ARCHAEOLOGICAL WATERCRAFT:

A REVIEW AND CRITICAL ANALYSIS OF THE PRACTICE

A Dissertation

by

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ABSTRACT

Vestiges of humankind's long-term interaction with the earth's rivers, lakes, oceans and seas lie beneath water, sand, soils and sediments in the form of archaeological waterlogged wooden ships and boats. These quintessential maritime artifacts, and the connections formed between humans and watercraft create an extensive artifact biography revealing a host of physical and metaphysical meanings. Over a span of the last nine millennium watercraft have acted as containers, vessels, a means of conveyance, a bridge, a home, a factory, a prison, a fortress or a life boat. They are emblematic of individuals and nations. Deep seated in many cultural beliefs, they are integral aspects of birth or renewal, and often a critical component for reaching the afterlife. All of these factors motivate individuals to save archaeological watercraft when discovered in the course of academic search and survey, or a civil/commercial excavation.

Although attempts by professional conservators to stabilize waterlogged wooden watercraft first occurred in the early 1860s with the finds from Nydam Bog (Denmark), there was little change in methodological and philosophical approaches from then until after World War II. Following the war, a combination of new products, dissatisfaction with previously tried methods, and a shift in attitudes towards preserving representations of the past, ushered in a new era in the conservation of antiquities, and in particular watercraft. Over the last 60 years, incremental advancements have taken place concerning the conservation techniques applied to waterlogged archaeological wood and

wooden structures. Investigations that focused primarily on methods that maintained the dimensional stabilization of the object are now beginning to share considerably more time with inquiries about the state of artifacts once stabilized and in storage or on display. The archaeological remains of one watercraft, *La Belle* discovered in the shallow waters of Matagorda Bay, Texas in 1995 provides a case study in this dissertation to address some of the issues surrounding the conservation of waterlogged ships and boats.

DEDICATION

To Suzanne: for years of support and sacrifice.

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I would like to extend my deepest gratitude and sincerest thanks to each member of my doctoral committee. Dr. Wayne Smith (Chair) worked extensively with me during my early postgraduate development, encouraging me to consider studying aspects of waterlogged archaeological wood conservation, and instilling in me the need to assess critically conservation questions and continually push against preconditioned notions in order to find the suitable answer for a particular challenge. Dr. Kevin Crisman and David Woodcock A.I.A, accomplished scholars and leaders in their fields, were a source of continual inspiration who gave freely of their time whenever consulted. Finally, no greater thanks can go to Dr. Donny Hamilton, Director of the Conservation Research Laboratory and the *La Belle* Conservation Project, mentor, friend, and boss, without whom this dissertation could never had been completed. He placed his trust in me to undertake the conservation and reconstruction of *La Belle*, and although during the past few years, he probably felt considerable empathy for Sisyphus in urging me to finish writing, I can only hope that future achievements warrant his Herculean effort.

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Over the last 18 years, the stabilization of the *La Belle* timbers and reconstruction of the hull remains has been the accomplishment of many individuals: 4 full-time and 4 temporary full-time staff, 75 part time graduate students, 6 interns and 26 volunteers. Jim Jobling, Dr. Helen Dewolf and John Hamilton, part of the core staff at the Conservation Research Lab, worked tirelessly throughout the project to guide different aspects of the overall artifact conservation, but always found extra time to lend a hand on conserving the largest artifact in the collection. Taras Pevny and Peter Hitchcock committed themselves to make the project succeed and were instrumental in the initial reconstruction. Both were exceptional colleagues to work with and my knowledge and experience was greatly enhanced through our association. In the last year of the project, while *La Belle* was slowly reassembled as a "living" museum exhibit in Austin, TX, graduate assistant Chris Dostel assumed many of the responsibilities and tasks of the final freeze-dried product. His competence and commitment to the project were a great relief while I was involved with the hull reconstruction. Finally, I would like to thank Dr. Jim Bruseth (Texas Historical Commission), Archaeological Director of the *La Salle Shipwreck Project* for also trusting that *La Belle* conservation efforts were in competent hands, and for his continued participation in the project through to the very end of the reconstruction.

During the summer 2003, a research trip through Europe, funded in large part by Dr. Hamilton, allowed me to evaluate 43 individual watercraft around Europe and the

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My parents Jack and Marcia Fix deserve considerable praise for a lifetime of continued encouragement, which led me to experience different cultures and explore my creativity through many different outlets. They have always given so much so that I might achieve whatever goal I set. Finally, to my wife Suzanne, who endured far more than should have been necessary during these last few years when my dissertation seemed always so close to being “almost done!”

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CHAPTER I

INTRODUCTION

Throughout world history, wood has been one of the most versatile and important natural resources available to humankind,[1] and a substance heavily exploited for the construction of watercraft.[2] The resource grew in great abundance, was accessible to both communities of the coastal plain and those residing deep into the hinterland along rivers and around lakes. Its chemical characteristics, formed by a polysaccharide stiffener set within a polyphenolic matrix,[3] create a natural composite material that is well suited for conversion into ships and boats. The combination of lignins bound by cellulose and hemicellulose forms long, hollow circular tubes (appearing in cross-section as pipe bundles) into a material with a high strength relative to a low density, which allows it to float in water, yet support a sizable structure for its mass. Its growth in curved geometric shapes, which mimicked the shape of a hull, allowed curved shapes to be fashioned that followed the wood grain. It was durable, relatively easy to work, and the subtle variation in physical characteristics among different timber species provided for specific selection based on intended function. This long list of attributes situates the material as the principal construction fabric for watercraft, a position it would hold for several millennia until replaced by iron and steel in the later part of the 19th century.

It should therefore be of little surprise that the largest artifact encountered by marine or nautical archaeologists excavating a shipwreck, watercraft inundation or

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[1] Perlin 1989.
[2] Bray 1986. Throughout this dissertation, the term *watercraft* will be employed in a similar fashion as Maynard Bray used the term to collectively describe the diverse inventory of ships and boats, large and small, in the collection of Mystic Seaport Museum, Mystic CT.
[3] Kerr and Goring 1975.

abandonment site, is the hull of a ship. Unfortunately, due to natural decay processes and/or negative human impacts, all that often remains of what was once a floating marine structure are disarticulated timbers and fragments that hold moderate to little diagnostic content or aesthetic value. When the deposition environment, however, has promoted the preservation of a substantial portion of the structure one inevitable question arises–"how the waterlogged remains should be handled?" While there are numerous options for managing the question, distilled down, there are four common courses of action:

(1) Analyze the structure *in situ*, leave it in place or rebury the timbers.

