-5.
[63] van Ginkel 2005, 75.
[64] Perez-Llorens 2019, 1; García-Vargas and Florido-Corral 2010.
[65] Bekker-Nielsen 2005; Puncher et al. 2015, 1626. The book edited by Bekker-Nielsen offers extensive evidence for tuna fishing throughout the entire Mediterranean, paying particular attention to the Black Sea.
[66] Collet 1987 notes that *almadraba* is similar to the Arabic *al mazraba* and *zrb*, which mean enclosure.
[67] Roesti 1966, 78.

several months of preparation.[68] The *tonnara* enabled entire Sicilian villages to share in the economic success. Not only were fishermen (known as *tonnaroti*) employed to maneuver boats and nets to gather the fish, but both men and women were hired to produce and mend nets, process tons of fish for canning, and repair the boats. Even the local Catholic priests became heavily involved, blessing the boats and fishermen, hosting services in the hopes of a bountiful yield, and erecting shrines to the *Madonna dei Tonnaroti*, the Mother Mary of the Tuna Workers.[69] It is estimated that the money and fish garnered from the tuna fishing season could sustain villages for at least half a year.[70] Work continued during the off-season, with net, equipment, and boat maintenance, and the *tonnara* factory turned to other canned fish processing, such as sardines.[71]

The *tonnaroti* were organized in a clear hierarchy, which facilitated authority during the often-chaotic operation of wrestling enormous fish. The most power was held by the *rais*, a respected and knowledgeable leader who was responsible for the majority of the decision making.[72] He was the one who decided where the nets would be placed, when the *mattanza* commenced, and directed the operation.[73] Assistants to the *rais* were two *capoguardie*, acting as lieutenants. The *capoguardia* captained their own boats, advised the *rais*, and helped to select captains for the other boats. Each boat consisted of at least eight men, two of whom were known as the *arringatori,* who were especially

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[68] van Ginkel 2005, 77.
[69] Maggio 2000, 80-3; van Ginkel 2005, 75-6, 78-9.
[70] van Ginkel 2005, 76.
[71] van Ginkel 2005, 75.
[72] The term *rais* comes from the Arabic terms for "head," leader, or captain, harkening back to the Arabic origins of many of Sicily's *tonnara.*
[73] Maggio 2000, 10, 18; van Ginkel 2005, 76.

important in hauling the tuna into the boats.[74] Another important role was held by the *Prima Voce* (lead singer), who was in charge of starting the ancient songs known as *scialome*, which ritually aided in both keeping rhythm while hauling in the fish and banishing bad luck.[75] In more recent times, since the widespread adoption of SCUBA in the 1950s and 60s, crews could also include a SCUBA-certified member who would help mend the nets that remain deployed at sea over the course of the season.[76]

The *tonnare* trap system involves seven divided chambers of nets, known as *levante*, *camera grande*, *bordonaia*, *bastardo*, *camera*, *bastardella*, and *camera della morte*. The final chamber, *la camera della morte*, translates to the "chamber of death" and is where *la mattanza* is conducted.[77] The chambers of nets were placed parallel to the shore, running several kilometers, culminating in the entrance of the *tonnara* net chambers. At the entrance, a portion of net known as a the *coda* or *pedale* diverted the course of the fish and directed the tuna into the chambers; another net wall called the *isola* reached toward the shore to prevent escape around the *tonnare*.[78] The nets were made of a combination of ropes, fiber, and steel cable and the *tonnare* was held in place with over 3000 stone or ceramic weights, assisted by 400 or more iron grapnel anchors (Figure 7).[79] The cables for the nets were a massive 22 – 24 mm in diameter and a 16

[74] Maggio 2000, 104, 215; van Ginkel 2005, 77-8. The author recognizes that word *arringatore* translates from Italian to "orator" or "haranguer" and coincides with the name of a famous Etruscan bronze statue. The connection might be that the *arringatori* are the ones who give orders.
[75] van Ginkel 2005, 77-8.
[76] van Ginkel 2005, 78.
[77] Maggio 2000, 129-30; van Ginkel 2005, 76, 94 n. 3.
[78] Bellabara and Guerreri 2002, 44; Longo 2009, 116.
[79] van Ginkel 2005, 76.

mm diameter for the anchors, necessary to withstand the movement of the sea's currents and the tension from the fish.[80]

Figure 7: Abandoned fishing nets with ceramic floats and stone weights. Image by the author, 2019. © Claire Zak 2019.

Sections of the nets could measure 500 to 600 m in length, held in place by stock anchors or iron grapnel anchors known as *grappini* (Figure 8). Some anchors weighed

[80] Bellabara and Guerreri 2002, 45.

between 400 and 500 kg, necessitating at least a dozen men to maneuver. Often the *tonnara* took several days and five or more boats of men to set up.[81] Once put in place, the nets required constant maintenance since the water's movements often shifted their placement and the large tuna and other animals tore holes in the nets while trying to escape.

Figure 8: An abandoned grapnel anchor used in tuna fishing to weigh down the nets. Image by the author, 2019. © Claire Zak 2019.

[81] Bellabara and Guerreri 2002, 45.

Three to five boats (or more depending on the size of the *tonnara*) with full crews were needed to conduct *la mattanza*.[82] Once the corrals became full, the *tonnaroti* would gradually raise the nets to the surface, forcing the fish into the subsequent chambers.[83] Hooked gaffs (handled spears) known as *crocchi* were then used to spear the tuna fish and help drag them towards the vessels.[84] The *arringatore* sported shorter gaffs known as *speta* that were used to heave the tuna into the boats.[85]

Several types of boats were integral to the operation of the *mattanza*. All of them tended to be made of oak framing with pine planking. The keels were incredibly strong to counteract the weight of the fish and straining nets.[86] The hulls were said to be caulked black in order to not disturb the fish, which were frightened by bright colors.[87] There are three sizes of vessels that vary in function and name depending on the regional dialect. The most basic name for the boats is *muggiara* or *muciara*. The typical *muciara* is a long, flat, rowed wooden boat 9 m in length used during the *mattanza*. Other derivations of this vessel reference their function and include the *muciara bastarda* (*muciara* of the opening of the *bastardo* net chamber) and the *muciara i raisi* (*muciara*

[82] Scariano 2015, 5-6; Sorbello 2019, 18.
[83] van Ginkel 2005, 76.
[84] van Ginkel 2005, 77-8.
[85] Maggio 2000, 104; van Ginkel 2005, 78.
[86] Bellabara and Guerreri 2002, 47-8.
[87] Smylie 2013, 218; Sorbello 2019, 18. It is curious that two of the Portopalo boats are painted green on the inside of the hull instead of all black.

of the *rais*).[88] Specific names are also given to *muciare* of different size categories. The largest vessels weigh around 30 t, while the smaller vessels weigh about 4 t.[89]

The largest are known as *scieri*, *palischerno*, or even more generally as *vascelli*.[90] These are the main boats with long hulls and flat bottoms that hold crews of at least eight men.[91] The hulls average between 15 and 22 m in length and 4.5 m in breadth and transported supplies such as cables, floats, and anchors during preparation, as well as tuna after the *mattanza*.[92] The medium-sized boats are known as *sciabiche* or *mudare* and essentially are a scaled down version of the *vascelli*.[93] The hulls averaged 8.5 m long and 2 to 3 m wide.[94] The smallest boats are known as *muscieri*, *musciara*, or *mociara*.[95] The *rais* gives commands from his small *musciara* vessel to the rest of the crew during the *mattanza*.[96] Together with the medium-sized boats, the small boats were also used to set up nets and anchors.[97]

Decline of Traditional Tuna Fishing

Traditional tuna fishing along the Italian, Spanish, and French coasts consisted of small vessels like those described above, small crews, and stationary traps. Both

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[88] Consolo 1986, 195.
[89] Bellabara and Guerreri 2002, 48.
[90] Bellabara and Guerreri 2002, 47. The singular of *scieri* is *sciere* and the singular of *vascelli* is *vascello*. *Vascello* is not to be confused with the larger Italian ship of the line of the same name, popular with pirates during the 17th to 19th centuries.
[91] Maggio 2000, 215; van Ginkel 2005, 77.
[92] Danzuso and Zinna 1987, 31; Bellabara and Guerreri 2002, 47-8; Sorbello 2019, 18.
[93] Bellabara and Guerreri 2002, 47.
[94] Sorbello 2019, 18.
[95] Bellabara and Guerreri 2002, 47-8. The Roman Althiburus mosaic in Tunisia depicts a *musculus*, a small vessel that may be similar to the modern-day *musciara*.
[96] Maggio 2000, 10, 18; van Ginkel 2005, 76; Scariano 2015, 5.
[97] Bellabara and Guerreri 2002, 47-8.

methods and technology changed very little over hundreds of years, doing little to increase productivity.[98] Since the migration patterns of the tuna remained constant and relatively plentiful, there was not an incentive to improve the boats or means of capture. As modern methods of fishing from steel-hulled boats encroached and fish farms were established, Sicilians were able to capture fewer and fewer fish per year. Although tuna are highly desired and fetch high prices, the small-scale fishing operations of Sicily still could not compete with industrialized commercial fishing. Between the middle and end of the 20th century, it became unprofitable to continue operating *tonnare*. Within 50 years, many of the *tonnare* around Sicily closed, leaving only Favignana's *tonnara* active. Even so, Favignana's catch has been low, either catching no tuna or only a few hundred per year and the *mattanza* is largely performed for tourists.[99]

In large part, this decline is due to unsustainable overfishing. Atlantic Bluefin Tuna are considered top predators and a keystone species, eating a combination of sardines, mackerel, anchovies, and most anything else that moves close enough to their mouths.[100] Without these fish, the Mediterranean ecosystem would change drastically, yet they have been considered overexploited since 1982 and endangered since 1996.[101] The International Commission for the Conservation of Atlantic Tuna (ICCAT) has moved to place restrictions on fishing numbers and warned that excessive harvesting could lead to severe ecological issues.[102]

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[98] Roesti 1966, 86; Longo 2009, 142.
[99] Longo 2007, 18; Longo 2009, 151.
[100] Maggio 2000, 135; Ottolenghi et al. 2004, 108; Longo 2007, 15.
[101] Safina 1996; Myers and Worm 2003; van Ginkel 2005, 74; Longo 2007, 8.
[102] Longo and Clark 2012, 205.

Some scientists believe that modern industrialized fishing is to blame for the overexploitation of the Atlantic Bluefin Tuna, claiming that Japanese, Korean, European, and American fishing has dominated the market in both supply and demand for the gigantic fish.[103] In 2000, the Mediterranean accounted for 48 percent of the Atlantic Bluefin caught globally.[104] Rapidly, tuna became one of the most desired fish in the global market and most of the fish captured in the Mediterranean are exported to Japan. Tuna are highly valuable in Japanese sushi markets, selling for rates between $500 to $900 per kg.[105] The average weight for a large adult tuna is between 500 and 650 kg. In Japan, entire tuna fish regularly sell between $20,000 and $30,000 and in 2001, a single tuna sold for more than $170,000.[106]

While the tangible infrastructure related to the *tonnare* are often in intense states of degradation, it is apparent that the memory of *la mattanza* remains central to the Sicilian communal identity. The erasure of this cultural practice and the loss of a local economic system will eventually lead to a loss of local culture. As the Sicilian economy moves from traditional fishing to other sources of revenue, the *mattanza* will also diminish. The rapid collapse of the traditional tuna fishing industry calls for archaeological preservation of this impactful aspect of cultural heritage.

[103] van Ginkel 2005, 80; Longo and Clark 2012, 205.
[104] Ottolenghi et al. 2004, 112.
[105] van Ginkel 2005, 74.
[106] Longo 2007, 12; Longo 2009, 158.

The Legacy of *La Mattanza*

Some anthropologists note that tradition often dictates identity, which is especially true when a certain way of life is threatened.[107] The tradition of *mattanza* is not only responsible for the economic success of so many Sicilians but also integral to the cultural, social, and religious identities of the community. It is therefore unsurprising that traditional tuna fishing continued in some places into the late 1990s. It is perhaps this significance that prevented public outcry at the tradition of killing tuna in such a gory and visceral manner, even when Bluefin Tuna became an endangered species.[108]

The rapid decline of the industry in Sicily left *tonnare* abandoned, with buildings and boats in disrepair, largely forgotten outside of small local communities. Pessimistically, some scholars believe that the authentic legacy of la *mattanza* is threatened, especially when heritage is put on display for tourists, as is the case at Favignana.[109] However, one only has to walk through a Sicilian coastal town with a historic *tonnara* to see the pervasive vestiges of the industry.

