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Visual Computing for Cultural Heritage

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Visual Computing for Cultural Heritage

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Preface

Cultural heritage is a priceless, non-renewable resource, which constitutes one of the core elements of peoples' identities. As such, the preservation, archival, comprehension, and study of cultural heritage is of utmost significance at local, national, and international levels and a key to the deeper understanding of our contemporary cultural and societal context. The advent of affordable imaging devices combined with the technological advancements in terms of computing and storage capabilities has contributed to the soaring interest of the broader scientific community of visual computing in cultural heritage. In the last decades, visual computing researchers have contributed a growing set of tools for cultural heritage, thereby offering valuable support to the preservation and promotion of cultural heritage. This interest has in turn uncovered a new series of research challenges to be addressed by the community.

Visual computing encompasses all computer science disciplines dealing with digital images and 3D models. In fact, image and video processing, computer vision and photogrammetry, 3D modeling, computer graphics, virtual and augmented reality technologies are nowadays widely employed to capture, analyze, conserve, virtually or physically restore, document, classify, recognize, and render cultural artifacts. These include historic buildings and monuments, archaeological sites and finds, artworks such as paintings, sculptures, etc., manuscripts, photograph, films, and other entities of artistic, historical, or archaeological importance.

The aim of this edited volume is to provide a point of reference for the latest advancements in the different fields of visual computing applied in Digital Cultural Heritage research, covering a broad range from visual data acquisition, classification, analysis and synthesis, 3D modeling and reconstruction, to new forms of interactive presentation, visualization and immersive experience provision via VR/AR, serious games, and digital storytelling. This book brings together and targets researchers, professionals, and students from the domains of computing, engineering, archaeology, and arts, and aims at underscoring the potential for cross-fertilization and collaboration among these communities.

In particular, the book reviews comprehensively the key recent research into visual computing for both tangible and intangible cultural heritage. It goes into details to explain how to make use of visual computing for both tangible and intangible cultural heritage. To illustrate the capabilities as well as the limitations of digital heritage technologies, the book provides a number of case studies.

The chapters of this book are organized in six main parts: Computer Graphics, Computer Vision and Photogrammetry, Extended Reality, Serious Games, Storytelling, and Preservation and Reconstruction.

In terms of computer graphics and visualization, three chapters illustrate ways that computer graphics and visualization can be leveraged to showcase cultural heritage assets and delve into the past. In respect to computer vision and photogrammetry methods are provided to interpret, represent, classify, summarize, and comprehend cultural heritage content. AR, VR, games, and storytelling demonstrate innovative examples of accessing and interacting with cultural assets. Finally, in terms of preservation and reconstruction, different approaches are presented showcasing the effectiveness of the techniques in both tangible and intangible cultural heritage.

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Part I
Computer Graphics

Chapter 1
Computer Graphics for Archaeology

Filipe Castro and Christopher Dostal

Abstract Archaeologists reconstruct past human activity from material culture remains. Recording, representing and reconstructing artifacts or contexts is a long, morose, and often expensive process. Computers have radically changed traditional methodologies and are creating opportunities to develop more eloquent images or graphic files that convey compressed information and engage the public in a more participative way. Archeological reconstructions are thinking tools that allow us to reason better and faster about our past and present, and computer graphics can replace the traditional long texts and orthographic images with a rich learning environment that transforms the learning experience into an active and critical mental process. This chapter analyses the current methodologies and evaluates the cost-benefits of the best off-the-shelf software packages and their potential to improve the recording, representing, reconstructing, and sharing archaeological contexts and artifacts.

1.1 Introduction

Computers are changing the world fast and radically, and they appear to archaeologists as exceptional tools to increase the social value of archaeology. In the past years we have been repeating the idea, advanced by the American philosopher Daniel Dennett, that certain bits of knowledge—what he calls thinking tools, or apps we upload to our 'necktops'—make us think faster and better (Dennett 2013). There are good reasons to believe that knowledge makes us smarter, and that knowledge about the past is a very important part of who we are. This is one of the most important reasons to preserve the planet's cultural heritage: educated societies are stronger, healthier, happier, and smarter. The social importance of archaeology is undebatable. We exist in a time frame that is impossible to ignore, and we are all interested in our condition. French historian Fernand Braudel explained how cultural change happens at different paces (Braudel 1958) and if we want to better understand who we are, where we come from, where we are going, and what can we know, studying the past

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is a good first step. Preserving, studying, protecting, and curating material remains of past human activity is important to everybody. As archaeologists say: few among us would throw away their family photo albums.

Computers offer a vast array of solutions to capture, archive, preserve, curate, and share our cultural heritage. As life in society becomes more complex, the pace of innovation accelerates, and we are confronted with new moral quandaries, sometimes posed by seemingly trivial developments, like the possibility of sharing one's DNA online. Intellectuals are more than ever called to help society navigate the intricate web of knowledge necessary to sustain our social reality. Economies are irreversibly interconnected worldwide, and their problems require partial solutions, which generate new problems, often unforeseen. Modern society is an organism whose survival depends on a large number of educated people, with a wide range of technical, cultural, historical, and philosophical skills. Few people would be able to survive alone in the present world: all of our artifacts are made through a long chain of skills, working like a functional organism, made of people with different knowledges, and computers are one of the best metaphors for this situation. More than half of the planet's population is connected to the internet, and computers are creating opportunities to transfer knowledge in ways that would be unthinkable only one generation ago.

In this chapter we propose to use two communities of domain experts—in computer science and archaeology—to produce and share narratives of the planet's past, and build into them the possibility to add voices that previously were not considered, such as those of women, minorities, the peoples that were colonized, or invaded, or lost conflicts and found themselves on the wrong side of history.