(2) Excavate, recover the structural components and analyze the elements in a lab before reburial.

(3) Recover, analyze, and stabilize the timbers for long-term storage and future evaluation.

(4) When found to be "significant" for its rarity, aesthetics, historic role or supplementary value, preserve and reconstruct the artifact for museum display.

The focus of this dissertation falls under the classification of the third and fourth options and more specifically, these two options as they relate to marine archaeological structures fabricated of wood.[4]

Dr. Frederick Van Doornick, Jr, PhD, Professor Emeritus of the Nautical Archaeology Program at Texas A&M University, once jokingly informed me, "every

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[4] Iron and steel structures have conservation issues unique to ferrous materials and therefore, are beyond the scope of this study. Owing to the fact that the motivations that drive the long term preservation of watercraft is similar regardless of the construction material, the only cross over discussion between wooden watercraft and those constructive of iron or steel will be in Chapter 2.

nautical archaeologist [or conservator] has at least one good ship in them."[5] The industry average[6] for completion of a project supports his observation. The amount of time and effort needed to satisfactorily complete the six primary phases–excavation, recovery, analysis, conservation, publishing and installation of the exhibit–often requires a decade or more for even small, simply shaped watercraft and several decades for larger artifacts, with commensurate expenses. The Royal Swedish Warship *Vasa* (1628)[7], recovered in 1962 from Stockholm Harbor, did not open for exhibit until 1990. *The Cog of Bremen* (1380), recovered from the Weser River in 1962, was not ready for exhibit in the Deutsche Schiffahrtsmuseum until the early 1990s. The *Mary Rose* (1545), the English Tudor period carrack excavated in 1982, will continue in conservation for several more years.

Medium-sized vessels also require considerable time and effort to complete. Scores of archaeologists and volunteers frantically "rescued" the *Doel Kogge* during September 2000, but the project is scheduled to last another 17 years (calculated from 2015) before completion.[8] *La Belle*, the barque-longue that was part of La Salle's New World colonization fleet of four ships and recovered by the Texas Historical Commission from Matagorda Bay, Texas (1995-1997), will not be installed in its new exhibit until

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[5] Personal communication Dr. Frederick Van Doornick and Peter Fix

[6] In the context of this study the word *industry* is rather loosely applied. The conservation profession seldom employs the term, however, Merriam Webster online defines "Industry" as a "systematic labor especially for some useful purpose or the creation of something of value".

[7] The date employed following the vessel name represents the known date of sinking, or in the case where the deposition date is unknown the date employed is based on the established dendrochronlogical date of construction.

[8] Lenaerts 2013.

late 2015–19 years after it was discovered! Even the smallest dugout canoe may require five to ten years to complete stabilization of the degraded waterlogged substrate.

It appears that Will Parker, the character portrayed by Matthew Modine in the 1993 Hollywood film *Wind*, was correct when he remarked, “Do you know what they say about boats? They are holes in the water where you throw money.”[9] Parker's movie quip was referring to America’s Cup yachts, but there is little difference between his metaphor to boats and the reality of what is involved with conservation of what many consider to be the quintessential maritime artifact.[10] With the costs tabulated, the sum of salaries, chemicals, facilities, overhead and capital purchases, the expenditure for saving even a small dugout canoe can easily reach into the tens of thousands, and into the tens of millions for the larger vessels, arguably making the saving of this class of archaeological artifact, singularly, the most expensive form of cultural patrimony not part of the land-built environment.

Nevertheless, even within a climate of restrictive or diminishing financial resources and international conventions recommending alternative options,[11] watercraft recovered from archaeological sites continue to be saved. The *Newport Ship*, located in Newport, Wales in 2002; fragmented remains of 38 craft unearthed during a 2005 public works project in the Yenikapi District of Istanbul Turkey; *Nanhai 1*, the 30.4 m (100 ft) long, 9.8 m (32 ft) wide, and 3.5 m (11 ft) high, 800-year-old Chinese merchant vessel recovered in 2007; and the remaining portion of an early 18th-century merchant ship

[9] American Zoetrope 1993.
[10] White 1994.
[11] UNESCO 2001

found under the 1966 foundations of the World Trade Center towers in 2010 are all at different stages of the preservation process.[12] These are just a few of the many examples of archaeological watercraft remains recovered for long-term preservation since the beginning of the millennia. Each holds to and perpetuates a long-held tradition of saving this artifact class.

For over 100 years[13] prior to the sale of the first Aqua Lung in 1943, which allowed for the mass exploration and exploitation of underwater cultural resources, and the later adaptation of land-based scientific excavation methods to submerged sites,[14] watercraft had been hauled out of terrestrial and accessible inundation sites with little or no long-term plan. However, two major recoveries undertaken during the second half of the 1950s (the remains of five Viking-age vessels from Roskilde Fjord and the ornate warship *Vasa* in Stockholm Harbor) became benchmark cases for the rapid growth in the number of excavated inundated archaeological sites. The work of these two excavations brought notoriety to the field and awareness to the greater public that shipwreck remains were in abundance, just out of sight underwater. Their serendipitous exposure coincided with the growing historic preservation movements and the introduction or strengthening of cultural laws, particularly in Western countries, that required mitigation of archaeological finds discovered during “undertakings."[15]

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[12] Including the preservation programs for the 36 watercraft found Yenikapı Byzantine harbor of Istanbul, there are 53 known ship preservation projects at some stage of material stabilization.

[13] The Calder River logboat, Yorkshire England, recovered in 1838 is the oldest surviving waterlogged marine structure cataloged for this project to remain on display. The written record of earlier finds is elusive and without proper stabilization many of the earliest watercraft examples to be saved deteriorated in storage or on exhibit.

[14] Bass 1967.

[15] “Undertaking” as defined by 36 CFR Part 800, Section 106.