In Marzamemi, restaurants such as *La Mattanza Pizzeria* reference traditional tuna fishing and gift shops are stocked full of canned, dried, and pate tuna fish products. Diagrams outside of shops show the methods in which tuna were captured in nets (Figure 9). Books about regional *tonnare* and fishing practices, such as *San Vito lo Capo e la Sua Tonnara* and *La Pesca del Tonno nel Capolinea del Sud* can readily be found in

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[107] Briggs 1996, 440; van Ginkel 2005, 72, 75.
[108] Safina 1996; van Ginkel 2005, 73; Longo 2007, 2.
[109] Briggs 1996, 440; Nadel-Klein 2003, 93, 171-5; van Ginkel 2005, 72, 80.

bookstores.[110] These titles, mostly written by local Sicilian scholars, indicate the importance of fishing as a topic of study and inevitably serve to connect the people of today to their perceived communal history.

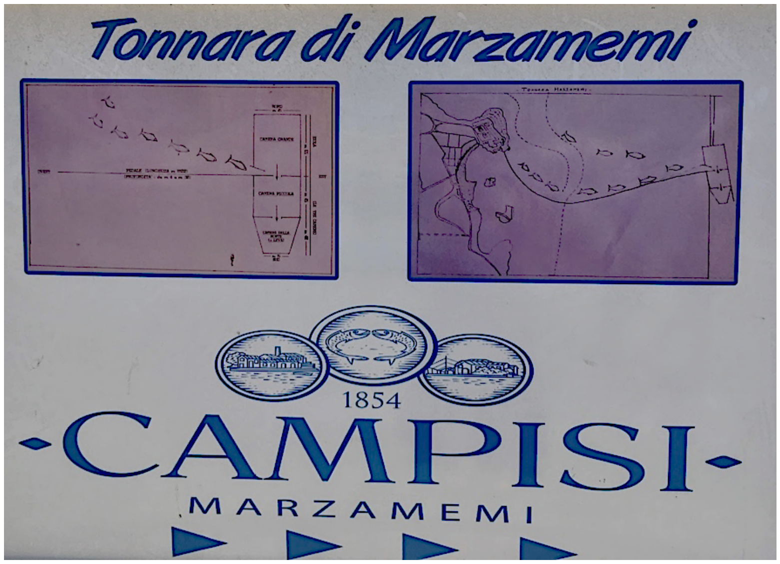

Figure 9: Shop advertisement explaining how tuna fishing in Marzamemi was performed. Image by the author, 2019. © Claire Zak 2019.

In August of 2019, the author had the opportunity to visit a small community museum called Ecomuseo Urbano Mare Memoria Viva in Palermo, the capital of Sicily. The exhibit, entitled *Mare Memoria Viva,* portrayed the fishing history of the city through photo albums, home family videos, interviews, postcards, and art.[111] As the first ecomuseum in Palermo, it functions as a community gathering space with events for children and adults to celebrate the city's relationship with the sea. *Mare Memoria Viva*

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[110] Ravazza 2017; Sorbello 2019.
[111] *Mare Memoria Viva*: https://www.marememoriaviva.it/?lang=en

is an ongoing community-led project, established in 2014 and updated every year with more stories, photos, and memories.

The Ecomuseo exhibit is one of the many examples of how Sicilian cities acknowledge their cultural and economic heritage. Artists, shops, and restaurants often incorporate *mattanza* imagery and references. Along the street near the museum is a mural of a life jacket-clad Saint Erasmus, a martyr from the third century B.C.E. and the patron saint of sailors, located above a shop that advertises an ancient fishery and "fruits of the sea," an Italian term equivalent to what English speakers call seafood (Figure 10).

Figure 10: A mural of Saint Erasmus by an unknown artist in Palermo. St. Erasmus is considered to be the patron saints of sailors. The mural is located over a shop that advertises fish products. Artist unknown. Image by the author, 2019.

Similar museums and exhibition spaces exist in towns such as Favignana and Vendicari, converting the once bustling *tonnare* into exhibit halls and preserving the local history and traditions in an educational format. For example, the *Ex Stabilimento Florio delle Tonnare di Favignana e Formica Museum* is located in nearby Trapani. The location of Vendicari's *tonnara* is within a nature preserve and adjacent to a popular beach location, allowing visitors to tour the abandoned facility at their own leisure (Figure 11). Marzamemi and Portopalo deal with their histories in distinctive ways, discussed below.

Figure 11: The remains of the *tonnara* at Vendicari. Image by the author, 2019. © Claire Zak 2019.

The MMHP conducted an educational campaign during the summer of 2019 to share with the residents of Portopalo the team's continuing research. The temporary exhibits appeared in the form of hulls of the Byzantine shipwreck, migrant boats, and *mattanza* vessels studied by MMHP participants during the field season. The displays presented the information in an interactive experience, incorporating film clips, sound and music effects, images, and text (Figure 12).

Figure 12: An exhibition boat by the MMHP depicting a tuna fishing vessel. Image by the author, 2019. © Claire Zak 2019.

Tuna Fishing Facilities at Marzamemi

The *tonnara* at Marzamemi has been in existence since at least 1648 when it was first mentioned in a contract created by Don Mariano Nicolaci.[112] It is often associated with the nearby *tonnara* of Vendicari due to their proximity and shared ownership.[113] In addition to *tonnara*-net fishing, tuna fish processing also occurred in the center of the village.[114] Throughout the 17th and 18th centuries, ownership passed hands many times but the tonnara was consistently profitable.[115] In 1760 the town of Pachino was established, lending another central location for economic success in addition to the Marzamemi *tonnara*.[116]

In the 18th century, Marzamemi was still considered to be one of the most profitable *tonnare* in Sicily.[117] Over the 18th and 19th centuries, the tuna fishing industry alternated between being highly successful or devastatingly unstable due to low fish turnout. The *tonnara* of Marzamemi often clashed with that of Portopalo di Capo Passero over jurisdiction limits since there was only approximately three km between them.[118] Once the *tonnara* at Vendicari was closed due to poor turnout, this greatly improved the fishing at Marzamemi and Portopalo di Capo Passero.[119] Still, a bustling market town developed around the tuna facilities there, growing to include two churches, several restaurants, and shops.

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112 Lippi Guidi 1993, 54.
113 Lippi Guidi 1993, 54.
114 Lippi Guidi 1993, 55.
115 Lippi Guidi 1993, 55.
116 Lippi Guidi 1993, 55-6.
117 Consolo 1986, 191; Lippi Guidi 1993, 56.
118 Lippi Guidi 1993, 56.
119 Consolo 1986, 191.

Tuna fishing and processing seriously slowed around World War II and stopped being productive around 1950.[120] Within the past 30 years, there has been no activity relating to *la mattanza*. Recently, the main halls of the *tonnara* were renovated and developed into a gathering space, while other areas of the *tonnara* have fallen into severe disrepair. Included are several large abandoned *mattanza* boats located in the central courtyard (Figure 13). The vegetation is overgrown and the shelter over the courtyard is minimal. Researchers performed only a preliminary examination. Due to local government setbacks, these vessels could not be recorded by the MMHP during the summer of 2019 but remain on the future project list.

[120] Consolo 1986, 191.

Figure 13: ***Mattanza*** **vessels in the courtyard of the Marzamemi** ***tonnara*****. Image courtesy of the MMHP, 2018.**

Tuna Fishing Facilities at Portopalo di Capo Passero

Early evidence for the existence of the *tonnara* at Portopalo di Capo Passero comes from a document from 1275, claiming that the complex was owned by King Federico II.[121] This *tonnara* was first located nearly 1 km north of its current location. Ownership of the buildings passed hands for many years and the complex was burned in

[121] Capodicasa 2016, 32.

1574 by the Ottoman navy.[122] An earthquake in 1693 forced the construction of a new *tonnara* at its current location along with a church, warehouses, administration buildings, and other relevant infrastructure (Figure 14).[123] There is evidence that the trap was abandoned by the end of the 18th century.[124]

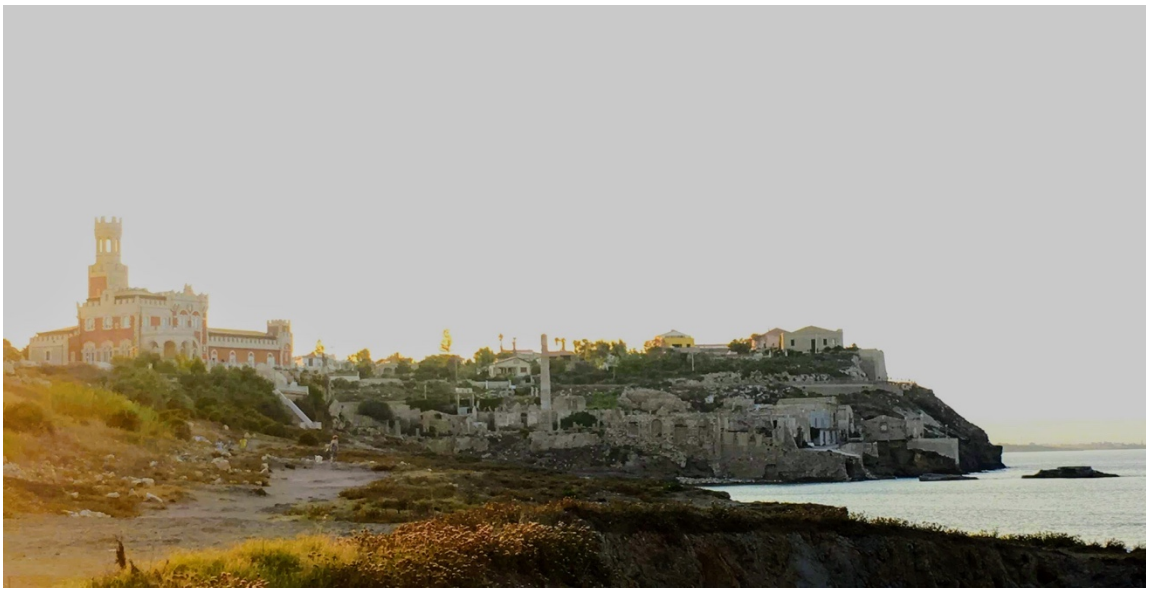

Figure 14: The *tonnara* complex at Portopalo. Note the more recent addition of a castle built in the 1930s that has been converted into a hotel. Image by the author, 2019. © Claire Zak 2019.

The feudal town of Portopalo was founded at Capo Passero by Baron Gaetano Deodato in 1792 through a license given by Fernando di Borbone, then king of Sicily.[125] Baron Deodato provided his own money to build houses for new inhabitants and the *tonnaroti*, which boosted the commercial success of the *tonnara*. Soon after, Baron

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[122] Capodicasa 2016, 32.
[123] Capodicasa 2016, 32.
[124] Capodicasa 2016, 36.
[125] Capodicasa 2016, 10.

Gioacchino Ferreri obtained rights to the abandoned *tonnara* at Portopalo and after a year of preparations and negotiations operations began.[126] After the trap was set up, Ferreri began rebuilding the *tonnara* factory and storage facilities for the boats and tuna processing (Figure 15).[127] Though ownership changed families several times, the *tonnara* continued to operate until the mid-1960s.[128] Today the facilities are the property of the local government, though part of the facilities are privately owned and have been turned into a vacation hotel in the style of a medieval castle.

Figure 15: Storage and work sheds on the Island of Capo Passero to house *tonnara* equipment and *mattanza* vessels. Image by the author, 2019. © Claire Zak 2019.

The storage facilities were located on the Island of Capo Passero as early as 1640, though they have been rebuilt many times. Today they are dilapidated, overrun

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[126] Capodicasa 2016, 36.
[127] Capodicasa 2016, 36.
[128] Capodicasa 2016, 33.

with vegetation and debris and subject to collapse. The derelict boats on the island are damaged by the collapsed roof and exposure to the elements (Figure 16). While the island was once connected to the mainland by a sandbar, it is now only accessible by boat. Moreover, since the island is private property, efforts to conduct research and conservation are complicated. Still, MMHP was able to gain permission to make laser scans of the warehouse facilities and the surviving vessels for digital analysis and information preservation purposes.

Figure 16: The collapse of the shed roof on the Isola di Capo Passero meant disaster for the several *mattanza* boats under its shelter. Image by the author, 2019. © Claire Zak 2019.

Project History

The desire for MMHP to digitally record Sicilian tuna fishing vessels began with several boats located in the *tonnara* in Marzamemi. Today the building has been repurposed as a municipal building and event space, though public access is limited. The boats are located in the courtyard of the building with little shelter or management. MMHP arranged with government officials in Marzamemi to record these vessels, though a government employee turnover temporarily postponed the endeavor. Additionally, the mayor of Portopalo di Capo Passero expressed great interest in recording and analyzing the vessels located in the piazza of the city. A collaboration between TAMU's Nautical Archaeology Program and MMHP enabled researchers to conduct photogrammetry during the summer of 2019 on these three vessels. The author also worked with Dr. Leopoldo Repola from the Università degli Studi Suor Orsola Benincasa and collaborators with the MMHP to laser scan these same vessels as well as the *tonnare* buildings on the Isola di Capo Passero. Following the initial data collection, the author and Dr. Christopher Dostal produced digital 3D models, while Elizabeth Hoffer of Brock University processed the laser scans.