As already mentioned above, archeology is becoming increasingly important to our understanding of culture change, politics, conflicts, and solutions. As the world becomes smaller and more homogeneous, the diversity of cultures and ways of life that could be found around the planet two generations ago are disappearing, and archaeology is presenting itself as one of the best sources for understanding the thick and rich patterns of culture that characterized each region of the planet. Diversity is becoming a thing of the past, and the old pledge that archaeology should be anthropology or it is nothing is as relevant as ever. But we propose a new pledge in this paper: that archaeology is public or it is nothing. The age of an archaeology almost exclusively for archaeologists is ending. The world needs and wants information about its past and it is no longer possible to sustain an archaeology—preferably paid for with taxpayers' money—that is not based on the full publication of all primary data. Moreover, as illiteracy diminishes worldwide and middle classes grow globally—mostly due to their fast rise in Asia—we expect to witness a rise in the demand for cultural products. Museums, libraries, concerts, movies, documentaries, magazines, and books are an integral part of the lives of middle classes everywhere, and archaeological discoveries are already a frequent theme in the media.

Combined with the rise of a diverse and international middle class, the rise of a more diverse and international body of archaeologists promises to break away with the basic tenets of the traditional Western discipline that characterized the 19th and 20th centuries, and will bring about more diverse narratives of the past, including voices that traditionally were not heard. Archaeology has been largely a European invention, and the growing geographical and cultural diversity in the field promises to offer us different points of view, different narratives, and different interpretations of archaeological data. This trend is increasing the social value of archaeology, making it public, participatory, and incomparably richer than it has ever been.

Computers will certainly play increasingly important roles in this process, and we believe that social media can turn archaeology into a dynamic, public, and exciting discipline, helping specialists to construct and deconstruct new and better narratives, accelerate the iterative process of interpretation of archaeological data, and yield more complete and diverse reconstructions of the planet's common past. Our perception of who we are is built on memories and amnesias, more often than not based on narratives developed by the winners in the historical process, the conquerors, the upper classes, religious leaders, or majorities. Archaeology can give a voice to the people without history, those whose voices were never heard, or recorded in historical documents.

Computers and social media are excellent vectors for the diffusion of new ideas. New ideas can of course be good or bad, accurate or fabricated, and enlighten us or fuel conspiracy theories. Like it always happens with all forms of communication, it is up to us to build the trust of the public, make our points clearly and eloquently, and stand corrected when we find out that we were wrong on any issue. There are also opportunities for computer science to help develop a reliable online peer-review processes, and perhaps even resolve some of the problems of structural injustice or asymmetry posed by gate keepers' networks in the peer-review journal business, but these are not within the scope of this paper.

As maritime archaeologists, we present here a particular set of relatively simple applications for maritime archaeology—applicable to any other sub-disciplines of archaeology—and propose a methodology to simplify and standardize the description of ship's hull remains.

1.2 Maritime Archaeology

It is difficult to find a person on the planet that is not interested in ships and boats, the history of seafaring, maritime travels and adventures, migrations, shipwrecks, piracy, or any other subject connected to seafaring. Ships are fascinating artifacts, and maritime archaeology is concerned with their conception, construction, and handling. Maritime archaeologists study maritime communities and their artifacts, including boats and ships. The range of emotions and thoughts that ships and boats evoke is vast and exciting. There is something poetic about ships, either sailing on a landscape, against the margins of a lake or a river, or a coast, or sailing on the sea, an immense desert that covers a large part of the planet.

This dichotomy between the ships that sail against a landscape, and those that cross the oceans was best described by Barthes (1957), who saw ships simultaneously as a mobile environment from which one could perceive the amazing diversity of the world—inspired by Rimbaud's poem "Drunken Boat"—and as a safe, closed environment that protect human life from the dangers and the isolation of the sea, as in Jules Verne's Captain Nemo and his submarine *Nautilus*.

As Barthes puts it, "The image of the ship, so important in his mythology, in no way contradicts this. Quite the contrary: the ship may well be a symbol for departure; it is, at a deeper level, the emblem of closure. An inclination for ships always means the joy of perfectly enclosing oneself, of having at hand the greatest possible number of objects, and having at one's disposal an absolutely finite space. To like ships is first and foremost to like a house, a superlative one since it is unremittingly closed, and not at all vague sailings into the unknown: a ship is a habitat before being a means of transport. And sure enough, all the ships in Jules Verne are perfect cubby-holes, and the vastness of their circumnavigation further increases the bliss of their closure, the perfection of their inner humanity. The *Nautilus*, in this regard, is the most desirable of all caves: the enjoyment of being enclosed reaches its paroxysm when, from the bosom of this unbroken inwardness, it is possible to watch, through a large window-pane, the outside vagueness of the waters, and thus define, in a single act, the inside by means of its opposite."

Conrad (1897) called ocean-going ships "dark and wandering places of the earth." As so many other authors, Conrad was fascinated with the culture of the ship's crews. He wrote: "Old Singleton, the oldest able seaman in the ship, sat apart on the deck right under the lamps, stripped to the waist, tattooed like a cannibal chief all over his powerful chest and enormous biceps. (…) He was intensely absorbed, and, as he turned the pages an expression of grave surprise would pass over his rugged features. He was reading 'Pelham.' The popularity of Bulwer Lytton in the forecastles of Southern-going ships is a wonderful and bizarre phenomenon. What ideas do his polished and so curiously insincere sentences awaken in the simple minds of the big children who people those dark and wandering places of the earth?"

Another example of ship's wide interest in cultural studies is that of Foucault (1984), who wrote that "the boat is a floating piece of space, a place without a place, that exists by itself, that is closed in on itself and at the same time is given over to the infinity of the sea and that, from port to port, from tack to tack, from brothel to brothel, it goes as far as the colonies in search of the most precious treasures they conceal in their gardens, you will understand why the boat has not only been for our civilization, from the sixteenth century until the present, the great instrument of economic development, but has been simultaneously the greatest reserve of the imagination. The ship is the heterotopia *par excellence*. In civilizations without boats, dreams dry up, espionage takes the place of adventure, and the police take the place of pirates."