The explosion of excavated finds continued to accelerate through the 1960s and into the 1980s, and there was a steep learning curve related to the preservation of timber recovered from the sites. As Peter Throckmorton later recalled, in reference to one of his early excavations:

> I confess that every time I think of the wood of the Torre Sgarrata ship, now rotting away in the tanks in Taranto, I blush. It is perhaps too easy to argue the responsibility of the Italian Archaeological Service, which has neither the time, nor the money, nor the interest, perhaps, to send a workman once a week to the tanks where wood is rotting, in order to top up the tanks with freshwater and put in fungicide.[16]

Throckmorton's experience was not a singular occurrence. The year before he admitted his frustration with the mismanagement that led to the rapid deterioration of his project's excavated timber, G. D. Van Heide published "Wrecks as Monuments" in Anders Franzén and Lars Barkman's *Underwater Archaeology: A Nascent Discipline*, which enumerated a list of specific problems related to the conservation of waterlogged timber and timber structures. Van Heide, in assessing the need for better understanding of the waterlogged medium, enumerated a list of issues and the steps required to remedy the problems associated with the recovery and preservation of waterlogged structures. He devoted considerable attention for the need to keep the wood wet.[17] He also pleaded for more funding to be dedicated to marine monuments. A review of this document 40 years later reveals how much, and how little, the industry's approach has changed. Most archaeologists and conservators today with even a cursory knowledge of the subject understand the critical importance to keep artifacts recovered from marine environments

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[16] Throckmorton 1973, 500.
[17] Van Heide 1972, 162.

wet until the final phase of stabilization. In fact, in most cases it is such an accepted notion that few recite the need in publications. This is a far cry from Van Heide's reiteration in his prose for the need. While archaeologists and conservators better understand the physical requirements of conservation, what has not changed is his argument regarding the need for adequate funding required to keep up with the growing demands placed upon the industry because many times the financial resources still do not match the ever increasing need to preserve maritime monuments.

All professional preservationists acknowledge that it would be impossible to excavate every discovered wreck. There are simply too many sites and the excavated yield would be greater than could be reasonably handled by the world's cultural institutions. Over the last 2015 years–the Common Era–if just one watercraft foundered or was abandoned each day, there would be 735,100 wrecks to recover, conserve and exhibit. If the tabulation were to begin at what is perhaps the oldest dated archaeological watercraft to be preserved, the Xiaoshan dugout from China (c. 7000 B.C.E.) the possible number expands to 2,260,474. Of that number, the world has only saved a very small percentage. A catalog of conserved watercraft worldwide illustrates the age, type and location of the saved structures, or portions of structures, many of which have received little or no stabilization treatment.[18]

Reacting to the tradition of saving and looking for an acceptable methodology to mitigate finds without curation, many archaeologists and conservators began to question

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[18] Although certainly not complete, the catalog formulated during the course of this study, approaches 300 saved watercraft excavated globally from archaeological sites. MS on file Conservation Research Laboratory, Texas A&M University.

if it was a better practice to rebury the remains of waterlogged watercraft *in situ* instead of recovering the timbers for re-presentation.[19] Even so, despite their pleas and the expense, the decision to recover examples of watercraft from archaeological sites continued and will continue. The question that needs to be asked is “why”? Even with so many people cognizant of the economic burdens involved with watercraft recovery and conservation, if one person or group of stakeholders with access to the initial required financial resources desires the object, then with a passion similar to one person’s quest to build an antique collection of special objects, the funds will be appropriated or sought through donation. The passion must be sustainable and not allowed to wane as under the current state of affairs, where large projects will most likely require a generation or two to complete.

If preservationists are going to continue to save and preserve watercraft for future generations, the industry must develop and learn to maintain high standards for methods and practice. These must be economical, consolidated and streamlined processes that reduce the burden of time and the expenses associated with a long drawn-out conservation program and provide a framework for ensuring long-term economic sustainability for the watercraft preservation industry.

When first proposed as a research topic, the focus of this study was to produce a document that critically assessed archaeological watercraft conservation. At the time, it seemed such a simple, straightforward notion. But rapidly, a multitude of details soon became entangled in the incredible complexities involved with the preservation of

[19] Brunning 1990.

waterlogged marine structures. At the heart of the issue was how to develop a model and frame the assessment in a manner that might prove some use to the industry. To assess only what chemical treatments or applicable methods that demonstrated satisfactory results, or to enumerate the problems, would not provide particular guidance to the community of conservators tasked with understanding the past and future of the discipline.

The answer was found in the term *Gesamtkunstwerk*. In this case, the term is thought of as it was applied to the arts movement in the 19th century and architecture. For music, as exemplified by Wagner and Debussy, it represents the totality or synthesis of the arts. As applied to architecture it is the totality of the commissioned work from design of the furniture, windows and other accessories that make a complete (total) presentation model as exemplified by the works of Frank Lloyd Wright.[20]

One of the greatest issues encountered by the archaeological and conservation industries is that of a culture of compartmentalization, and the operational belief that functions run sequentially not congruently. The archaeologist records the site and structure and then hands it over to the conservator for stabilization. Once in the lab, documentation and recording are followed by materials assessment, chelation of ferrous material (if applicable), impregnation of the bulking agent, dehydration and final cleaning, followed by reconstruction and re-presentation or storage. Although the length of time it takes to complete certain processes are dependent upon the artifact, if the industry is to make strides toward more efficient and less costly practices it should

[20] Vidalis 2010.

perhaps evaluate the issues by using a modified whole system approach found in general design and business organizational models.

Chapter II represents a causal analysis by assessing the factors why humans are apt to save the artifact. Entitled “The Quintessential Maritime Artifact,” it evaluates the position of human attraction with the object. Through a discussion of cultural biography, romanticism, heritage identity and cultural resource management, it presents and draws heavily on the data derived from an extensive catalog prepared for this dissertation,, which lists the preserved archaeological ships and boats in order to determine what has been collected and when collected. Chapter III, “The Forest and the Trees,” introduces the doctrines and principles that continue to guide the field of conservation and briefly discusses the differences between small artifacts and the conservation of large integrated structures. Chapter IV provides a comprehensive overview of the extraordinary body of work undertaken by the conservation community over the last century and a half, and in particular the last 60 years, to conserve waterlogged archaeological wood. This chapter utilizes the collected data and synthesizes it in a way to observe overall trends in the conservation of waterlogged wood and archaeological organic materials, and to evaluate the strengths, interests and focus of the industry since discovery of the *Vasa* and Skuldelev vessels.

Chapters V through IX break down and illustrate the primary steps involved with watercraft conservation. Chapter V, “Watercraft Conservation–Delineation and Recording,” evaluates the first of five steps involved with conserving ships and boats, from *in situ* delineation through to timber tracings, photogrammetry, molding and casting to create accurate representations of the artifact for future planning and analysis. Chapter 6 discusses various aspects of recovering a waterlogged wooden structure. Chapter VII details the methods of materials stabilization utilized to safely remove the water from the timber and bulk the cell structure. Chapter VIII combines the two final steps, reconstruction and exhibition, judging specifically what methods, influences and issues have been presented over time. In chapter IX, issues concerning the designed shape of watercraft displayed in a foreign design environment and comprised of degraded construction material are discussed. Chapter X proposes using a whole system approach in the design phase of planning from the beginning of the project in order to incorporate crossover issues and encompass flexibility. The final chapter, Chapter XI, uses the conservation of *La Belle* as a case study to highlight the features developed in chapters IX and X.