Conclusions

Tuna fishing has endured on the island of Sicily since Neolithic times, spurred in turn by the Phoenicians, Greeks, Romans, and commercialized by the Muslim Caliphates, Norman and Spanish rulers, and Sicilian kings. Traditional methods of tuna fishing (*la mattanza*) using a series of nets and small wooden boats remained successful for centuries in the harvesting of this then-plentiful resource. Yet, in modern times, the tuna fishing industry has been taken over by commercial fisheries and farms and the ecological stress of overharvesting the resources caused the Atlantic Bluefin to decline in numbers and the *tonnare* to become unprofitable. Continued economic decline forced traditional tuna fishers and processors to cease operations, losing a vital part of the Sicilian cultural heritage.

However, despite its rapid decline in the late 20th century, the *mattanza* did not disappear from the local narrative. It is almost impossible to turn around in a coastal Sicilian city without seeing a reference to the sea and *mattanza* fishing. The relationship of sea to shore is fundamental to the communal identity that lingers even after the decline of the *mattanza* tradition and the closure of the *tonnare* in the 20th century. The significance of the remaining cultural heritage is regaining value for municipal governments like Marzamemi and Portopalo, which are calling for the preservation of their *tonnare* and *scieri*. As these cultural resources are preserved, digitally or physically, more people will gain access to the communal heritage of coastal Sicily.

CHAPTER III

DIGITAL RECORDING METHODOLOGIES

The *Mattanza* Vessels at Portopalo

The three *mattanza* vessels at the piazza of Portopalo are beloved cultural objects that represent the city's history of tuna fishing and processing. The boats have been displayed in the square for a number of years and are therefore subject to disrepair and degradation due to the effects of weather and passerby interaction. One of the boats is directly located adjacent to a playground, leaving no doubt that children have also used the boat as a jungle-gym. The author also witnessed a tourist throwing an empty plastic water bottle into the hull of one of the smaller vessels. Trash lines the hulls of all three, while the paint and wood are chipped and damaged. Recognizing their value and the slow effects of dilapidation, the mayor of Portopalo invited the MMHP to record the vessels and conduct a conservation project.

Notable Construction Features of the Mattanza Vessels

The boats used for Sicilian tuna fishing are simple in their construction but do have some special characteristics that differentiate them from other traditional fishing boats. Like many traditional European and Mediterranean craft, *mattanza* boats are flat-bottomed and the smaller vessels are double-ended.[129] Vessels used for *mattanza* are rowed with no engine or sails.[130] Larger boats contain either one or two insets in the keel that appear to be mast-steps. However, these are not used as mast-steps, but serve as

[129] Smylie 2013, 218.
[130] Longo 2009, 141.

mounting points for various stanchions that hold flags or tarps that shade the fish. The medium and large *sciere* consistently exhibit a longitudinal bulwark that is known as a *scivolo*.[131] The *scivolo* provides support for the *tonnaroti* while hauling in tuna fish from the *mattanza* and is necessary as a place for the *tonnaroti* to stand when the hull is full of tuna. Many of the later ships contain winches on the stern, used to lift fish from the water into the hulls. These winches are designed to prevent damage to the flesh of the tuna, motivated largely by the sushi industry, since tears in the body of the tuna can reduce the price that the fish fetch in the sushi market[132]

Sciere

The largest vessel at the west end of the piazza is referred to as *Sciere*. It is approximately 13.94 m in length, with a breadth of 3.42 m, and a height 1.23 m and has a transom stern (Figure 17). These measurements indicate that it is a vessel of medium size based on the general size classifications.[133] The boat is perched on wooden trestles on a grassy area and shaded by tall palm trees. The hull is unpainted on the inside and coated with black paint on the outside. Much of the wood is subject to warping and rust stains populate the majority of the frames. On the stern is a metal support for a winch system. A bulwark runs along the entire port side about 0.3m from the hull. Decaying ropes and trash fill the hull.

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[131] Sorbello 2019, 14.
[132] Longo and Clark 2012, 216.
[133] Bellabara and Guerreri 2002, 47.

Figure 17: *Sciere* Vessel in Portopalo. Image by the author, 2019. © Claire Zak 2019.

Muggiara 1

From the east, the boat to the right of the *Sciere* is referred to as *Muggiara 1* (Figure 18). *Muggiara 1* has an approximate length of 6.55 m, 1.8 m breadth, and is 1.08 m tall, which is a small sized vessel. It is located near a children's playground on the stone piazza and is subject to direct exposure to sun, wind coming across the southeastern shore, and the elements. It is a small double-ended hull with closely-spaced framing. The inside of the hull and the wales are painted a bright green color, which is peeling and faded in some areas, and the outside is pitched black. Planks of plywood, rope, and bits of trash fill the hull.

Figure 18: ***Muggiara 1*** **Vessel in Portopalo. Image by the author, 2019. © Claire Zak 2019.**

Muggiara 2

From the east, the boat to the left of the *Sciere* is *Muggiara 2* (Figure 19). The approximate measurements of this *muggiara* are 7.25 m in length, a breadth of 2 m, and a height of 1.3 m, indicating a small vessel. It is beside a café seating area and receives some shade during the day and partial shelter from the sun, wind, and weather. The hull is small and double-ended with closely-spaced framing and a similar size and shape to

Muggiara 1. The inside of the hull and the wales are painted the same green color as *Muggiara 1,* but the paint is in much better condition. The outside of the hull is black. The hull is filled with bits of trash as well as old chain and rope.

Figure 19: *Muggiara 2* Vessel in Portopalo. Image by the author, 2019. © Claire Zak 2019.

Data Collection

In June of 2019, the author and Dr. Christopher Dostal, researchers from Texas A&M University, in collaboration with scholars from the Università degli Studi Suor Orsola Benincasa and Brock University, collected the initial recording data to create 3D models of the *mattanza* boats at Portopalo. The primary datasets consisted of a collection of hundreds of photographs, supplemented with GoPro video footage, in addition to laser scans of the piazza performed with a Faro Focus 3D Laser Scanner. From the photography and laser scan datasets, photogrammetry and PTM methods were employed to produce archaeologically accurate 3D models. These models were used to project ship's hull lines and an orthophotograph. Together, these endeavors encompass a preliminary condition report for the future conservation of these vessels.

Photography

Photography was performed on two separate occasions around midday with basic Canon and Nikon DSLR cameras. Scales of 15 cm were placed on the vessels in order to properly scale the objects within the computer software. The images were taken at a size of 3456 by 2304 pixels by a 22.5 by 15 mm sensor and stored as JPEG files to accommodate storage space; they were not color corrected or edited prior to processing. If possible, it is preferable to use RAW or TIFF files since other formats such as JPG (JPEG) compress the data and may cause unwanted noise in the image. Photographs were taken at the maximal possible resolution with the lowest ISO value in order to reduce noise. Researchers were careful to take sharp images without blur due to movement and the use of flash was avoided.[134] The weather conditions were not ideal because of the direct overhead lighting from the sun, which can cause glares on reflective or bright colored objects and shadows that block out detail. This reflection can also be an obstacle to accurate laser scanning. For the *Sciere*, 489 photographs were

[134] Agisoft LLC 2021, 8. The photographic settings were informed by Agisoft's recommendations.

taken, along with 311 for *Muggiara 1* and 459 for *Muggiara 2*. Because of limited continued access to the vessels, the researchers also took walk-around videos using a GoPro, from which video stills could be used to fill gaps in the photography.

Laser Scanning

Laser scanning is an active form of remote sensing that emits a laser pulse, measures the time and distance of the return, and geopositions objects accordingly. Every laser recorded by the sensor generates a point on a map, thereby creating a mesh in the form of the recorded environment.[135] The *mattanza* vessels were laser scanned using a Faro Focus 3D Laser Scanner (Figure 20). The process of generating laser scans is relatively straightforward. The scanner must be positioned on level ground with a satellite GPS location for at least the first scan and an active altimeter to record height. The scanner will record a scan area both horizontally and vertically for 360 degrees. After each scan, the scanner can be repositioned to the next predetermined location. Nearly 30 scans were necessary to cover the entirety of the piazza. The laser scan data is crucial for the production of a PTM model, which will be covered in the next section.

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[135] Lillesand et al. 2015, 471.

Figure 20: The Faro Focus 3D Laser Scanner used at Portopalo. Image courtesy of the MMHP, 2019.

Digital Modeling Methods

The models of this project rely heavily on previously successful and established methodologies for photogrammetry, laser scanning, and digital heritage preservation. When recording cultural heritage in a digital format, it is imperative to first consider the intended outcomes for the project. If the model is meant for display in a public museum, the platform and methodology might vary greatly from a model meant to elucidate construction features prior to a conservation venture. For this project's purposes, the aim is to create models that are both technical enough for academic study while also remaining accessible to a wider audience and manageable file sizes to share among colleagues. The workflows and software programs below are meant as an evaluation for producing various types of models that can offer different sorts of archaeological and conservation data. The resulting models are displayed and discussed in the following chapter.

The success of modeling software is made possible through the use of fast-processing hardware. The models were generated on an Alienware Aurora computer with 32 GB of Ram, which streamlined and reduced the processing time. It is also salient to note that many of the model processing software platforms can be quite expensive, ranging from several hundred to thousands of dollars per license. However, many of these companies offer discounted rates to both students and universities. Sometimes, open source and free platforms do exist as alternatives though the processing speeds may be greatly reduced. For photogrammetry, Agisoft's *Metashape* was chosen for its ubiquity within the archaeological field and ease of use. Laser scans were processed using Geomagic's *Design X*, often used for its ability to work with many types of files from various types of software. McNeel's *Rhinoceros 6* was used for its capabilities to model objects in 3D.

Photogrammetry

Photogrammetry is sometimes called computer vision photogrammetry since digitized 3D models are produced from photography or video footage.[136] The

[136] Lillesand et al 2015, vi; Yamafune 2016, 1, 52; Dostal and Yamafune 2018, 1. When photogrammetry is produced from videos, the photogrammetry is referred to as structure-from-motion.

photogrammetric process uses the concept of stereogrammetry to produce 3D models; photos should be taken with at least 60 percent overlap.[137] The resulting digital models can be accurate enough that proper measurements of the dimensions and curvature of the hull can be determined from them, allowing for observations about the planking, framing, and propulsion as well as wear, usage, and potential repairs (Figure 21).

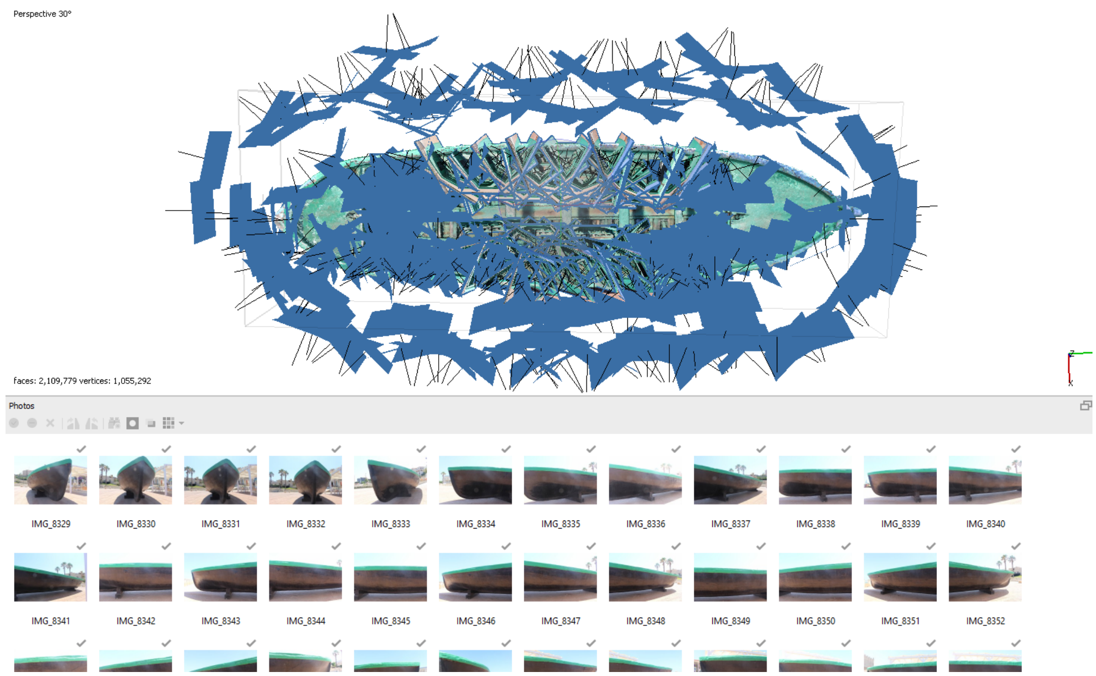

Figure 21: Photogrammetry of objects require many photos to produce a model. This model is of *Muggiara* 2. Image by the author, 2020. © Claire Zak 2020.