There are endless literary examples of the importance of ships and boats in our imaginary. George Bass used to remind us that "long before there were farmers, there were sailors." Our relationship with the sea and other bodies of water runs deep in our veins and has inspired many artists and intellectuals. An important part of maritime archaeologists' work is, however, to patiently and tirelessly describe and classify all known types of ships and boats, to understand how they were conceived and put together, handled and lost. To understand Conrad's "dark, wondering places" and Rimbaud's "drunken boats" we need to approach each archaeological site with a solid methodology to record and interpret every piece of information, starting by the artifact itself, which is one of the most complex artifacts produced by our species.

As land archaeologists proposed for vernacular architecture, ships can be analyzed from four different viewpoints: as objects (*object-oriented*), as part of the life of a society (*socially-oriented*), as products of a particular culture (*culturally-oriented*), or as objects that have symbolic meanings for the peoples that use them, interact with them, or see them (*symbolic-oriented*) (Upton 1983).

Our first, basic approach to the study of ships or boats is generally *object-oriented*, concerned with the ships as artifacts. In this case we want to know when were these ships built, how they were built, by whom, if they suffered changes during their existence, or why. We look at each vessel as a particular artifact that is the product of a long and diverse list of factors—some serendipitous—which go from where did the knowledge to build them reside to the price and availability of materials, to the specificities of the function each one was designed to fulfil, to the taste of the shipwright and the beliefs and fashions of the people for which it was built. More technical and perhaps more specialized, this approach is intimately connected to the history of technology and is based on detailed descriptions of the hull remains under study. Archaeologists must measure and describe each vessel as if they were going to be destroyed forever. Capturing the curves that define a hull shape is one of the goals of this approach. It is paramount to understand how each type was conceived of and built, what ranges of sizes were considered, how the space was distributed, occupied, transformed, and when possible, what the characteristics were that defined a particular type in a particular period and region (e.g. caravels, cogs, galleons). The other goal is to describe the ship's structure in detail, registering the ship's construction sequence and recording each timber, its scarves, fasteners, tool marks, coatings and paints, and carpenter marks. As we will show, computers have considerably simplified these tasks and set much higher standards for archaeologists: as tools become more accurate, the demand for operator's precision increases.

The second way to look at these ships, as *socially-oriented* objects, takes them as "a part of everyday existence and […] as evidence for aspects of the past that can be known imperfectly from other kinds of evidence" (Upton 1983). As social objects vessels are considered artifacts, and though the technical characteristics of the ship like size and shape are important, they are important from the viewpoint of how these characteristics impacted the social use of the vessel. Depending on their sizes and functions, archaeologists try to understand how the spaces were used and by whom, when, and for what purposes. Social stratification, gender, labor specializations, and function defined the shape and content of each ship or boat, its decorations, equipment, and sturdiness. The occupants of a ship can be first divided between crew and passengers, and then hierarchies, generally separated for each of the groups. For instance, throughout the early modern period in the Western World, ocean-going ships were spaces where social mobility was accepted with naturality. In the Spanish New World routes it was normal for apprentices to become sailors and later, if they were competent, masters or even pilots. In the 15th-century Venetian galley trade a rower could rise to much higher positions. The unwritten rules regulating social mobility, freedom of association, and acquisition of knowledge or working experience, to cite only a few, applied to crews, passengers, and everybody on the shore, effectively all of the inhabitants of the maritime communities and landscapes where ships were built, sailed, and lost. Anthropologists are interested in understanding culture change. As Braudel (1958) wrote, social change happens at different speeds and influences our lives in different ways, and ships are excellent subjects of study, for they reflect changes in social organization, subsistence modes, division of labor, fashion, and the history of the ideas.

The third approach, *culturally-oriented*, looks at construction features (*memes*) related to the different cultures at play, something that Ole Crumlin-Pedersen called 'cultural fingerprints', and Eric Rieth calls 'architectural signatures' (Crumlin-Petersen 1991; Rieth 1998). Upton (1983) defines culture as "learned behavior that embodies the enduring values and deepest cognitive structures of a social group," and archaeologists look at ship and boat remains as means of retrieving ideas, gestures, practices, and tastes that may allow them to better reconstruct the political, technical, and cultural environment in which they were built. The history of wooden shipbuilding is an important part of the history of technology because ships tend to be rather complex machines. The *culturally-oriented* approach tries to select and systematize the characteristics and solutions of ships and boats that are specific to a particular culture or region, and trace their paths as they cross-pollinate along the shores of the planet. Ships were vectors of culture and technological change because they carried people, merchandises, and ideas. To trace the evolution of shipbuilding and the convergence of shapes, sizes, and design and construction solutions is one of the main concerns of maritime archaeology. It aims at understanding both the material folk culture and the higher-end scientific understanding of the maritime cultures, their theoretical boundaries, and the dynamic processes through which these were reinterpreted, adapted, changed, and evolved from region to region and through time. In this context, archaeologists collect ethnographies, catalog and organize artifacts to understand in which ways they embody local cultures, and describe design and construction solutions, trying to trace the paths through which knowledge travelled and changed. The end-result of this approach is the proposal of models of evolution based on taxonomies and cultural processes by which they change. Linguistics play an important role in these studies, and the collection of vocabulary and elaboration of glossaries are integral to any *culturally-oriented* look at ships, crews, harbors, and routes. Computers are particularly useful in these studies, namely because they are the perfect tools to design databases or ontologies.