CHAPTER II

THE QUINTESSENTIAL MARITIME ARTIFACT

> "Thou, too, sail on, O Ship of State! Sail on, O UNION, strong and great! Humanity with all its fears, with all the hopes of future years, is hanging breathless on thy fate!"
>
> -- Henry Wadsworth Longfellow
>
> *The Seaside and Fireside, 'The Building of the Ship*.[21]

Introduction

In the collection of the Russian Naval Museum, St. Petersburg, Russia, resides a small sailing craft that holds great distinction. Its notoriety is not derived from being the oldest boat ever found, or even the oldest boat removed from service for preservation.[22] It has not been associated with a significant event. Its importance is that it was the first watercraft explicitly removed from service and saved for posterity that retains a strong provenance. The reason for the craft's preservation was an intense emotional attachment that developed with the owner during years of use. Built of wood following traditional northern European construction techniques, the craft was the property of Czar Peter the Great (1672-1725), who reportedly so cherished the boat that he removed it from service and provided funding for its long-term care and storage.[23] From that point, its service

[21] Longfellow 1990, 185.

[22] In Turkey, construction of the Sultan's galley (KADIRGA) dates from a period between the reigns of Sultan Mehmet II (1451-1481) and Mehmet IV (1648-1687). Used for transport and ceremonial purposes, the vessel was not removed from service and preserved until the reign of Mahmut II (1808-1839) nearly 100 years after the boat of Czar Peter the Great. KADIRGA was laid up at the Topkapi Palace until 1913 when transferred to the Naval Arsenal at Kasimpasha where it remained until 1956. The galley was then moved to Beshiktash, near the Bosporus and finally accepted into the collection of the Naval Museum in 1970.

[23] Martin 1997; Also, Carcraft 2003.

was strictly ceremonial and it was used only in parades or placed on exhibition during special events. The emotional bond that the young Czar developed with the boat influenced his choice to study Dutch and English boatbuilding practices that would later be influential in the development of the Russian navy, and help shape the emerging nation into an 18th-century regional power.

Ever since our ancestors developed both the ability to fashion specialized tools, and the aptitude to master the construction of a stable floating marine structure, watercraft have played an important role in the development of cultural folkways by facilitating human interaction with the watery portions of the planet. To date, the three oldest excavated and saved watercraft with archaeological provenance are the Pesse Logboat (Netherlands, ca. 6,300-7,000 BCE), the Xiaoshan Dugout (China, ca. 7,000 BCE) and the Dufana Canoe (Nigeria, ca. 6,000 BCE).

The archaeological record for seafaring is considerably older however. Seafaring, as defined herein, is the use of some form of mechanical assemblage that allows for the navigation of open waters, and includes the safe return to the point of origin or some other desired location. Evidence of Melian obsidian and large bluefin tuna vertebrae (*sp: Thunnus thynnus*) found in the Franchthi Cave (Greece), initially dated early seafaring activity in the Aegean to the Mesolithic Period (8,300-7,000 BCE).[24] These dates closely coincided with the oldest watercraft found in archaeological contexts at that time, although subsequent hydration dating of Melian obsidian by Secondary Ion Mass Spectrometry-Surface Saturation (SIMS-SS) recovered from several sites around Greece

[24] Rose 1995, 4.

has pushed these initial dates back to the Late Pleistocene or Early Holocene periodsm approximately 14,000-11,000 BCE.[25] More recent discoveries of Melian obsidian on the island of Crete, which has been separated from any significant landmass for five million years, provide evidential dates to suggest that some form of overwater travel, at least one way, occurred in the Lower Paleolithic period approximately 130,000 years ago.[26]

Beyond this physical evidence for early use, the importance of watercraft to the contemporary cultures throughout time is revealed by the multitude of symbols and icons that have and continue to saturate today's daily lives just as they have for generations. Gods and goddesses, prophets and saints representing almost every religion are associated with ships and boats. Some of the earliest documented petroglyphs also link watercraft with life and fertility,[27] as well as death and the final journey on the River Styx, to Valhalla, and across the "waters" to the afterlife of many Southeast Asian and Pacific Islander cultures. Throughout the millennia, watercraft have retained their cultural significance, and collection of the tangible evidence by our contemporary society represents that high-level of prominence.

The boat that belonged to Peter the Great may have been the first to be set aside; however, for the last two centuries, thousands of watercraft have been located in various contexts. Many met an unfortunate fate at the end of a mechanical excavator. Others, saved as novel attractions, or evidence of primitive societies, eventually disintegrated due

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[25] Laskaris et al. 2011.

[26] Strasser et al. 2010. (Artifacts from 28 pre-ceramic lithic sites were dated by geological context).

[27] Gimbutas 1989, 102. Anthropomorphic objects originally labeled "Frying Pans" excavated from graves at Syros, Greece in 1899 (as well as from other sites) depict incised motifs of female genitalia, boats, fish or bird's feet connecting to the boat and occasionally a snake which are all part of the belief in regeneration and renewal associated with worship of the Archetype (earth).

to a combination of the weakened nature of the degraded wood, and inadequate knowledge of appropriate preservation techniques. As a result, of the recorded watercraft recovered and saved between the 1830s and the 1950s, only a modest handful survive, and many are in such delicate condition that moving them could prove catastrophic.[28]

The push to collect ancient or historic watercraft is a relatively modern phenomenon. In the last 75 years, however, there has been a substantial worldwide increase in both the number of craft removed from service for historic preservation purposes and watercraft saved from archaeological contexts. The increase in the quantity of saved watercraft is a reflection of shifting global attitudes towards cultural heritage. Before World War II only a handful of destinations focused on maritime heritage; today there are well over 200.[29] There are in excess of 2000 ships over 40 feet in length and at least five net tons currently collected and exhibited by these cultural institutions in over 50 countries.[30]

An even greater unknown quantity is the number of small craft held in perpetuity by cultural institutions representing local, regional and national, history, science or state interests. A complete global inventory of small craft does not exist. To date, no agency or individual has accepted the challenge to complete its compilation. Conservative estimates of their numbers, drawn from small, regional or specialized surveys, would potentially establish an inventory for the worldwide stewardship of small craft in excess of 7,500 objects.

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[28] Christensen 2007.
[29] International Council of Maritime Museums 2013.
[30] Brouwer 1999.