The workflow of the Agisoft's *Metashape* is as follows: align the photos, build the dense cloud, build the mesh, and build the texture.[138] First, several hundred photographs are taken from every angle around an object. The photos that the

[137] Agisoft LLC 2021, 9.
[138] This workflow is modeled after the one in Yamafune's 2016 dissertation.

researchers took were uploaded into the *Metashape* software program, which geospatially positions the photographs during alignment using pixel overlap.[139] Photos were aligned utilizing the High Accuracy setting with a Key Point Limit of 50,000, and a Tie Point Limit of 10,000. Key points are locations that the software identifies as the same among several images, while tie points are simply sets of key points identified as the same 3D point on different images.[140] A High Accuracy alignment ensures that the software will use full resolution images while processing the photographs.[141] Increasing Key and Tie Point Limits increases the number of pixels used in the images to detect shared 3D projections between images.[142] Out of 489 photos, 463 aligned for the *Sciere* model with 874,512 tie points. *Muggiara 1* aligned all 311 photos and had 503,289 tie points and *Muggiara 2* aligned 454/459 cameras with 881,704 tie points. A point cloud was then generated from the aligned photos using the Build Dense Cloud feature, on the Medium setting and with Mild Depth Filtering. A dense cloud is simply a point cloud representing color, shape, and depth of a 3D object. In choosing a medium quality setting, *Metashape* uses 50 percent of the full size resolution, which affects the number of points in the dense cloud.[143] Depth filtering accommodates various colored surfaces, depth, and void; mild depth filtering ensures that monotone surfaces are recognized, while simultaneously filtering out void space.[144] The dense cloud was then used to

[139] Agisoft LLC 2021, v.
[140] Agisoft LLC 2021, 29.
[141] Yamafune 2016, 53.
[142] Yamafune 2016, 53.
[143] Yamafune 2016, 57.
[144] Yamafune 2016, 59-60.

generate a polygonal mesh. The source data for this step was Depth Maps, the surface type was chosen as Arbitrary, and the face count was Medium. When Depth Maps is chosen as the source data instead of Dense Cloud, Metashape will use the point cloud to pair images with a tie point limit over 100 to generate the mesh instead of each individual point, which takes less time and computing power.[145] An arbitrary surface must be chosen when the recorded object is 3D, since the other option Height Field is used when the surface is flat.[146] When a Medium face count is chosen, only 1/15 of the total Dense Cloud points will be used to create the mesh.[147] The final step was to create a texture using a photo mosaic with the Generic setting, which allows the computer software to choose the best photographs suited for the location.[148] The mesh polygonal surface of the model is draped by a texture created from a photomosaic, which is a compilation of images matched at their shared points.[149]

Photographic Texture Mapping

Photographic Texture Mapping (PTM) is a form of 3D Digitization that combines a laser scan and photogrammetric model to produce a hybrid 3D digital model.[150] The workflow of *Design X* consists of taking laser scans, aligning the laser scans, editing the point cloud, and generating the mesh. First, the researcher must first manually align each scan to render the full scene of the research area. For this project,

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[145] Agisoft LLC 2021, 29, 31.
[146] Yamafune 2016, 62; Agisoft LLC 2021, 35.
[147] Yamafune 2016, 63; Agisoft LLC 2021, 35.
[148] Yamafune 2016, 67; Agisoft LLC 2021, 38.
[149] Yamafune 2016, 67.
[150] Dostal and Yamafune 2018.

laser scan alignment was performed by Elizabeth Hoffer of Brock University and the scans were made available to the author by the MMHP. The extraneous scan area not relevant to the model were deleted to focus solely on the vessel subjects. From here, the dense point cloud further produced a mesh using the Mesh Buildup Wizard and HD mesh construction features, which estimates vectors from the points. The mesh was then run through the Healing Wizard and Global Remesh tools to fill in some holes and convert the polygons to an equal size. The model can then be exported as a .OBJ file to *Rhinoceros 6* to be later aligned with the photogrammetric model.

The next focus was the photogrammetric model. For this process, the same steps for photogrammetry were taken in *Metashape* as described above, including aligning photographs, generating a point cloud, and forming a mesh. After the mesh was created from the point cloud, the model was also exported as an .OBJ file. Both the laser and photogrammetric models were opened in *Rhinoceros 6.* After ensuring that the scale was accurate, the laser scan mesh was locked into place and the photogrammetric mesh was aligned to the laser scan mesh (Figure 22). The photogrammetric mesh was the replaced with the laser scan file. From *Rhinoceros 6*, the file was moved back into *Metashape* as an .OBJ file to generate a texture map. Since PTM combines the geometric accuracy of laser scanning with the photogrammetric detail, the resulting model is more accurate and aesthetically pleasing.

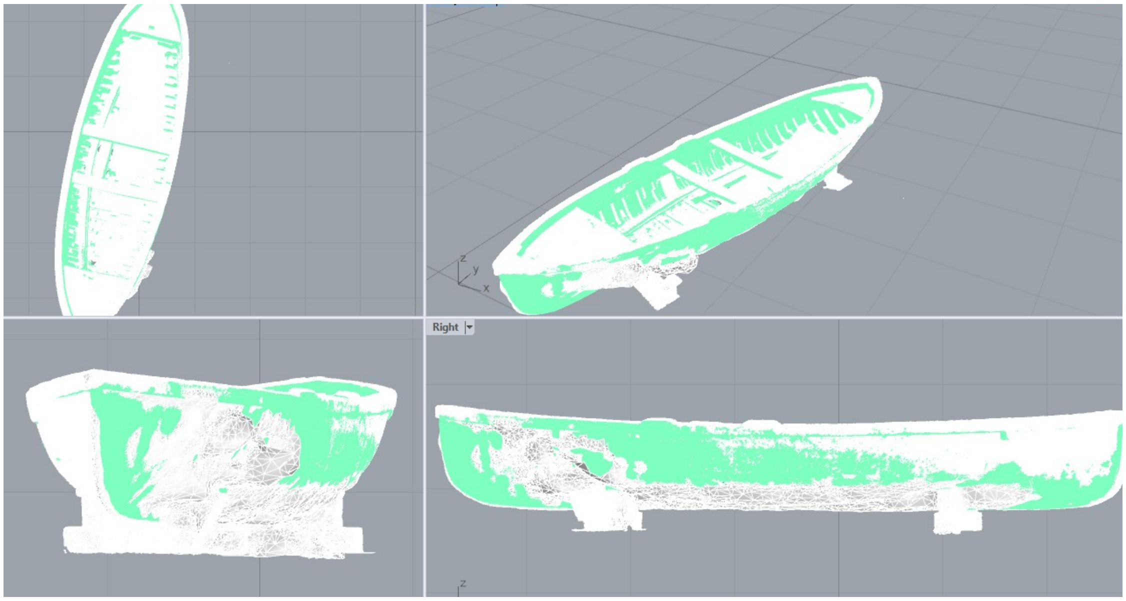

Figure 22: Aligned laser and photogrammetry meshes. Image by the author, 2020. © Claire Zak 2020.

Section Curves with Rhinoceros

In traditional recording, one of the major concerns of nautical archaeologists is how to represent a 3D object on a 2D platform while still retaining volumetric data.[151] This is often done through ship's lines that represent three different views: body, sheer, and half-breadth plans. 3D technologies can assist in displaying the hull curves and sections in preparation to production of the hull lines. The software *Rhinoceros 6* enables the creation and manipulation of objects in a 3D space. Photogrammetric and laser scan models can be imported into *Rhinoceros 6*, and a researcher can trace sections the hull for curve analysis (Figure 23).

[151] Steffy 1994, 214-5, 221, 250.

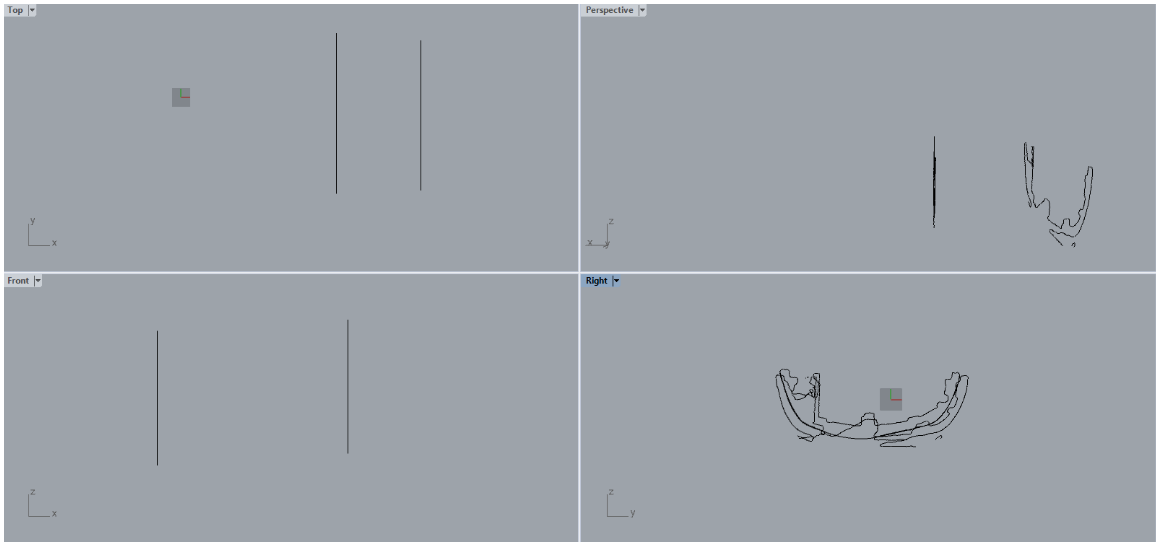

Figure 23: Results of tracing hull curves at two sections. Image by the author, 2021. © Claire Zak 2021.

In order to import the photogrammetric model into *Rhinoceros 6*, the file was exported from *Metashape* in an .OBJ format with the texture or an .STL format without the texture. The .STL format produces a smaller file and is easier to manage within *Rhinoceros 6*. The model was scaled within the program and the Section command was selected. With this tool, slices of the hull were taken in increments to indicate the overall vessel shape. By using the curve tool, the sections were traced to form a fair derived curve. The derived curves are then lofted to generate surfaces between the curve lines and form a volumetric shape (Figure 24). Faired hull sections were printed to scale to enable accurate measurements of height, breadth, and length between sections. These can be incorporated directly into the ship's lines.

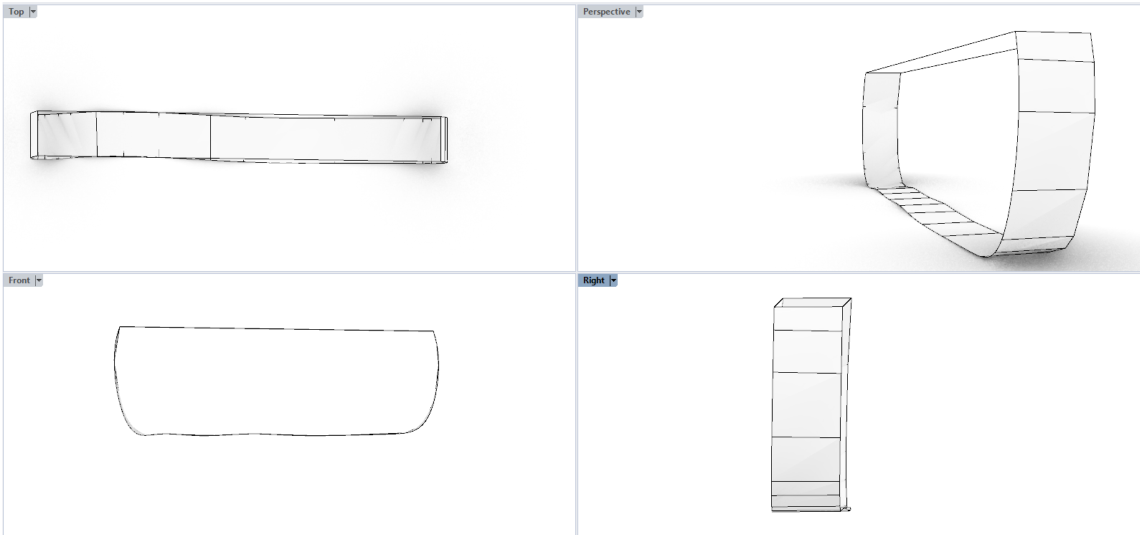

Figure 24: An example of a section of the derived hull faired and lofted. Image by the author, 2021. © Claire Zak 2021.