The fourth and last approach, *symbolic-oriented*, focuses on decorative and aesthetic elements, as well as the symbolic character of architectural solutions and the images and emotions that ships evoke(d) in peoples' minds (Bachelard 1957). Trying to reconstruct and understand the *meaning* of ships and boats is not an easy task. Ships and boats mean different things to those who design, build, operate, inhabit, or watch them from the shore. The archaeological symbolic approach is concerned with the more pedestrian, functional aspects of the ships, such as how they address the demands and tastes of those who ordered their construction or bought them, and with more personal and complex aspects such as aesthetics. Ships have been portrayed in a variety of ways to evoke different emotions, from delicate lines and landscapes eliciting gentle beauty, to imposing hulls with an imposing armament displayed, projecting military might. Again, Upton guides us through the theoretical definitions of his four approaches, mentioning semiotics—the study of the lives of symbols in our lives—and proposing that ships' formal elements can be recorded as systems of signs with particular meanings to different social groups. Ship's appearances can be obvious in the objective conveyance of power, dignity, elegance, or strength, but they can also trigger subjective feelings through their size, shape, internal division, decoration, rigging, or construction materials (Eriksson 2014).

All four of these approaches—also barely described above—help archaeologists understand each particular vessel studied, and create a narrative that may explain the economic and social role of each vessel type, define what features they have in common, and what variations in shape and size are allowed before it compromises the definition of a particular type in a particular cultural environment. Perhaps more important, these four approaches call for a creative set of informatic tools—based on ontologies—that will allow archaeologists to share their discoveries and separate descriptions from interpretations so that other persons can reinterpret the data and construct and deconstruct new and old narratives.

Before we even look at the social and economic role of a ship, however, there are shapes, scantlings, scarves, connections, fasteners, timber species, tree morphology, construction sequences, geometric aids, and a vast array of other characteristics that we use to describe and classify boats and ships. And that is just one of the ways in which computers come in handy.

In this chapter we propose a methodology to record, store, and publish shipwrecks with hull remains. Although maritime archaeology is over half a century old, there are no generally accepted formats for the recording and publication of shipwreck remains (Castro et al. 2018). We find the increasing use of computers an excellent opportunity to change this situation and propose a series of steps and off-the-shelf software packages to record and publish ship's hull. Even though it is likely that the software packages will change or be replaced, we believe that it is easy and desirable to establish a standardized methodology to record, store, and share the primary data in ways that simplify comparative studies.

1.3 Surveying

The first step we want to address in this chapter is the survey process. The primary goal of a survey is to assess an underwater archaeological site and estimate its area and limits, and the secondary goal is to generate a description of the archaeological context or object. Remote sensing devices have simplified these tasks considerably, and they have made large, previously unreachable areas accessible, such as those below the professional diving depths. Magnetometers, side scan sonars, multi-beam sonars, and sub-bottom profilers are constantly evolving and can be towed behind a boat or deployed in remotely operated and autonomous vehicles (ROVs and AUVs).

Remote sensing has been around for a long time. Devices to measure magnetic fields created by submerged or buried metal masses, and devices to record the shape of the bottom of a body of water with sonar technology have evolved considerably in the past 50 years, together with sub-bottom profiling, which also uses ranges of frequencies to probe differences in rigidity of the sediments and other objects they main contain. The present challenges are related to the coordination and representation of these heterogeneous sources of data, and a good amount of energy is being aimed at synchronizing and representing it.

Filming and photography have also evolved for over a century now and archaeologists have better lenses, better cameras, digital imaging, and constantly evolving software to interpret and reconstruct images, as well as increasingly smaller, cheaper, or more sophisticated remotely operated vehicles (ROVs) to capture images. Unmanned vehicles—autonomous underwater vehicles (AUVs), and autonomous surface vehicles (ASVs)—can be programed to perform all sorts of tasks and return to harbor or to the vessel from which they were deployed with the data acquired. In some cases it is possible to retrieve these data remotely. All the data generated by these vehicles is stored in digital formats and can be represented on a computer screen.

The first step of a publication is a location map and an undisturbed site plan. Traditionally developed on paper with a variety of measurements, offsets, and sketched descriptions, site plans are now more often than not developed from remote sensing data, or from video or photography images, which can be treated with single-image photogrammetry software to produce point clouds or meshes that represent the surface of a site before disturbance. The shift toward digital documentation to produce site plans has resulted in a massive increase in the amount of data accumulated at each stage of documentation. The storage of all these data is a complex problem, and there are no cheap and easy to use software packages that streamline the archaeological site plan development in a way that directly addresses these problems. The first step to even aspire to have such computer capacities is to define the basic chain of processes that form an archaeological survey (Fig. 1.1).

All files generated in each one of these processes need to be stored and assigned metadata with basic information: date, location, keywords. Geographical Information Systems (GIS) are a perfect environment for the storage and synthesis of layered information.

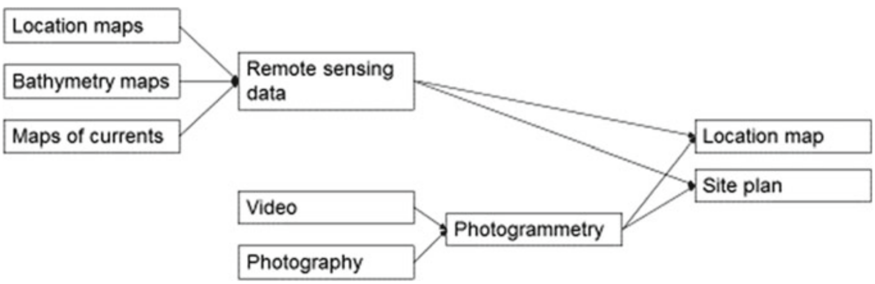

Fig. 1.1 Chain of processes required to produce a location map and a site plan

1.4 Recording

Starting in the 1980s, J. Richard Steffy proposed that computers were the most promising tools for the study of shipbuilding. Comparative studies being the natural way to understand shipbuilding as a particular type of human behavior, he proposed that the first step was inventorying and comparing construction features. Steffy fully understood that this was not an easy project. In 1990 he mentioned the absolute lack of a standard to publish ship hull remains and wrote: “we must admit to an unbridled confusion in the recording and publication of our vessels. Of the forty-four subjects considered for this study, little more than half of them have been reported formally. Of the eighteen categories I chose for comparison, only a few wrecks filled all of the columns, even though the information must have been available on many others. I am not criticizing the way in which anyone documents their shipwrecks, because we have differing priorities and varying opinions about what is and what is not important. But I do think that in the future we must take a clue from the older artifact disciplines and all record the same basic features where they survive” (Steffy 1990).