The number of watercraft saved from archaeological contexts is considerably smaller. A catalog created in conjunction with this study registered over 300 once floating watercraft recovered from archaeological contexts in varying sizes and levels of completeness that retain a strong provenance. There is a large representative assortment of craft, collected from nearly every millennium, leading back approximately 9000 years. These include representatives of almost every size and type of watercraft, from the small ubiquitous dugout canoe all the way up to the enormous size of ships such as the *Vasa* and the *Mary Rose*.

The focus of this chapter provides an overview of collecting and saving representative examples of the quintessential maritime artifact. To some readers it may seem odd that a critical analysis of watercraft conservation and the materials stabilization of once floating marine structures would dedicate the opening chapter to a discussion of human behaviors, cultural heritage concepts, and the use of archaeology in the promotion of (or reflection of) state interests. After all, archaeological conservation is a technical discipline that blends individual technique and artisanship with the principles of natural and material science. The practice involves requisite actions undertaken to set aside the object and ensure its material integrity for the benefit of future generations, because "excavation without conservation is tantamount to vandalism."[31] Within the framework of the hybrid critical evaluation discussed in the introduction, it is important to understand what has been collected, and why. Numerous factors create an attraction to watercraft and prompt the act of saving. <u>These factors construct connections and</u>

[31] Throckmorton 1972, 217.

meaning, which, in turn, determine value. Without value there is little desire to save. If there is no desire to save, there is no reason to conserve.

Why We Save Watercraft

The public, along with most professional archaeologists, conservators, museologists and preservationists believe that watercraft are significant. They are important for understanding our individual or collective past, and by collecting them we preserve part of our history and celebrate human achievement. If queried, most individuals or groups would acknowledge that they prescribe to the notion that saving watercraft for exhibition allows the visiting public to be able to interact with the tangible evidence of maritime history and enhance their journey of museum discovery. When in the institutional setting, watercraft assume a similar role to large, imposing skeletal remains of dinosaurs, and frequently spark curiosity and individual imagination. They awaken interest because "capturing the image of a ship does not capture her essence. There's a human need for a tactile response to our heritage."[32] There is a mystery and an "otherness" involved with viewing something so large and different. Watercraft have the potential to provide an excellent venue for people to learn about their own or a nation's maritime past.[33] Furthermore, social scientists argue the act of saving, even if only for long-term storage, allows future researchers the opportunity to reevaluate the original objects, which validates the scientific method. However, while these are viable and strong arguments, I believe the reasons are more deeply rooted at the individual level.

[32] Delgado 1987, 20.
[33] Maounis 1987; Stanford 1981, 1987-88.

In support of this need to access the tangible object, Peter Stanford, a founder, and the first President of the South Street Seaport Museum, in New York, relayed some primary reasons for saving watercraft monuments in an article that appeared in a 1987 issue of *Sea History* magazine. In the article Stanford cited the thoughts of one of the world's most notable early ship savers, Karl Kortum (1917-1996). "The second most noticeable thing about the museum ship is that she is vividly real and speaks to visitors in a language that they all can understand. The ship is 12 inches to the foot and needs far less interpretation and conceptualizing then does a model, photo or painting."[34] While echoing the thoughts on the previous page, it is true that the physical or tangible sense created by the artifact is important to illustrate place, and impart its physical presence, but as Kortum noted, it is "the second most noticeable thing." The most prominent notion is that "a ship properly invested as a museum and set up as a display sends out emotions of loyalty, humanity, history, adventure, geography, art, literature and so on. These elements have brought me pleasure and they seem capable of doing the same thing for other people."[35]

"Pleasure" is a far more visceral, intuitive and personal response than the frequently endorsed scientific or educational objectives. The fundamental heritage concepts of identity, linkage, and memory more closely relate to the "pleasure" response generated by Kortum's list. These components bind together the foundations of motive

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[34] Stanford, 14; Kortum 1987.
[35] Ibid., 12

and "send out emotions" that drive most projects forward. All others are reasoned, intellectual responses, or values that derive from emotion.

The Appeal of Watercraft

In an age when astronauts and cosmonauts reside in lower Earth orbit,[36] and air travel allows for one to be immersed in a foreign culture within hours of leaving their

Figure 2.1. When the site was opened to the public for one Sunday in October 2000, over 10,000 people came to view the Doel Kogge 1. Photograph courtesy of the Archaeological Service of the Waasland.

[36] The International Space Station (ISS) is in an orbit around the earth that ranges from 205 miles and 255 miles.

front door, historical and ancient ships retain considerable allure to preservation industry professionals and the general public alike. The number of maritime museums is currently at an all-time high.[37] A poignant example is that during the last few years, attendance at the Vasamuseet (*Vasa* Museum) in Stockholm, Sweden rose to around 1.2 million visitors per year and the museum has been consistently able to maintain that level of visitation.[38] What is it about watercraft that would pique the curiosity of an estimated 10,000 people to spend their Sunday trudging along the muddy banks of a canal attached to the River Scheldt near Antwerp, Belgium (Figure 2.1) to view the upside down hulk of a newly uncovered ancient ship?[39]

It is important to create stakeholder communities and establish preservation trusts such as "Friends of the Newport Ship," "Friends of the Hunley," and "Friends of the Texas Historical Commission," which aided the conservation of *La Belle*, and "Friends of the *Viking* Ship," which saved the replica of the Gokstad ship built in 1893 for the Chicago World's Fair from ruin. These groups primarily function as financial development arms for particular projects, but also provide grassroots publicity and education that codifies public sentiment to promote the saving of floating maritime heritage and pleads for the strengthening of cultural heritage laws.

> I wish to express my deep concern at the increased loss to the United Kingdom of historic ships, especially those from the West Country, from sale abroad or rot and rust. Will he [British Government] initiate a process to give historic ships the same legal protection as historic buildings. If historic ships must be licensed for sale abroad, ensure the

[37] http://www.icmmonline.org/index.php?option=com_content&view=article&id=59&Itemid=40
[38] Personal communication between Peter Fix and Emma Hocker, April 2013.
[39] Terfve 2002, 10.

> licence [sic.] includes conditions that ensure continued appearance at UK festivals at intervals.[40]

How can the discovery of a single shipwreck transform the career of a successful marine geologist and make him into an overnight celebrity? The case can be made that few other patrimonial objects could be the catalyst for such a meteoric ascent. From the perspective of scholarship, while a significant find, the discovery of HMS *Titanic* did not significantly alter the global understanding of history or material culture. Nevertheless, the episode had the magnetism required to connect stakeholders together and coronate the man as "Dr. Robert Ballard–Discover of the *Titanic*." This is the same sort of compelling force that drew 30 men from the small village of Barangay Casanicolasan, Philippines to wade into the Lagasit River and labor for three days in an attempt to recover a large dugout canoe from the riverbank. The newspaper article that reported the find described the canoe as a "treasure" that would bring "pride" to the village.[41]

A force frequently pits those with competing interests against one another causing heated debates and legal action. Following discovery of the wrecks of *Hamilton* and *Scourge*, approximately 11 kilometers north of Port Dalhousie Ontario, Canada in 1973, controversy arose over ownership and access to the underwater site. In a court deposition where individuals sought to gain access permits to the submerged wrecks one diver testified that divers are "very

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40 Seagrave 2013 E-petition - *Protecting floating maritime heritage.* http://epetitions.direct.gov.uk/petitions/45755?goback=.gmr_800667. Accessed 2/2013. (Note: within the first few weeks that the petition was posted online, it had already received 880 signatories.)