Orthophotography

It is useful to create an orthophotograph of a 3D model since it represents and undistorted image from which to take direct measurements. An orthophotograph is simply a photomosaic displaying only one projection plane, or one perspective view.[152] This combines the benefit of a 2D image with a map with detailed texture representation.[153] By utilizing a series of photographs (usually taken from above at a vertical angle), an orthophotograph rectifies the relief displacement and scale distortion between the images. The production of an orthophotograph depends on reliable DEM information, which can be acquired through photogrammetric rendering.[154] A DEM

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[152] Yamafune 2016, 68.
[153] Lillesand et al. 2015, 201.
[154] Lillesand et al. 2015, 149.

represents the topography of a landscape by assigning a number value to each pixel, representing elevation in a 2D format.[155] An orthophotograph is an image placed over the DEM information so that the pixel values for photo brightness are matched with the values for elevation. *Metashape* has the ability to convert DEM data into a point cloud, which allows the orthophotograph to be "draped" over the DEM.[156] The result is a photorealistic map with a consistent scale that allows for direct measurements.

The *Metashape* program has the capability to produce an orthophotograph using DEMs from a set of images and ground control points (GCP) (Figure 25). The DEM data is already calculated by *Metashape* and contained within a photogrammetric model. An orthophotograph also requires the input of a coordinate system and photo alignment steps similar to the photogrammetry process. The selection of GCPs assist the software in aligning the relevant photographs, which makes the orthophotograph more accurate.

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155 Lillesand et al. 2015, 35.
156 Lillesand et al. 2015, 39.

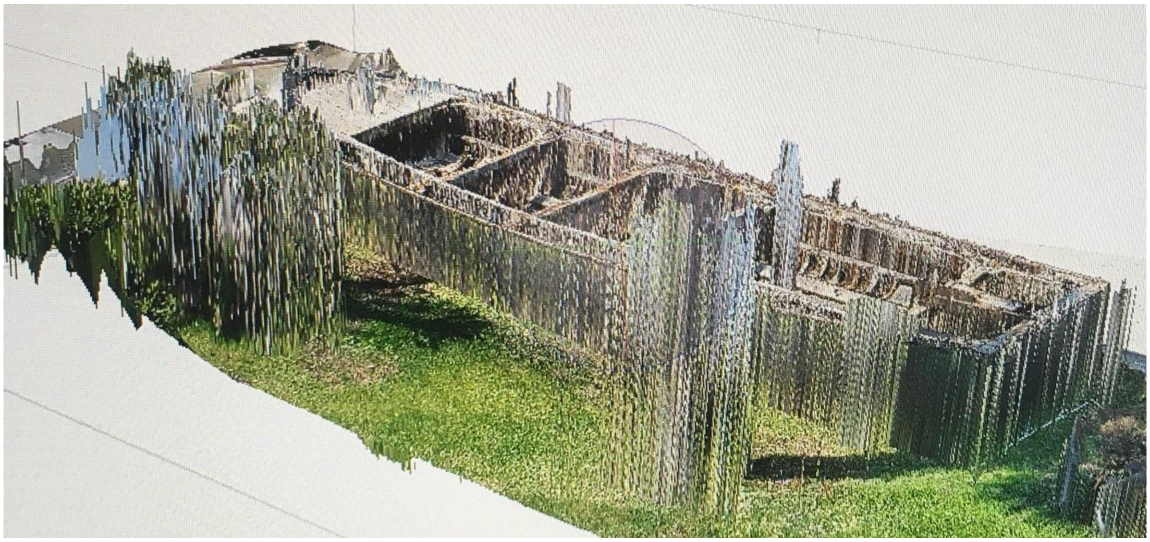

Figure 25: An unedited height map used to create a DEM prior to the generation of an orthophotograph. Image by the author, 2020. © Claire Zak 2020.

In order to demonstrate the utility of an orthophotograph of the *mattanza* vessels, the process is explained for the *Sciere* model. The author selected ten GCPs to properly align the 489 photos, generate a height map, and build a mesh. The height map setting indicates that the surface of the model is flat, and not a 3D structure.[157] Prior to mesh generation, distortion was reduced by manual editing the GCPs in each relevant photograph (Figure 26). The remainder of the process is to build a dense cloud, mesh, and texture layers similar to the steps outlined in the photogrammetric workflow.

[157] Yamafune 2016, 62.

Figure 26: Choosing GCPs is an important step in creating an orthophotograph, which assists in aligning the photographs and georeferencing the model. Image by the author, 2020. © Claire Zak 2020.

Conclusions

The researchers conducted field work data collection by taking photographs and laser scans of the *mattanza* vessels and the Portopalo piazza in order to produce digital models, which are displayed fully in the Chapter IV. The primary models generated from these data sets were photogrammetric and PTM. From the models, the data was further manipulated in *Rhinoceros 6* and *Metashape* to generate sections of the hull and an orthophotograph. Before producing digital data, it is essential to evaluate the goals of the project in order to choose the proper modelling platform. The models of this thesis were chosen to highlight various types of information that can be gained from the primary photography and laser scan data sets. The cost-benefit analysis of the methodologies are discussed in the following chapter.

CHAPTER IV

ANALYSIS OF DIGITAL MODELING TECHNIQUES

Digital Recording Results

The production of several 3D models using different platforms allows for comparison. The integrity of the models within a processing method vary to some extent, most likely the result of data collection hurdles. Notable results, challenges, and explanations are outlined below first for the vessels themselves, then followed by each digital processing method.

Sciere

The *Sciere* was the most complete and accurate model for several reasons. Since the boat was the largest and most complicated, more photographs were taken of the *Sciere* than the *muggiara* boats. The larger data set ensured smoother photo alignment and georeferencing than the other data sets, which were sparser. The vessel was not directly in the sun, receiving shade from overhead trees. This, in conjunction with the black and natural wood color of the hull allowed the digital software platforms to process the photographs and laser scans more easily than the brighter and more exposed *muggiara* vessels.

Muggiara 1

One of the main complications for the *Muggiara 1* vessel was the color and direct exposure to sunlight. Harsh overhead light and bright colors often create challenges for the photogrammetric and laser scanning processes. There are a few holes in the model seen on the inside of the hull due to data gaps or processing complications.

Muggiara 2

In regard to lighting and color, the same issues of the *Muggiara 1* models apply to *Muggiara 2*. Another complication of *Muggiara 2* however, was the nearby placement of an unmovable cement bench that blocked necessary angles for the recreation of the lower hull.

The photogrammetric processing of the *Muggiara 2* model was especially complicated. Perhaps due to color confusion between the shadows and black hull, *Metashape* incorrectly displayed two overlapping boats of different size when there should have only been one (Figure 27). This required manual alignment of a batch of 60 photographs and a re-rendering of the dense cloud. From here, *Metashape* failed to produce a mesh twice so the author decided to build the mesh from the dense cloud and not depth maps before generating the final texture.

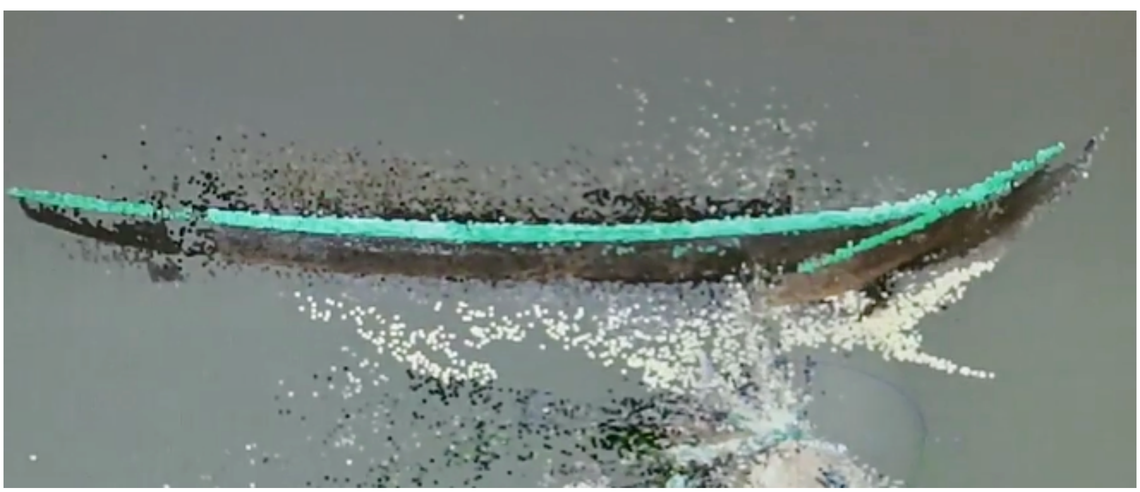

Figure 27: An error in photogrammetric alignment, where two boats were projected at different sizes when there should only be one. Note that the second vessel is the green patch in the cluster of points in the bottom right. Image courtesy of Christopher Dostal, 2019.

Analysis of Digital Modeling Techniques

Every 3D modeling platform presents its own set of circumstances, abilities, and challenges. The selected evaluation criteria include the overall cost, usability, typical issues, and benefits. In addition to software package price, file size was also considered when exporting and sharing the projects. These measures are often taken into account along with the necessary technical skills and challenges of a recording project. Researchers with economical budgets might need to consider the possible outcomes of each software in contrast to their cost and convenience.

Analysis of Photogrammetry

Photogrammetry remains a dependable method for digital recording of objects in 3D. The models produced were reliable and accurate despite difficulties with lighting and the vessels' positions. The process itself is quite manageable however, with *Metashape*'s Workflow option for batch processing, which allows a researcher to queue a series of tasks to begin automatically upon the completion of the previous task. Still, with only one computer system, only one model could be worked on at a time. With hundreds of photographs, processing speeds were slowed down, taking several days to generate the point clouds, meshes, and textures requires to produce all three photogrammetric models. Some photograph batches required manual alignment, but after the placement of several GCP markers, which are also used in the orthophotography process, all photos were eventually aligned. The results of the photogrammetric modeling are displayed in Figures 28, 29, and 30.

Figure 28: Photogrammetric model of *Sciere*. © Claire Zak 2021.

Figure 29: Photogrammetric model of *Muggiara 1*. © Claire Zak 2021.

Figure 30: Photogrammetric model of *Muggiara 2*. © Claire Zak 2021.

Photogrammetry works best when all the photos are taken at the same time of day, preferably in the early morning or late afternoon to avoid overhead glare. Shiny objects such as metal do not photograph well. Therefore, the process is largely weather dependent. Since the timing for digital recording relied on the convenience of the city of Portopalo, photography sessions were held under non-ideal circumstances on two different days, producing different lighting effects that was sometimes difficult for the computer software to rectify. This was especially the case for the *muggiara* vessels, which were painted a bright green color on the inside of their hulls. The outside of the hulls were painted black, which then blended in with the shadows. The *Sciere* model is the most complete, due in part to the overhead trees that provided some shade to the recording area. While this sometimes produced uneven lighting in the models, there was less of a heavy glare than appears on the *muggiara* models.

Moreover, the vessels were positioned on supports low to the ground, making it difficult to record the underside of the hulls. These two factors caused the models to have several holes, especially in the lower portions of the hull. Though scales were used while photographing, there are some scaling issues due to the distortions produced in the modeling (Figure 31). This resulted in blurring where the computer modeling software attempted to fill in the gaps but could not represent the actual timbers properly. These issues can be partially mitigated by skillful photography and image editing prior to model processing.

Figure 31: A shaded photogrammetric model, showing distortions, which can be seen along the framing timbers and keelson. Image by the author, 2020. © Claire Zak 2020.

Photogrammetric software does not often display the objects in the correct scale automatically; scale markers are necessary to replicate scale within the program. In the case of this project, small 15 cm scales were placed on the vessels with the idea that the photogrammetric models would be combined with the laser scan data, avoiding this issue. The model produced by *Metashape* did not display the scale bar clearly enough to create scale to the greatest accuracy possible. Without the laser scan models to input the scale data, this could potentially create a large problem, especially if access to the object is limited or travel is restricted. Alternatively, future projects could ensure the use of large scales within the images, perhaps a meter long.[158]

Overall, the photogrammetric process was user-friendly and relatively quick to perform, both in terms of data collection and digital data processing. While more time for data collection is always preferred, the short recording sessions still produced models of academic archaeological quality, as evidenced by the ship's lines. Photo aligning took the greatest amount of time and tweaking, but almost all photos were aligned within *Metashape*. After this step, most of the subsequent steps in the workflow took an hour or less time to complete. Further manual editing, smoothing, and gap filling would improve the look of the model for both academic study and public display, though this was left to the stylistic discretion of the MMHP to refine the models as their needs require. The author chose to abstain from this editing in an effort to clearly communicate missing data and limit biased interpretation.