In a 1994 paper archaeologist Roger Hill proposed a set of development lines for the application of computer technology to archaeology (Hill 1994). He noted that the data are preserved in the ground in different conditions, having been deposited there by a range of dynamic processes, and that time and human activity have made the ground “a database in which an imperfect memory of those processes is retained.” According to Hill, the purpose of archaeological recording “is to transfer the ground-based record system into a form accessible not just to the site archaeologist, but to all potential users.” As we have written elsewhere, the most important part of Hill’s seminal paper is a call to understand that the nature of the output generated by computers is the primary concern in the adoption of computers to record archaeological sites: “the technology used to record the data (…) is central to the activity of archaeology properly considered” (Yamafune et al. 2017). Hill proposed a paradigm change in archaeology by making the possibilities of digital technology the base for a new philosophy “for planning and managing the recovery of the soil database, recording deposited materials,” and modeling the site formation process.

The year after, in 1995, Steffy—following his seminal 1990 paper—wrote a second call for standardization in the study of shipwrecks, and argued that computers were going to change maritime archaeology in a drastic way—noting that archaeology was entering “the computer age, bringing with it expanded possibilities for examining data and analyzing hull structures. More than ever before, we must document our finds more completely to take advantage of this new medium. At the same time, we must reevaluate the ways in which we have been considering our hull remains and take new approaches to these old problems. (…) In the past, theories [about the ways in which shipwrights projected and controlled hull shapes] have ranged from the use of standing control frames to the haphazard assembly of planks, but I am not convinced that any of them are accurate and certainly none of them are complete” (Steffy 1995).

Being an outstanding field archaeologist, Steffy did not mention the recording process of individual components of ship's hull, which he had described and established as a standard in his 1994 book (Steffy 1994). In it, he explained that archaeological recording requires precision and accuracy. The first depends on the tools, and the second on the skill of the archaeologists involved. It is paramount that archaeologists are trained both in archaeological and anthropological methods and theory. Archaeologists typically have only one shot at a site. Excavating is destroying.

Recording is a process that entails therefore two complementing tasks: measuring and describing. Measurements can be taken directly, with tools, or indirectly, with photographs or scaled 3D models, like those produced with computer vision photogrammetry. Photogrammetry has been around since the 19th century, but the recent development of computer software to represent and process digital images has simplified the process and increased the precision of the measurements obtained from a collection of scaled images.

Describing a site requires a different type of knowledge. Archaeologists must know what they are describing and select a number of characteristic measurements that defines each feature or component of an archaeological site.

The excavation process typically entails a cycle of four tasks: digging, cleaning, tagging and recording. All these tasks need to be recorded for each cycle, both through images, measurements, and descriptions, and multi-image photogrammetry provides accurate surfaces of each stage of an excavation. This is an extremely useful tool, because the exposed surfaces of wooden structures often erode during the excavation process, and the software utilized to store and manage the excavation processes will save the fresh surfaces exposed in each excavation cycle. In the Nautical Archaeology Program at Texas A&M University we have been using *Agisoft Metashape* with good results.

Artifacts are traditionally tagged, bagged, and positioned before being lifted, and subsequently entered in a database designed to keep their provenance, main dimensions, images, characteristics, and conservation treatment steps. At A&M we have been using both *FileMaker Pro* and *Microsoft Access* with similarly good results to not only track each artifact through the conservation treatment steps, but to house all metadata for each artifact to streamline study and analysis.

Hull timbers are treated differently. When they can be raised, we scan them with a FARO ScanArm laser scanner to create a point cloud for each individual timber. The ScanArm is a fixed-base coordinate measuring machine (CMM), meaning that as the arm is moved, the position of the scanner relative to the base remains known, which allows for highly accurate data capture. CMM arms can be used with a probe attachment or a laser scanner, the former being a contact measuring device and the latter being a non-contact measuring device. Using the laser scanner instead of a probe attachment means that for each timber, millions of data points are collected, capturing every tool mark, fastener, and wood grain detail. These details are of course captured with manual probing by tracing the details on the surface of the wood with the probe, but the laser scanning captures more detail in substantially less time. Working on a project with the city of Alexandria, VA, two researchers with Texas A&M's Conservation Research Laboratory were able to scan, process, virtually arrange, and 3D print an entire disarticulated vessel (207 timbers, with hull remains approximately 15.6 m long by 2.8 m wide) in six weeks.

Each timber is scanned in sections, with enough overlap between sections to allow for alignment during the processing phase. For ship timbers, the data is collected as a point cloud with an average point spacing of 0.25 mm. This is a higher resolution than is needed for virtual arrangement or 3D printing, but the high resolution is collected to 'future proof' the data; or, perhaps merely to slightly delay its obsolescence. The point clouds for each timber side/section are saved as separate files for maximum redundancy of data, and then later combined into a single, aligned point cloud, that we mesh using *Design X*. With each timber saved as a water-tight mesh, they are then exported as an .stl file, which is a cross-platform, non-proprietary file time that allows the meshes to be used in a wide variety of programs. An additional lower resolution mesh is made from this full-resolution mesh, by 'decimating' the files to <200 MB. The decimating process is essentially lengthening the sides of the polygons that make up the surface of the mesh, which lessens the details visible in the model, but reduces the file size. Often the difference in detail is negligible to the naked eye. The decimated files are then saved as separate .stl files. The 200 MB threshold works both as a way to keep the file sizes manageable by our assembly software, and also to allow us to upload each timber file to the online 3D model hosting site Sketchfab.com, where each file can be made available as a free download to the public to maximize open access to our data. The hull remains are then assembled in *Rhinoceros* and generally 3D printed to a 1:10 or 1:12 scale for preliminary analysis and observation.