41 Visperas November 24, 2010 http://www.philstar.com/nation/632462/centuries-old-wooden-boat-retrieved-pangasinan.

Figure 2.2. Top, the flotilla of small craft escort the CSS *Hunley* into Charleston Harbor. Below, re-enactors in period-dress salute the precession as it passes in July, 2000. Photograph courtesy The Friends of the *Hunley*.

interested in shipwrecks and in the history that comes from shipwrecks and the feeling that we get from them being close to historic shipwrecks and observing though shipwrecks."[42] Is there another artifact, either lost, or cast off during the course of human endeavor that evokes such a passionate response? One that would draw thousands, many dressed in authentic-looking American Civil War period costume, to the banks of the Charleston River (South Carolina) to "welcome home" with a salute the last arriving Confederate States naval vessel *CSS Hunley* (Figure 2.2). After 34 years of professional involvement in the field of heritage preservation, I have yet to experience its equal.

Intuitive Behaviors and Environmental Influences

Following Kortum's assertions, if emotion and sentiment are the principal motivators for the preservation, or saving of watercraft, the logical question to pose is what are the triggering mechanisms that prompt individuals or communities to act on that emotional desire and convert an object into a monument that some would consider little more than an incomplete form of statuary? Unlike the preservation of buildings, without significant reconstruction there can be little rehabilitation or reuse of the marine floating structure and a disarticulated waterlogged structure has no future use, except as a museum exhibit or stored away for its diagnostic evidence. Since the discovery of noteworthy watercraft will continue and the trend to save seems to persist, understanding this trigger is critical.

[42] Gentile 2004, 81.

It is difficult to establish a single reason for saving watercraft because each case is most likely influenced by genetic responses to environmental factors that are grounded in contemporary culture. Could we be attracted to ships and boats as Joe Flatman suggests, due simply to the fact that watercraft "are emblematic of–and can be represented as–a penis, weapon or coffin?" Is the trigger just "partly attributable to a fascination with sex and violence,"[43] or is there something more innate involved as expressed by Igor Medelev-Mead. "In time, I fell under the spell of boats–their organic, living quality. I came to believe, as many boat lovers did and still do, that small wooden boats possess personalities and souls."[44]

The two opposing perspectives result from the circumstance of their context. Flatman, writing from the standpoint of the trained maritime archaeologist, seeks to poke fun of and rebuke the readership–mostly other maritime archaeologists, regarding the obsession many have with watercraft and for paying less attention to other important aspects of marine archaeology. Perhaps Flatman's assertions are oversimplified and too one-sided. Medelev-Mead's perspective appears to be generated more as a non-cognitive response. An architectural landscape painter, he admits that "for a long time [he] had been unaware of boats" until one day he had an epiphany and "was attracted to boats intuitively." [45] John Adams, in *Ships and Boats as Archaeological Source Material,* points out that the relationship held with watercraft is due to the fact that a ship "is a social and technical entity [and] its use life can be positively kaleidoscopic."[46]

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[43] Flatman 2007, 81.
[44] Medevev-Mead 2005, 10.
[45] Ibid.
[46] Adams 2001, 297.

Human societies have created, manufactured and fabricated numerous forms of transportation–cars, trains, planes, carts and wagons–and many of the earliest examples discovered through archaeological contexts, but none of these artifact classes generates the same type of reaction in contemporary society as the previously illustrated examples of watercraft. So what is it that stirs up these emotions? In many cases, it is a linkage; a relationship to the object generated deep within the individual that touches the consciousness as if perhaps, even as a result of non-cognitive function. These are intuitive sensations similar to those expressed by Frank Carr, director of the National Maritime Museum, Greenwich, England (1946-1966), founder of the Maritime Trust, and first Chairman of the World Ship Trust, who was instrumental in the saving of the composite clipper ship *Cutty Sark*, built on the banks of the Clyde (Scotland) in 1869.

> We go to a cathedral and see a beautiful building. We go into a ship and see a beautiful vessel. But, in the cathedral there is something more-something of the religious spirit and something of the spirit the people who have worked and worshiped there, who have served their, who may have been buried there-that remains. So, to me, when I go aboard the *Cutty Sark*, she is not a dead ship, she's not just iron and elm and teak and hemp. [She is pervaded by] something of the spirit of the men who created that ship, imagined her, filled her, put their loving craftsmanship into her because the shipwrights were proud of their skills. And the man who sailed in her, who hated her, who suffered in her, and yet, who loved her. I do not believe that all those generations of people left *Cutty Sark* with nothing of their spirit behind. To me, she's alive, and when I go on board I feel as I feel when going into the cathedral.[47]

For Carr, ships stirred up a sense of profound reverence that allowed him to connect with the spiritual aspects of the object. For others the connection generates a different reaction whether that is pride, awe, excitement, self-awareness, or even feelings

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[47] Stanford 1987-88, 14.

of providence and destiny. They are also responsible for Kortum's "pleasure," and Medevev-Mead's intuitive love of the boat's "personality and soul."

Human interaction with objects, similar to those described by Kortum, Carr and Medevev-Mead, creates meaning, revealing that watercraft have a "social life," and are "objects in motion" as defined by cultural artifact biographers. The cultural biography created by watercraft is an interconnected and complicated subject. It concerns the characteristics that create the relationship between people and objects, which are so varied they cause considerable ambiguity. The reasons and motivations are numerous, but some sense of it can be achieved by stitching together a "bricolage"[48] of available concepts and perceptions in order to identify some of the basis for triggering the desire to save watercraft.