The benefits of photogrammetric modeling greatly outweigh the costs. One of the main drawbacks can be the cost of the software, though in an academic setting this can mostly always be supplemented with student and university discounts. The average

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[158] *RealityCapture* has the ability to place scale bars on the original images before modeling but *Metashape* has yet to incorporate a similar feature. Personal Communication, Christopher Dostal, 2021.

amount of time necessary to process a model depends on the size of the image files, the number of images, and the shape and color complexity of the object, among other things.[159] More often than not, settings can be chosen that will still ensure the integrity of the model and its data while only slightly compromising on resolution and detail, allowing for shorter processing times.[160] Still, the geometric accuracy of laser scanning remains greater than that of photogrammetry.[161] Despite this, photogrammetry is relatively a low cost, and a straightforward process for heritage recording. The methodology is both easily taught and learned, and the models are easily disseminated to the public and shared between colleagues.

Analysis of Photogrammetric Texture Mapping

While still a relatively new method, PTM is gaining traction among the archaeological and cultural heritage preservation communities.[162] The clear benefit of more accurate geometric data while also displaying realistic detail is apparent both in principle and the modeled results. Though more time consuming than solely photogrammetry, if the use of the model is for serious academic study, PTM should be highly considered. The same issues regarding time and processing speeds encountered during photogrammetry are also relevant to PTM, though additional time must be spent processing the laser scan data. Overall, this process is more complicated than photogrammetry and requires more human input in the alignment process. The results of

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159 Yamafune 2016, 79.
160 Vacca 2019, 243-4.
161 Dostal and Yamafune 2018, 430.
162 Ebolese et al. 2019, 311-2; Samosir and Riyadi 2020, 63.

PTM are featured in Figures 32, 33, and 34 and can be compared with those of the photogrammetric models.

Figure 32: PTM model of *Sciere*. © Claire Zak 2021.

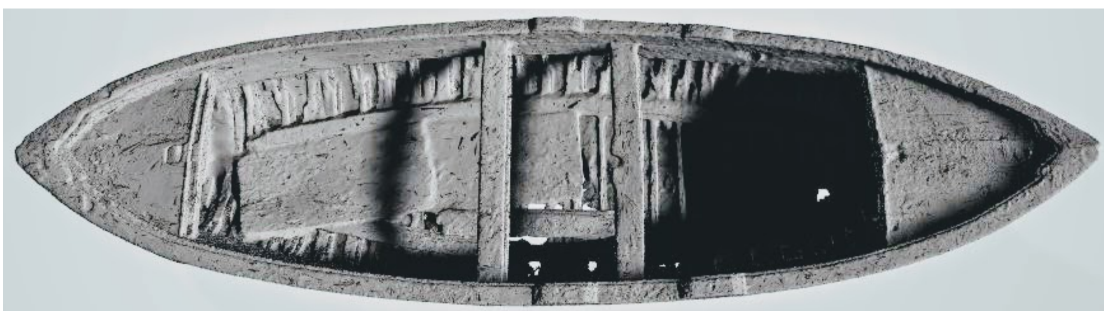

Figure 33: PTM model of *Muggiara 1*. © Claire Zak 2021.

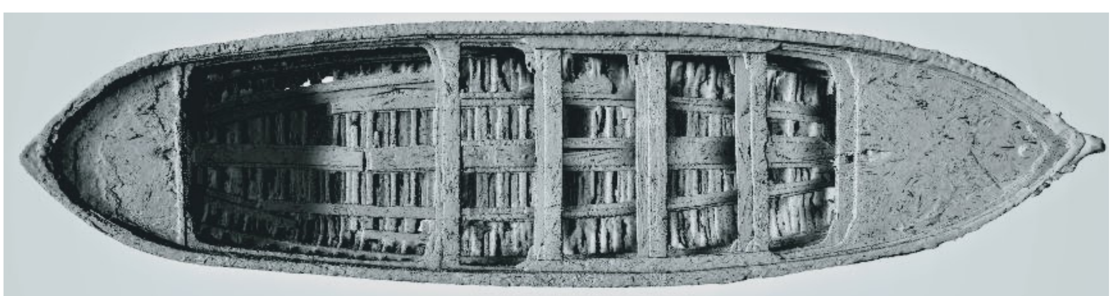

Figure 34: PTM model of *Muggiara 2*. © Claire Zak 2021.

Since the process for PTM is initially very similar to the photogrammetry method, it is possible to use the same photogrammetric model for the basis of the PTM model. Nevertheless, the additional step of producing laser scan data and aligning each individual scan in *Design X* to the other laser scans takes up significant time (Figure 35). Multiple scans of the piazza were taken to capture all sides of the vessels. Targets placed on the scan objects can aid in the alignment process; in the case of this project, white spheres were placed on the vessels to help match up scan iterations in the software.

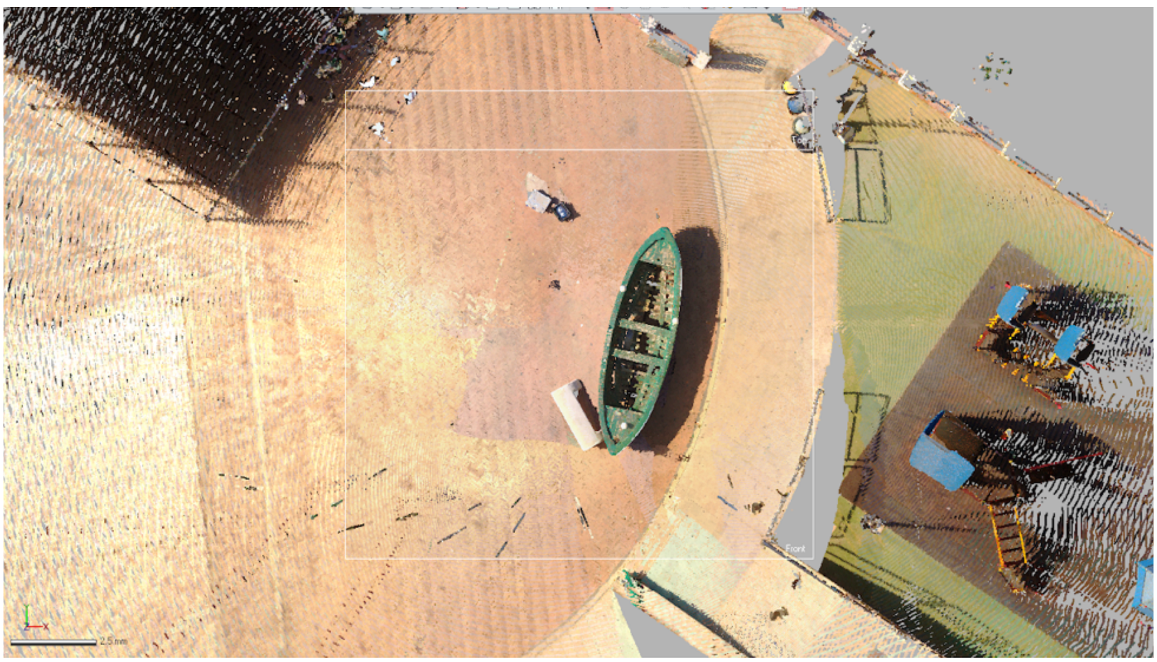

Figure 35: Several laser scans were combined to produce this image. Note the three white spheres on the vessel used to align different scans. © Claire Zak 2020.

The same considerations of data collection and processing that are taken into account during photogrammetry must be repeated during the PTM methodology. Laser scanning is also subject to weather complications, both lighting and precipitation. Both the quality of the laser scan data and photogrammetric models play a role in the quality of PTM. While the method enhances the desirable features of each model, it cannot correct bad data.

One of the drawbacks to laser scanning is the expense, which is much steeper than photogrammetry. The PTM process also requires multiple software platforms, which could be an issue for smaller projects with tight budgets. Some open source platforms such as *Cloud Compare* can be used in exchange for expensive licenses, though the cost of a laser scanner purchase or rental cannot be avoided when utilizing PTM.

A major benefit is that laser scan data is automatically scaled within a software platform due to global positioning during the scan process.[163] This information is retained with the data during processing. If the photogrammetric model is not properly scaled, aligning it with the laser scan model will correct the scaling, solving this problem. The PTM modeling method results in the most accurate dimensional data along with of a high resolution texture. The quality of these models is ideal for the high precision measurements and analysis requirements for academic study.

The software necessary to process laser scan data is less intuitive than *Metashape*, though the workflow is comparable. Though the initial input to align the laser scans is considerable, the subsequent mesh and model processing were completed

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[163] Abdel-Bary 2015, 323; Lillesand et al. 2015, 472. Lillesand et al. discuss LiDAR acquisition, which uses laser pulses and GPS on an aerial platform in a similar way that a laser scanner collects data.

in only a few hours. The overall accuracy of the model hinges largely on the manual alignment of the photogrammetric model to the laser scan one in *Rhinoceros 6*.

Despite large upfront costs both for technology and labor, the PTM method is well worth the effort. In fact, the actual data collection process is quite speedy relative to photogrammetry. Some of the costs can be reduced by renting equipment or using open source software. Laser scanning is compatible with various software programs, such as *Cloud Compare*, an open source software that can align laser scan and photogrammetry models. *RealityCapture*, while more expensive than *Metashape* and *Rhinoceros 6*, can also accomplish this in significantly less time.[164] Regardless of what software is used, PTM undoubtedly produces the best geometric detailed models with high accuracy and resolution, features that are indispensable for archaeological and conservation analysis.

Analysis of Curve Sections in Rhinoceros

Using *Rhinoceros 6* to display hull curves is an easy way to visualize volumetrics and elucidate construction features. The program has the ready ability to work with files from other software packages. *Rhinoceros 6* is often used as an in-between platform, as demonstrated in the PTM methodology, where models can be adjusted in scale or combined with other model files.[165] In order to demonstrate the utility of the process, the results of the curve sections for the models are shown in Figure 36, 37, and 38. The

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[164] Rebekah Luza, 2021, Personal Communications. The Analytical Laboratory at Texas A&M purchased a license for *RealityCapture* for $3770 USD for two years. Compare to a perpetual *Metashape* Professional license at $3499 USD and Rhinoceros 7 license at $195 USD.

[165] *Rhinoceros 6* features a “layer” concept similar to *Photoshop* where data can be locked, displayed, or hidden during the manipulation process.

section lines in *Rhinoceros 6* are only preliminary, meant to guide the researcher as they produce more detailed and accurate ship's lines, depicted in Figures 39.

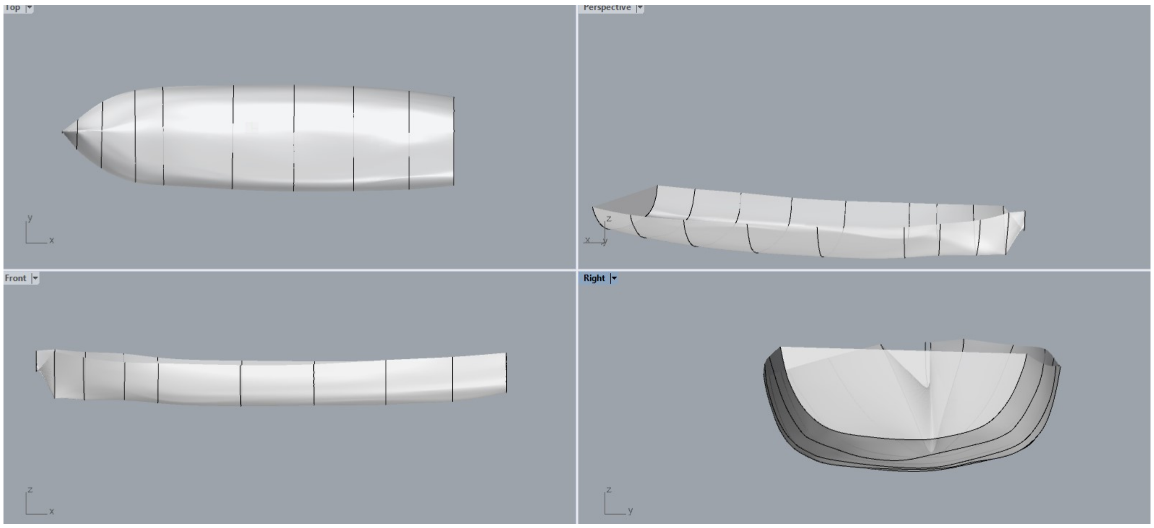

Figure 36: *Rhinoceros* model of *Sciere*. © Claire Zak 2021.