For publication purposes we treat the 3D files with rendering software *plug-ins* for *Rhino*ceros like *Penguin*, which allows the development of non-photorealistic drawings, ideal for technical publications. Traditional timber drawings can be produced by using *Rhinoceros* to outline the timbers at each elevation, and then these outlines can be exported to other programs like *AutoCAD* for easy markup and layout. It is increasingly important to ensure that the implementation of rapidly evolving computer programs does not eclipse the past century of recorded archaeological data sets. Though arguably superior data can be obtained by published the digital models, failure to produce data sets that can be directly compared to older methods of documentation make holistic understanding of the archaeological record impossible.

When possible, a set of tentative lines is developed from the surviving hull in *Rhinoceros*. Once the disarticulated timbers are imported and arranged in Rhinoceros, data points are taken on the exterior portion of the framing timbers, where they would meet the exterior planking. The data points collected along the frames can then be connected, forming the basis for a set of ships lines. By connecting the data points along the water lines, station lines, and the buttock lines, a complete set of partial lines can be developed from the 3D model. Once those lines are established, they can be printed on paper and extrapolated using traditional naval architecture drafting techniques to elucidate the original dimensions and shape of the hull. If available, we use coeval iconography, or similar archaeological remains.

Other types of software—such as *AutoDesk Maya* and *SideFX Houdini*—have been used in the treatment and reconstruction of shipwreck hull with impressive results (Figs. 1.2 and 1.3). The problem is that the sophistication of these software packages requires the involvement of domain experts, which are not always available. *AutoDesk Maya* has been used to model shipwreck hulls and explore issues like interior space use because it allows the construction of VR models (Fig. 1.4), which can be used to provide full immersion experiences and acquiring a better understanding of the full-size reconstructions (Wells 2008; Castro et al. 2010; Suarez et al. 2019). *Maya* is also an excellent tool for creating animations and dynamic models that allow for better immersion into the data, though the program is incredibly expensive for non-academics. Other applications associated with the outreach phase of a project will be addressed below.

Houdini is perhaps the most promising package, for its versatility and flexibility. Again, this is not a software package for archaeologists and all projects developed in this environment need a domain expert (Saldaña 2015). We have experimented with *Houdini* to create a procedural model of a lower hull from a typical early modern European merchantman with very promising results (Suarez et al. 2019). The goal of this project was to reduce the large investment of time and expertise that is currently required to create 3D reconstruction models for nautical archaeological research

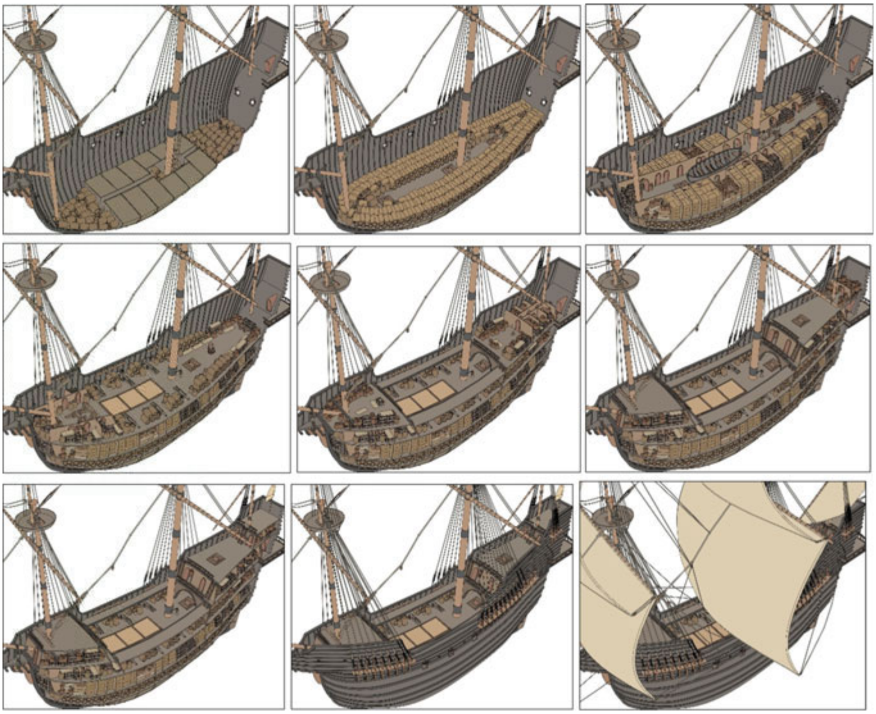

Fig. 1.2 Virtual model of a 17th century Portuguese Indiaman, based on a reconstruction of the Pepper Wreck, 1606 (Wells 2008)

Fig. 1.3 Virtual model of the Audrey Wells reconstruction represented on Fig. 1.2. It can be downloaded from https://texag64.itch.io/nossa-senhora-dos-martires-wreck (Josh Hooton, Jacob Stafford, Cody Leuschner, Thomas Sell, and Bruce Gooch, 2016)

Fig. 1.4 A Bluetooth virtual visit to Audrey Wells' 17th century nau (Troy Edwards, Josh Higginbotham, Humayun Syed, Mitchell Blowey, and Bruce Gooch, 2017)

using typical modeling methods. Our strategy was an approach leveraging computer-based modeling, both parametric- and rule-based. We developed a procedural model of the lower hull of a 16th century European merchant ship through an iterative process of prototype implementation. The resulting model was flexible and versatile, and could be iterated through parametric controls, greatly reducing the traditional change and revision time. The results of this project provided evidence of the time-saving effectiveness of a procedural approach to create 3D models as research tools.