"The Social Life" of Watercraft

Cultural artifact biography is a methodological approach used to study the relationship that develops between people and objects. A component of material culturalism, "at the heart of the notion of biography are questions about the links between people and things; about the ways meanings and values are accumulated and transformed."[49] This conceptual approach grew out of papers presented in 1983 and 1984 by a group of anthropologists and historians looking to understand and value

[48] Levi-Strauss 1966, 17, 22. In *The Savage Mind* (*La Pensée Sauvage*), Claude Levi-Strauss elaborates on the distinctions he made between mythical thought and science by inserting the term bricolage. The expression is from the French verb, "bricoler," referring to the kind of activities that are performed by a tinkerer or Jack-of-all-trades as he or she performs tasks with a diverse range of materials, and with the tools that are available at hand. Execution of the approach has gained great success in the Postmodern Era in the subjects of visual arts and fashion, theater, architecture, philosophy, education, business, and software design.

[49] Gosden and Marshall 1999, 172.

commodities, at a symposium hosted by the Ethnohistory Program at the University of Pennsylvania. The product of the collaboration was a collection of papers edited by Arjun Appadurai, entitled *The Social Life of Things: Commodities in Cultural Perspective* (1986). The work brought about a major change in cultural perspectives concerning the manner in which humans view material "things" in every day circulation. In the chapter entitled "The Cultural Biography of Things: Commoditization as Process" Igor Kopytoff contended, "biographies of things can make salient what might otherwise remain obscure."[50] In forming a biography, the questions that one might ask of the object are not much different from what would be required of a human narrator.

> What, sociologically, are the biographical possibilities inherent in its 'status' and in the period and culture, and how are these possibilities realized? Where does the thing come from and who made it? What has been its career so far, and what do people consider to be an ideal career for such things? What are the recognized 'ages' or periods in the thing's 'life,' and what are the cultural markers for them? How does the thing's use change with its age, and what happens to it when it reaches the end of its usefulness? [51]

By understanding the object as it moves through its "life" trajectory, it is possible to approach an assessment of it through the ever-changing cultural perspective. Kopytoff divided all "things" into two categories "common" and "singular."

> The only time when the commodities status of a thing is beyond question is the moment of actual exchange. Most of the time, when the commodity is effectively out of the commodity sphere, its status is inevitably ambiguous and open to the push and pull of events and desires, as it is shuffled about in the flux of social life. This is the time when it is exposed to the well-nigh-infinite variety of attempts to singularize it."[52]

[50] Kopytoff 1986, 67.
[51] Ibid. 66-67.
[52] Ibid. 83.

Commodity singulariazation frequently occurs when people create special associations with or place value upon the object. At that point, they elevate the object beyond the realm of commodity, and consider it “priceless.”

In the two decades that followed publication of *The Social Life of Things* different perspectives of the original premise continued to broaden the scope and application of “fetishism methodology.” It is generally accepted that object biographies do not specifically have to relate to small movable commodities or gifts, but that large, seemingly static, non-movable megalithic stone ruins such as those at Avebury, Wiltshire, UK[53] can also develop special associations .

The manner in which an object is perceived by two different societies can allow for better understanding of the structural forms in each culture.[54] For instance, how object meanings that are shaped by context can provide insight into the relationships formed by two distinct cultures over the same subject.[55] Objects that one culture might consider an heirloom are not simply random commodities handed down from one generation to the next for a family unit or group to retain established wealth–they also preserve the power lineage. “In chiefdoms, heirlooms serve to objectify memories and histories, acting as mnemonics to remind the living of their link to a distance, ancestral past,,"[56] thereby passing the mantle of power to successive generations.

Since the meaning of an object is placed or evaluated in context and time, meaning is a subjective application of individuals; a biography can be constructed for

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[53] Gillings & Pollard 1999.
[54] Seip 1999.
[55] Saunder 1999.
[56] Lillios 2013, 236.

objects that never were commodities, exchanged as gifts, ceremonial, or ritualistic artifacts. Tim Dant exemplified this assumption by utilizing a fruit box that his father had turned into a toolbox following World War II. In constructing a biography of the box, he was able to make a strong case that even seemingly mundane objects can provide commentary and insight beyond the realm of commodity and the singularization proposed by Kopytoff.[57]

Individual watercraft, acting as “vehicles of major social enterprise such as communication and trade and as manifestations of technical and social change,"[58] have extensive biographies. The reasoning behind the saving of certain watercraft is frequently the result of linkage to special points in time or based on the significant individual accomplishments. The gondola *Philadelphia*, excavated in 1935 and now in the collection of the Smithsonian’s National Museum of American History, was part of the fleet assembled by General Benedict Arnold at the Battle of Valcour Island on Lake Champlain (1776) that delayed a British plan to separate New England from the Atlantic colonies, at a critical juncture of the American Revolutionary War. The *Mary Rose* (1545) sailed out of Portsmouth Harbor to help stave off a French naval invasion. The first rate ship H.M.S. *Victory* has been and will forever be associated with Lord Admiral Horatio, 1st Viscount Nelson (1758-1805). The *Vasa* may have been "an ill-fated ship but she represents the Navy which helped to make Sweden into a great power." [59] The cog (kogge) links many countries to the Hanseatic League, which was the predominant

[57] Dant 2001.
[58] Gibbons & Adams 2001, 281.
[59] Franzén 1972, 78.

commercial, and to a lesser extent, defensive union of merchant guilds and their market towns that dominated trade along the coast of northern Europe during the middle ages. The longboat, the knorr and the faering connect many excavated craft to the roving exploits of medieval Vikings to Scandinavia and northern Europe. If individual vessels and types (cog, knorr, etc.) can create a relationship through their social lives, could not an entire classification of comparable objects (all types), in this case all watercraft, have a general biography that extends through every culture and the many millennia of use? This would then create a path for ascendance of all watercraft, making the artifact group itself "singular" and provide the catalyst to trigger the imagination, and draw so many individuals to ships and boats–from the smallest dugout canoes to the largest warships and merchant vessels.

While it may be because preservation management decisions are made on the local and regional level, and therefore no "global maritime heritage" exists,[60] watercraft track the course of human endeavor, and the multitude of singular stories collectively proclaim human achievement. Taken as a group, they in fact do blur national and international boundaries as the quintessential maritime artifact. If any one of a multitude of different artifacts were found during the course of an archaeological excavation, it is doubtful that any immediate fervor would develop that extended beyond the group of excavators. That is not the case with watercraft. Find a ship or boat, even one so disarticulated that it is barely recognizable by its shape or form, and the story hurriedly reaches multiple news and information outlets. Cross-culturally and across time,

[60] Maarleveld 2012.

watercraft demonstrate value as an object class through their ascension to "singular" status, and the means with which the defined values have shaped connections to unite stakeholding individuals or communities to the object. The biography relates to the function of watercraft as a class of object that humans associate by use, and by the semiotic messages encoded within them for continued interpretation.