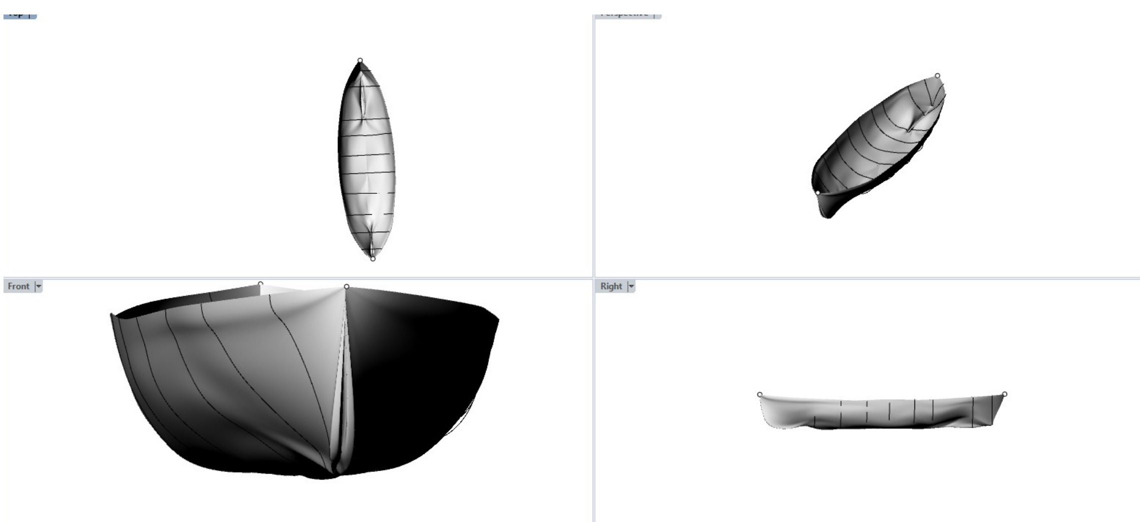

Figure 37: *Rhinoceros* model of *Muggiara 1*. © Claire Zak 2021.

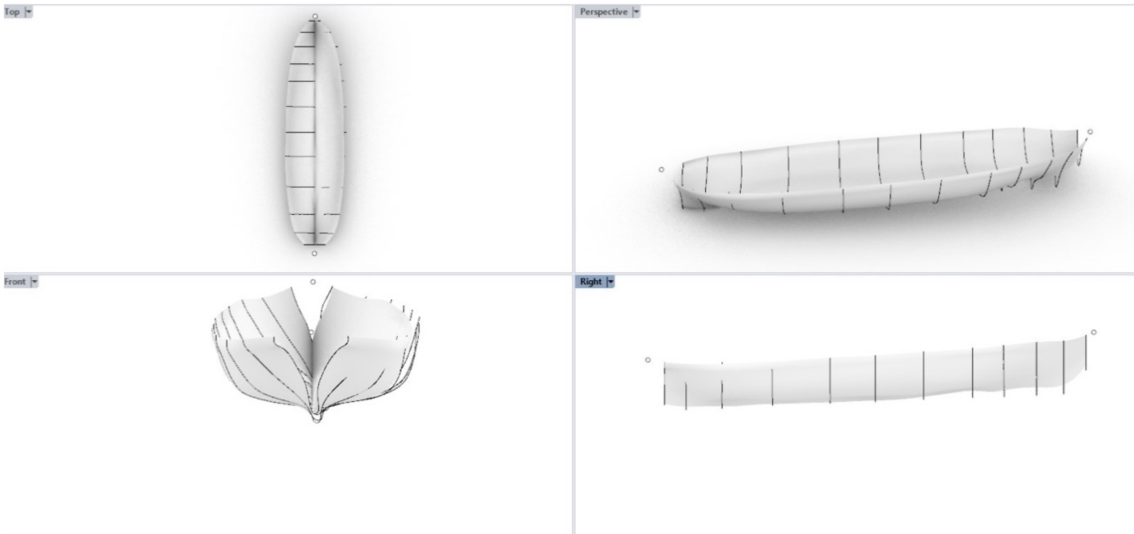

Figure 38: *Rhinoceros* model of *Muggiara 2*. © Claire Zak 2021.

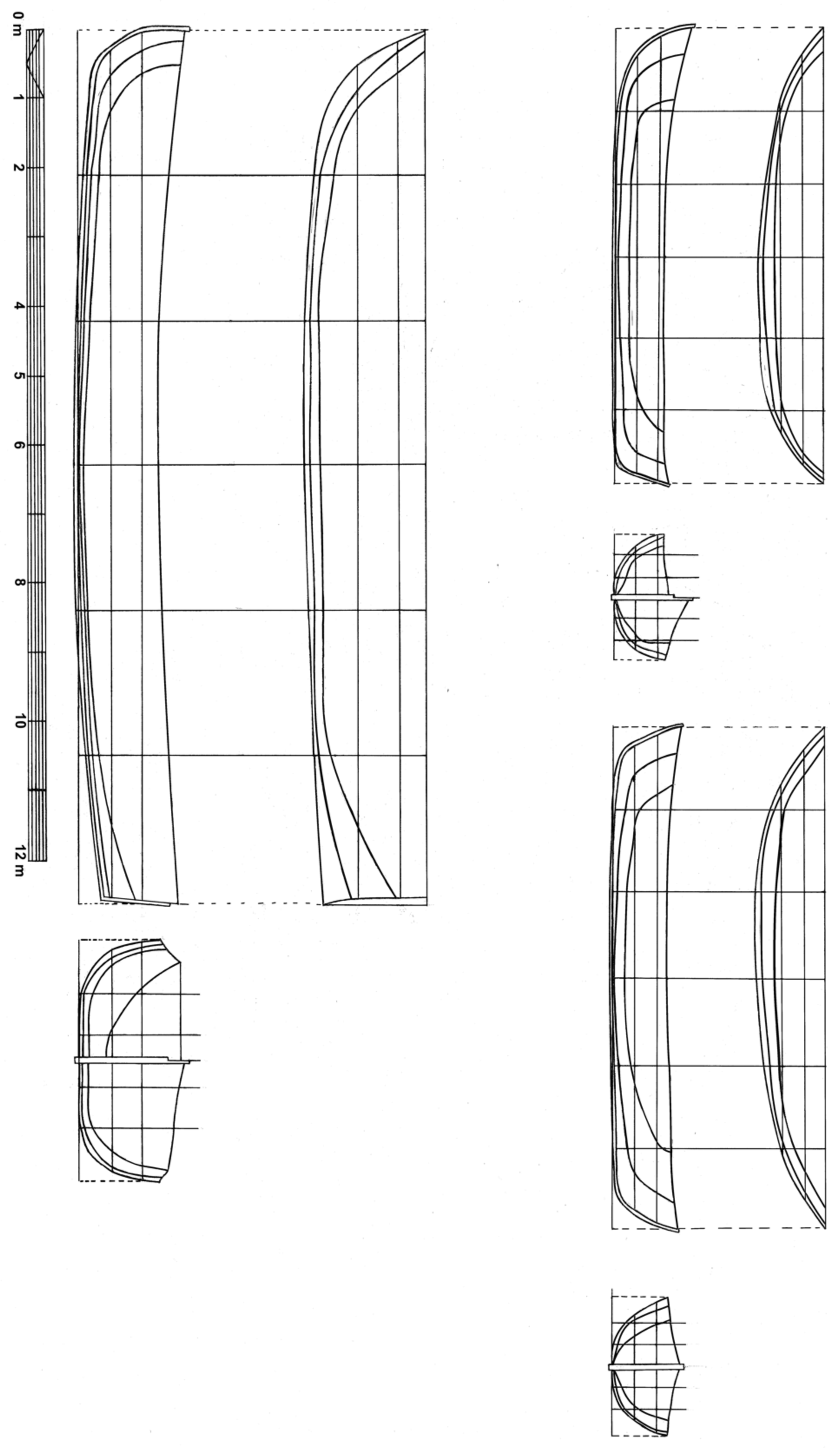

Figure 39: Ship's Lines of *Sciere* (bottom), *Muggiara 1* (top left), *Muggiara 2* (top right). © Claire Zak 2021.

A fundamental concern is that *Rhinoceros 6* is not an intuitive program to utilize and requires tutorial instruction. It takes some time to become accustomed to visualizing the model within a 3D space and manipulating the object accordingly. Once this hurdle is overcome, archaeologists can direct the software to modify models for shape and feature analysis. A few criteria must be recognized for this process. First off, the section curves produced will not be an exact representation of the actual hull but rather a simplified version. The goal is to demonstrate the general shape of the hull. Additionally, the hull is assumed to be symmetrical when using the section curves methodology, similar to assumptions made during traditional line's drawings. The displayed scale is defined by the input model.

A key strength of using *Rhinoceros 6* for hull analysis is the affordability and compatibility of the program. While the curves are simplified in some respects, the base model is still the high-accuracy laser scanned or photogrammetric model, ensuring that the information gleaned from the *Rhinoceros 6* model remains reliable. This digital rendering of the vessel's volume was used to great effect while drafting the ship's lines.

Analysis of Orthophotography

Orthophotographs are frequently employed in aerial survey and underwater archaeology applications.[166] Typically the photographs necessary to create the orthomosaic are taken from an aerial platform and used to combine the photorealistic

[166] Lillesand et al. 2015, 148; Vasilijevic et al. 2015, 5; Green 2019, 39; Semaan and Salama 2019, 76; Radić Rossi et al. 2019, 50.

detail of a photograph with the informational elements of a topographic map.[167] Since the same software used for photogrammetry is used to also generate orthophotographs, time and cost are reduced. Though some error is present due to insufficient data collection, the results of orthophotography for the models are presented in Figure 40, 41, 42.

Figure 40: Orthophotograph of Sciere. Image by the author, 2021. © Claire Zak 2021.

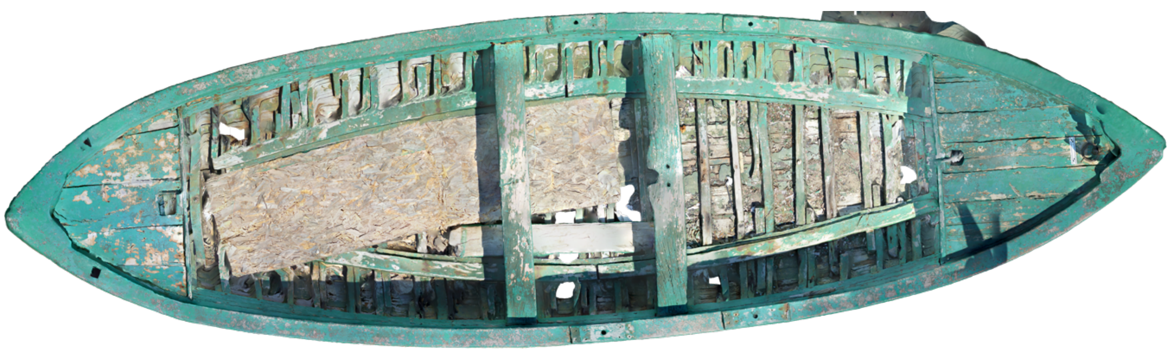

Figure 41: Orthophotograph of *Muggiara 1*. Image by the author, 2021. © Claire Zak 2021.

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[167] Lillesand et al. 2015, 148-9.

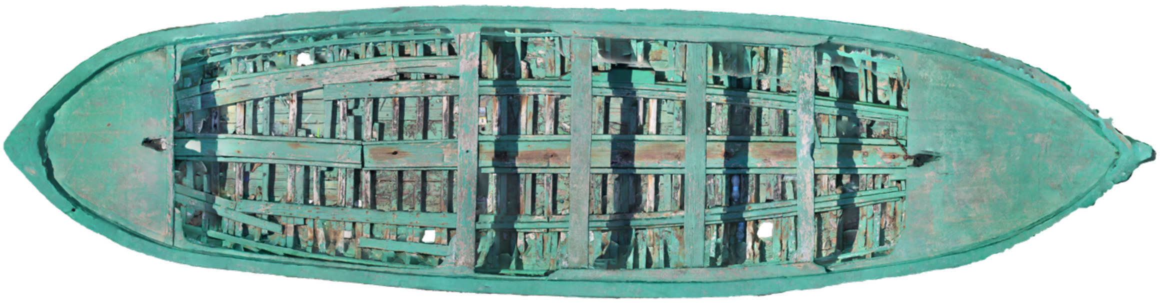

Figure 42: Orthophotograph of *Muggiara 2*. Image by the author, 2021. © Claire Zak 2021.

For the *Sciere* model with ten GCPs and 489 photographs, the production of the DEM and orthophotograph took nearly eight hours of processing time without time factored in for correcting geometric error. The time and effort needed to produce such a model is considerable. In this situation, since the original photograph collection was meant to produce a 3D model and not an orthomosaic, the angles of most of the photos made producing an orthophotograph slightly complicated. Most of the photographs were taken at oblique angles from the object with few images captured from above, which produced some error in the resulting model (Figure 43). This could be easily corrected by intentionally taking photographs from above the vessels, perhaps using a drone.