Once procedural models are created, they provide both accessible and powerful means for researchers to create and test multiple interpretations of the archaeological data. Although the development of a procedural model requires skilled computer operators and a significant investment in design, construction, and trouble-shooting, these problems are outweighed by the flexibility the models offer.

The generic hull model developed could be easily changed by changing its parameters, and adapted to the scantlings, shapes, sections, scarves, and connections of a set of timbers from a 16th century ship—designated Belinho 1—that we were recording and studying at the time.

1.5 Sharing

The only purpose of archaeology is to produce knowledge that can be shared and enjoyed by as wide an audience as possible. The best form of archaeology is communal archaeology, which involves the audience from the first steps and strives to include as many stakeholders and as many viewpoints as possible (Hodder 2006, 2013).

In the past archaeologists have not, however, been famous for sharing their data (Bass 2011). In the western world archaeologists do not publish all the sites they excavate (and therefore destroy), and it is difficult to imagine this situation changing, at least as long as we don't change the technological paradigm. In fact, a number of studies suggest that over the last 50 years less than 25% of the materials and results of professional archaeological excavations have been properly published (Boardman 2009), 70% of the Near East excavations have not been published (Atwood 2007; Owen 2009), and that perhaps 80% of all Italian archaeological materials remain unpublished (Stoddart and Malone 2001). It is difficult to argue that the situation in maritime archaeology is better than those mentioned above.

The reasons for this are many, starting with the difficulty of making data available in many different formats, from the diving slates to the daily diving sheets, to the evolving sketches and the notes from the daily excavation debriefings. But the recording process can be organized and streamlined to simplify the excavation and recording process. Like and engineering project, archaeological excavations are organized in consecutive tasks, some of which are repetitive (e.g. digging, cleaning, tagging, photographing, measuring, describing, and sometimes raising), others have preceding activities, and others can be carried out in parallel, at the same time.

Documenting is a responsibility. Archaeologists destroy the sites they dig, and recording every step of the way is an ethical obligation. Interpreting and reconstructing are perhaps the most interesting phases of an archaeological project, but they are often not completed, and many excavations never see the final publication (Bass 2011). The perceived problem of people stealing credit from one archaeologist and publishing it behind there back will always happen, but it is much less frequent than people have assumed in the past. The harsh reality is that even when one puts all their source data freely online, the biggest hurtle to overcome is attracting any attention at all. There are more items online, both academic and not, competing for our attention than ever before. The days of a handful of archaeological projects dominating the public eye are long over. Even the biggest discoveries vanish from the public eye in a matter of days today, because there are so many people learning and sharing so many new things.

We see the implementation of digital data and online file sharing as the antidote to the long-standing practice of hoarding data. Younger generations of archaeologists are far less likely than their mentors to shun the idea of freely sharing data amongst one another. This openness with data may be in part due to the societal erosion of personal privacy over the last several decades; as a society, we have happily traded privacy for convenience. This tradeoff may well have disastrous consequences for personal liberty in the future, but the long-term impact on academic work and intellectual property is proving to be incredibly healthy. Whatever the cause, more and more archaeological data is being freely and openly shared online.

3D model hosting sites such as sketchfab.com have massive collections of archaeological models, and academics, museums, and state agencies are nearly all moving towards a model of sharing digital models of their collections online and encouraging public engagement of their data. With so many new and exciting projects being undertaken around the world, openness and collaboration, combined with effective use of digital data and computer driven organization, are the only effective ways to manage and interpret all the data being collected.

1.6 Reconstructing

The interpretation phase of an archaeological project is arguably the most interesting component and it cannot, by definition, be separated from the measurement and description phase. When excavating, cleaning, tagging, measuring and describing an archaeological site, archaeologists have an idea of what they are representing, and their drawings, measurements, pictures, and descriptions are informed by that idea. No excavation should start without a good idea of its outcomes and deliverables.

The reconstruction phase depends on the amount and quality of the information acquired during excavation. The implementation of digital documentation techniques like laser scanning and photogrammetry allow archaeologists to create ever more informed and convincing interpretations of sites. Computer-aided extrapolation of even the slightest impressions can tease out long lost shape and details that might have otherwise been missed. Statistical analysis of the shapes of certain timbers across many ships can help us develop methodologies for identifying de-contextualized fragments from future ships (Castro et al. 2018). Additionally, animating reconstructions can help convey the mystique of the ship, and to create a tantalizing connection to our past through the scant remains we are lucky enough to happen across.

While this is almost entirely a positive shift, care must be taken to ensure that the distinction between interpretation and primary data is always made clear. Jeffery Clark wrote that an emphasis on reconstruction has been detrimental to the discipline of archaeology because the false sense of knowledge a reconstruction might present can make it difficult to entertain competing interpretations of data (Clark 2010). This is especially true with the power modern computer graphics have in conveying realism. Without a consistent methodology for emphasizing what is based on evidence and what is based on interpretation in a model, there is a real danger of building future studies on a faulty foundation.

Pencil and paper, wooden models, and even cardboard approximations have been used to represent shipwrecks and shipwreck sites, and to propose reconstructions. Marrying these traditional techniques with the newest technologies helps us refine what we have been able to accomplish in the past and expand the impact our reconstructions can have on the public for whom we work. At Texas A&M, we have been combining traditional ship modeling, naval architecture, 3D modelling, and 3D printing to build models of disarticulated ships that integrate each of the best aspect of the different techniques.