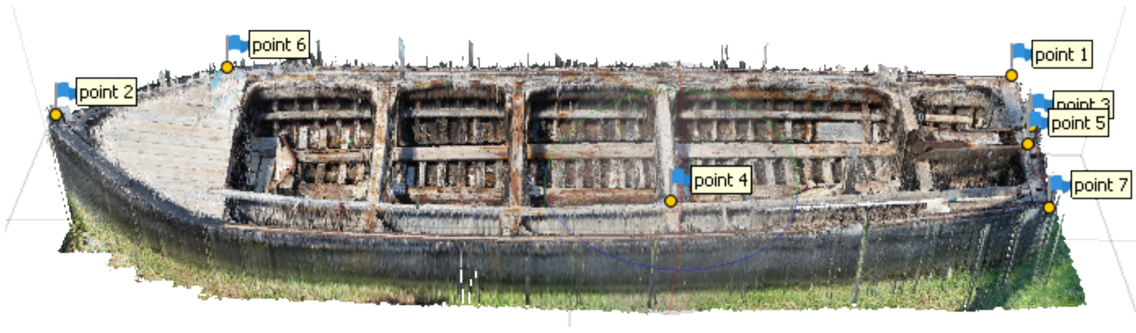

Figure 43: The orthographic model of the Sciere, seen from an angle to discern error from data collection. Image by the author, 2021. © Claire Zak 2021.

Continuing to be a staple on nautical archaeology projects, an orthophotograph displays 3D landscapes in a 2D format that communicates detailed information without relief displacement and scale distortion. Orthophotographs are useful in constructing construction plans and section lines of the hull.[168] In the case of archaeological sites, the features in an orthophotograph can be traced to create a site plan. Once the scale established, measurements can be taken directly from the model. They can also contain georeferencing data, which can be used in Geographic Information Systems (GIS) applications.[169] Georeferencing is a process of assigning a position within a space, which is relevant to GIS programs, which have the ability to link other types of data, such as demographics, sediment composition, and ground cover, to a georeferenced location. In fact, orthophotographs are often used as GIS backgrounds for additional layers of data

[168] Green 2019, 39; Semaan and Salama 2019, 76; Radić Rossi et al. 2019, 50; Vasilijevic et al. 2015, 5.
[169] Lillesand et al. 2015, 146; Radić Rossi et al. 2019, 56.

since the information is so compatible.[170] The orthophotographic process is manageable and overlaps with steps taken in photogrammetry.

Discussion

Recording data is one of the most important steps in an archaeological project. When the site is located in a different geographical area than the research base and collaborators are located in different countries, it is especially imperative to share data in a user friendly and accurate format. Due to the surge in 3D technological development in the 21st century, digital recording and modeling has become a viable way of capturing and displaying archaeological objects.[171] These 3D technologies, such as photogrammetry and orthophotography have been modified and improved to record larger objects such as boats and ships.[172] Implications for this technology expands beyond archaeological recording and has use in cross-global collaborative research and museum applications.[173] An impactful way to communicate ideas about the importance of cultural heritage and preservation involves showing the public audience tangible examples. Digital 3D models can provide an interactive exhibit for museum visitors to handle, experience, and appreciate artifacts located either within the community or thousands of miles away.

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[170] Lillesand et al. 2015, 146, 200.
[171] Frischer and Dakouri-Hild 2008 is one of the many examples of discussions of 3D digital technologies and their uses in archaeology.
[172] Yamafune 2016; McCarthy et al. 2019.
[173] Repola et al. 2017. The MMHP has strong connections between American, Canadian, and Italian scholars and the Sicilian Ministry of Culture that demonstrate one example of the potential for global collaborations while using 3D digital recording technologies.

Still, despite the advancements in technology, the benefits and drawbacks of each method should be considered before a recording method is chosen for a particular object. The strengths of digital recording include the ease of sharing, the high accuracy of the models, and the ability to disseminate the data to multiple audiences from scholars to museum visitors. The weaknesses are that 3D modeling requires expensive software and hardware to process the data, and the method are time consuming.

Each method discussed has its own pros and cons that need to be weighed before using a technology. Photogrammetry requires good weather and indirect sunlight for best color capture and photograph overlap is imperative to forming a complete model without holes. In the case of this project, the nature of the display for these boats produced large unavoidable gaps at the bottom of the vessel since it was impossible to capture the undersides of the hulls (Figure 44). Regardless, photogrammetry is a rather uncomplicated process which can be completed rather easily with the workflow functions of *Metashape*.

Figure 44: Since the vessels are positioned low to the ground, it is impossible to capture the underside of the hull, producing a gap in the model. Image by the author, 2020. © Claire Zak 2020.

For PTM it is necessary to have multiple software program platforms to process the model in a series of steps and file compatibility of the laser scanned data with the processing software might be a concern. The results of PTM are far more aesthetically pleasing and scientifically accurate than that of photogrammetry models.[174] PTM models feature both a high level of detail and high-definition geometric data. The laser scanned data are already scaled, unlike the photogrammetric models, which must be scaled by hand in the software. Once the photogrammetric mesh is aligned to the laser scan mesh, the resulting model remains properly scaled.

Hull curves are integral in communicating the shape and nature of a vessel. From the section curves produced in *Rhinoceros 6*, a natural subsequent step is the drafting of body, sheer, and half-breadth hull lines in a traditional 2D format. Despite the beginning learning curve, *Rhinoceros 6* allows for the manipulation of digital models in 3D, which were used as a guide for drafting. In addition to the affordability of this software, this program is friendly with other software packages and files can be easily transferred.

Finally, to generate an orthophotograph from a photogrammetric model, 10 – 15 GCPs must be chosen to georeference the model.[175] These GCPs must be manually aligned in each relevant photograph, which can be tiresome and time consuming for sizeable chunks of photographs.[176] An orthophotograph is useful for specific research questions which require a DEM such as a site plan.

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[174] Dostal and Yamafune 2018, 434-6.
[175] Agisoft LLC 2021, 9.
[176] Agisoft LLC 2021, 65, 73.

Communicating cultural heritage in a digital format is a versatile way to accomplish goals of preservation, scholarship, and collaboration. Digital modeling records the state of an object at a particular moment in time, with high levels of detail and accuracy. 3D models have a significant role in the expansion of learning since their reliability allows for scientific analysis directly from these digital models. Computer-based models are easily shared amongst colleagues, which is especially relevant in our globalized community. Scholars from different parts of the world can simultaneously work with data related to an archaeological object without having to travel to the site. This increases cooperation between universities, project teams, and countries. Archaeological scholarship greatly benefits from the sharing of knowledge and collaboration between colleagues.

CHAPTER V

CONCLUSIONS

Traditional Sicilian tuna fishing that culminated in a ritual-killing of tuna fish known as *la mattanza* prospered from the medieval times up until the end of the 20th century. In more recent years, the number of tuna fish in the Mediterranean has dropped significantly while commercial fishing has increased, forcing the stall in traditional *mattanza* fishing. The boats that facilitated such traditions are integral to understanding such an important aspect of Sicily's economic, cultural, and social past. Three boats at Portopalo were digitally recorded by Zak, Dostal, Repola, and Hoffer using photography and laser scanning during the summer of 2019. These data sets were further processed to generate photogrammetric, PTM, hull curves, and orthophotographic models. This thesis serves not only as an evaluation of these digital conservation methods for the preservation of cultural heritage, but is also the preliminary conservation report for the three *mattanza* vessels. The MMHP team continues to digitally reconstruct and analyze the boats prior to their conservation. The study of this aspect of Sicilian history ultimately allows the MMHP to discuss the socio-cultural history of southern Sicily's coastal towns.

It has already been established that the most crucial part of the archaeological process is recording and documenting information about the status of the object in question. The use of digital modeling technologies in archaeological recording has increased drastically in the past 15 years due to the advancement in 3D technologies. As the methods continue to develop, it is important to evaluate which methodology, scanning platform, and software program will be the most effective for a specific project. Additionally, file size and compatibility, cost of software, and the necessary processing speeds and power must be factored into the decision-making process. Since these *mattanza* models are the basis of academic analysis and conservation evaluation, it is imperative that the models be accurate, detailed, and easily transferable. The comparison of these methodologies recommends that PTM be used to conduct further conservation analysis due to its high geometric precision. However, photogrammetry offers a suitable alternative as a quick, cost effective, and straightforward means of modeling.

Digital preservation and conservation research has benefited through the use of high-precision 3D models of artifacts and sites. The plethora of digital recording options available to researchers have greatly empowered collaborations between archaeologists. The future implications of these resources appear to encourage even more cross-cultural research projects, which will increase archaeological knowledge and the preservation of cultural heritage resources.

Recommendations for Digital Preservation

It should be reiterated that digital recording should only follow an assessment of several considerations related to data collection, software platforms, and the purpose of research. Data collection methodology is just as important as model processing. If field time is limited or if the researcher will not have continued access to the object, a plan must be instated to ensure efficient and optimal data collection. The researcher should also contemplate ideal weather considerations and potential obstacles. For photogrammetry and laser scanning, it is best to collect photographs on a cloudy day or under indirect sunlight. Passersby and immovable objects may present complications for data collection. Enlisting volunteers to talk to curious onlookers will not only raise awareness for the project but will prevent compromising the source data.

When choosing a software program for digital model processing, costs, compatibility, and file size are chief concerns. Updated computer technology and fast processing speeds often reduces the time necessary to generate 3D models. The cost of software licenses can sometimes be inhibitive, which is why open-source software should always be considered for the task at hand. Programs that are able to work with and produce different file types allows for greater ease of sharing and reduces cost.[177] File size becomes an issue when transferring files between computers and colleagues so a plan must be in place for file sharing and storage.

Photogrammetry and PTM methodologies offer opportunities for optimal digital modeling, balancing resolution, costs, processing time, and accessibility. PTM exhibits the higher resolution and geometric accuracy compared to photogrammetry but requires a more complicated workflow and processing time. Photogrammetry is relatively straightforward for data collection and processing, though *Metashape* is an expensive software package. Without educational discounts, *Design X* is less expensive than *Metashape* and is able to work with a number of different file types.[178] The quality of

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[177] Dostal 2017, 86. Dostal briefly discusses file incompatibility between programs and some solutions. Small projects with tight budgets might benefit from purchasing one or two software packages that are able to accomplish many tasks.
[178] Rebekah Luza, Personal Communications, 2021. The Analytical Laboratory at Texas A&M purchased five licenses of Geomagic's Design X for $5400 USD at $1080 each. Compare to *Metashape* Professional licenses at $3499 USD. However, with an educational discount, a *Metashape* license costs $550.

both model types offers and academic level of study and is aesthetically pleasing to the viewer. The author recommends that the PTM process be employed for digital preservation projects but recognizes photogrammetry as a more than acceptable alternative.

Further Research and Recommendations for Conservation

The preliminary work of this project inspires implications for compounding research. Digital recording technologies are rapidly developing and expanding, offering exciting avenues to pursue further analysis. The digital reconstructions can be used for additional recording and analysis, and perhaps the laser scanning of individual timbers. Since the ultimate goal of the MMHP is to preserve these vessels in an accessible manner, a conservation plan and strategy for museum conservation should be developed.

Any archaeological conservation project must begin with a written report detailing the timeline, proposed treatments, and post-conservation plans. It is important to document pre-treatment conditions in order to compare the effectiveness of treatments. The digital models can serve as this documentation and also aid in determining what treatments are necessary and how long they might take.

If the researchers of MMHP determine that the ships need to be disassembled for conservation, laser scanning of the disarticulated timbers could be employed for an even more thorough documentation. Similar research methodology is being conducted for the individual scanning of ships' timbers at the Alexandria ships project.[179] CMM arms with

[179] Dostal 2017, especially 29-85.

laser scan attachments used to record minute detail items such as construction marks, fasteners, and feature degradation. The laser scans are then uploaded in software that allows for the digital reconstruction of the vessel from the individual scans.

The entire *mattanza* project would greatly benefit from direct ethnography from those that participated in the Sicilian tuna fishing industry. Anthropologists and archaeologists can learn insightful information by talking to the *mattanza* fishermen, their family members, and those who worked in the *tonnare* factories. While the cultural remains of the tradition and industry are disappearing, the true loss of cultural information will happen when the generation of workers are no longer around to tell their story.

Communication of archaeological evidence through the engagement of non-specialists is beneficial for the continued success of academic pursuits. As academics, it is vital to maintain a relationship with the local community and constituents. This often takes the form of outreach events and museum curation. The MMHP is fortunate to already possess a museum and laboratory space that is operated in conjunction with the Sicilian Ministry of Culture and the government of Marzamemi. Display of the team's projects allows both community members and visitors to visualize the scope of the MMHP mission to research entirety local maritime history.

The MMHP already has experience engaging with Marzamemi and Portopalo's citizens through open-air exhibit events discussed in Chapter II. Collaboration with Italian colleagues have generated ideas for further development of the museum space to accommodate an immerse experience of an underwater shipwreck environment.[180] Similar curation might include the *mattanza* vessels and digital models. The *scieri* located in the Marzamemi *tonnara* could be relocated to a more-visible and publicly-accessible location in town or at the MMHP museum. If the boats cannot be moved to the museum, digital models will serve as replacements. Visitors can engage with the digital models while also learning about the importance of cultural heritage stewardship.

[180] Repola et al. 2017.

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