European shipwrecks of the early modern period can be interesting to reconstruct due to the existence of written sources describing design and construction processes. When archaeologists can date a ship being excavated with some degree and certainty and identify its origin, it is sometimes interesting to try reconstructing the design process. In the 15th and 16th century some European ships were built following recipes that have been recorded in technical documents. In fact, the earliest shipwreck to have been reconstructed having in mind the relations between its dimensions was the 11th century Serçe Limanı shipwreck, excavated in Turkey by the Institute of Nautical Archaeology. Texas A&M professor and McArthur grant recipient J. Richard Steffy published a seminal paper describing the construction measurements and proving that it was built with a modular dimension precisely equivalent to a Bizantine Foot (Steffy 1982). This paper was later completed and refined in the ship's final publication (Steffy 2003). There are a handful of ship reconstructions based on the ship's dimensions and on sometimes clearly defined units (Castro 2003; Pevny 2017). This aspect is particularly important when archaeologists have access to procedural reconstruction tools, such as *Houdini*, for instance (Suarez et al. 2019).

In 2019, the timbers from the disarticulated hull of an 18th-century shipwreck discovered in Alexandria, VA were each laser scanned and modelled using the techniques described above. During the lengthy conservation of the timbers at the Conservation Research Laboratory, each of the timbers was temporarily removed from its vat and laser scanned with a CMM arm, the FARO ScanArm, with a laser line probe attachment using. The resolution of the scans was set to 0.25 mm spacing between the points, which was fine enough to capture details such as fastener positions, wood grain, and too marks, but not so fine that the files produced would be too large to quickly process (Dostal 2017). The point cloud models of each timber were then meshed, and the mesh models were imported into the computer graphics program Rhinoceros 6.

Each of the timbers were then virtually arranged in Rhinoceros using fastener patterns, excavation photos, and tool marks. An in situ photogrammetric model made during the excavation of the vessel proved to be a useful touchstone for the arrangement, though the goal of arranging the timbers in Rhinoceros was to correct for

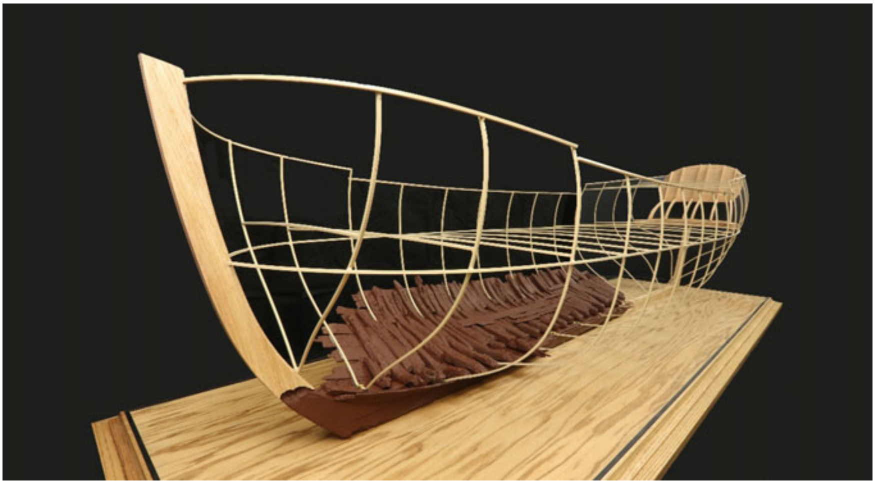

Fig. 1.5 Wooden, metal, and resin model of the Alexandria, VA shipwreck (Christopher Dostal and Glenn Grieco)

the deformation of the hull shape that had occurred over the centuries it remained buried. Once the arrangement was complete, a set of preliminary ships lines were pulled from the model by tracing the exteriors of select framing timbers at predefined stations. Those lines were extrapolated out virtually, and then printed out on paper and curves were extrapolated by hand to establish a plausible shape for the vessel. Extrapolating the lines virtually produced perfectly acceptable results, but tracing them out by hand allows for a more traditional means of verification. Comparing the lines established with this technique with archival sources, a draft of a ship was located that matched the general shape, size, and curvature of the vessel, and this draft was used as a basis to inform the reconstruction of the vessel beyond what remained of the timbers. Each timber was then 3D printed, reassembled, and oriented in a physical wire frame that was built to show the reconstructed shape of the vessel (Fig. 1.5). This helped contextualize the remains and point future researchers in the right direction to understand what that ship might have looked like.

Again, computers are simplifying this process by allowing archaeologists to make better, scalable models that are capable of being experienced either in person, on a computer screen, or even with VR masks.

1.7 Conclusion

We understand that it is not possible to propose a definite methodology to record, share, and reconstruct archaeological sites. There are too many variables between scholars for a one-size-fits-all approach to this problem, including varying skillsets, differing availabilities of resources, finances, and time. Despite this, the general shift towards comprehensive 3D documentation and an openness and willingness to share and collaborate internationally will continue to help push towards a much-needed standardized methodology. The more open we are and the more we work together, the greater the need for data compatibility, and this standardization will likely occur organically.

Although computers are not evolving as fast as they once were, their processing capacity is slowly increasing and allowing for more sophisticated software packages to be developed. Every time a new technology is adapted by the archaeological community it might seem like the end-all be-all way of preserving our collective cultural heritage that should be immediately adopted and standardized, but it is useful to remember that nobody could have conceived of computer image photogrammetry being used the way it is today just 30 years ago. It is important that as technology changes, we as archaeologists change with it and adopt the techniques that allow us to preserve history as thoroughly and efficiently as possible. While we do this, it is also important that we maintain backwards compatibility with the techniques that have proceeded us, so that a continuous chain of past knowledge can be maintained as we move forward.

In this chapter we propose several software packages, which we believe are suitable for the tasks necessary to achieve plausible and flexible reconstructions.

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