More than Melville's "Oaken Box"

In his poignant description of shipboard life, drawn from experiences before the mast on a number of different ships, the American novelist Herman Melville (1819–1891) chose "oaken box on the sea" to illustrate the confined space of the ship. On board, "like pears closely packed, the crew mutually decay due to the close contact, and every plague-spot is contagious."[61] Existence on the watery portion of the planet, out of sight of land, is a solitary practice, one that creates an extremely self-contained and closed society. The 19th-century novelist Joseph Conrad (1857-1924), who went to sea at the age of 17, and spent 19 years sailing in French and English merchant ships, likened the experience of a ship on a sea voyage to that of a planet in the vastness of space.

> The passage had begun, and the ship, a fragment detached from the earth, went on lonely and swift like a small planet. Round her the abysses of the sky and the sea met in an unattainable frontier. A great circular solitude moved with her, ever-changing and ever the same, always monotonous and always imposing.[62]

So dependent upon the ship or boat are we that Melville depicted watercraft as "a bit of *terra firma* cut off from the main."[63] The role of watercraft as container or means

[61] Melville 1850, 379. (Herman Melville also gained a particular insight by entering sea life as a young boy, a green hand on a Liverpool packet ship, partial voyages three different American whaleships and as a crewman on the American sailing frigate USS *United States*).
[62] Conrad 1999, 50.
[63] Melville 1850, 187.

of conveyance communicates uncomplicated connotations, but in different cultural settings a floating marine structure has acted as a house, fortresses, prison, factory, coffin, life raft, weapon and the foundations on which cities and countries were built. The use of symbols and metaphysical connection creates even stronger relationships by subconsciously keeping the thoughts of watercraft within the mind's eye. The complexity of meaning creates considerable duality between the actual and metaphoric sense of the term, but both serve to strengthen the bonds between object and human.

Containers and Conveyances

The typical view of watercraft is as a space used to pack articles and convey those materials or personnel to another place. Vessels, however, hold not only the manifest cargo, but also store the individual ideas and aspirations of all those on board and involved in the sea venture. Movement transforms the ship into a cultural carrier that spreads a host of technologies, customs and traits that can alter the landscape of the destination.

The social and other historical impacts involved with the cultural diffusion have been both positive and negative. History is full of examples of unintended consequences that have radically altered the receiving culture and landscape. Rats carried aboard ships promoted the rapid spread of bubonic plague known as the Black Death (1347-1400). Many people, especially those connected with the inland waterways of North America and Northern Europe, are familiar with the invasion over the last 25 years (in North America) of the zebra mussel (*Dreissena polymorpha*) and the economic or environmental impacts associated with this invasive animal. Native to the Black and

Caspian Seas, the species has been moved by ship around the North Atlantic.[64] What most people in North America do not know is that the common periwinkle (*Littorina littorea*), which by volume is currently the most dominant mollusk in North America, is also a European colonist, having hitched a ride on ships bound across the Atlantic. First landing around the middle of the 19th century the mollusk's voracious appetite for algae quickly altered the physical appearance of the landscape by vacuuming clean New England and Canada's rocky coastline.[65] How different might the landscape paintings of Edward Hopper (1882-1967) or Emile Gruppé (1896–1978) appear with a greenish hue covering all the rocks instead of the stark image of strength and defiance that so many of the marine landscape paintings of northeastern America have come to represent.

Homes and Communities

The freedom of movement afforded by watercraft has traditionally allowed for the fabrication of a house where no land is available or affordable–the houseboat. The solitude of life at sea, however, out of sight of land for weeks or months at a time, generates a reliance on ship and molds all facets of the ship and crew into a specialized, independent society. Although referring to a warship, Melville's characterization of life aboard the USS *Neversink*[66] could apply to any large vessel. "A man-of-war is a city afloat, with long avenues set out with guns instead of trees, and numerous shady lanes, courts and byways. The quarter-deck is a grand square, park, or parade ground, with a great Pittsfield elm, in the shape of the mainmast, at one end, and fronted at the other by

[64] Mackie et al. 1989.
[65] Chapman et al 2007; Grosholz 2002.
[66] The USS *Neversink* was the pseudonym given by author Herman Melville to refer to the Frigate USS *United States* (1797-1861) on which he sailed (1843-1844).

the palace of the commodore's cabin."[67] In this world, cut off from land, the relationships that form maritime communities are different than those on shore, which is due in large part to the effect of living and creating a "home" within an "oaken box."

Prisons

Even when tied to the quay, the relative isolation provided by the inaccessibility of ships and boats, in particular those no longer fit for ocean service, have created an ideal space to incarcerate convicts and prisoners of war.[68] Ships have frequently been turned into prisons in order to transfer large numbers of captives, convicts or political prisoners to an internment camp. Two of the best-known examples of this use include slave ships that transported captive Africans to Europe and the Western hemisphere, and the convicts immigrate to Australia.[69] A lesser known form of prison ship was conversion of several ships into the Soviet ghulag fleet operating in the region that is now northeastern Russia.[70] Soviet convicts and political prisoners were transferred by rail across the continent to the railhead at Khabarovsk on the eastern coast. From Khabarovsk, the prisoners boarded ships to Magaden and the labor camps in the Kolyma region. "During the 1930s the only way to reach Magadan was by ship from Khabarovsk, which created an island psychology and the term Gulag archipelago."[71]

If being a prisoner entails the imposed loss of free will the ship became a *de facto* form of prison to any sailor who was "Shanghaied," pressed into service, or "crimped." The requirements of life at sea created a very specialized and ordered society. Coupled

[67] Melville 1850, 118.
[68] Dye 1987, 299; Branch-Johnson 1970.
[69] Clark and Bisbane 2011.
[70] Bollinger 2003.
[71] Jackson 1987.

with the loss of freedom of movement, even those who voluntarily joined an ocean voyage were very much prisoners of the ship and were frequently subjected to harsh treatment. The constant need for discipline and the hierarchical command structure, often administered by tyrannical commanders (jailers and wardens) prompted Richard Henry Dana to remark, "in no state prison are the convicts more regularly set to work and more closely watched."[72] Although a ship, in theory, projects a sense of free movement, within the microcosm of the seaborne society there are severely reduced personal liberties that restrict individual freedom, thereby creating a prison-like environment.

Fortresses and Weapons

A naval vessel is a weapon by design and a movable fortress as a coincidence of its operation. "A man-of-war is a lofty, walled, and garrisoned town, like Québec, where the thoroughfares are mostly ramparts, and peaceful citizens meet armed sentries at every corner."[73] Not until the latter half of the 19th century, when advancements in naval ordnance allowed warships to remain at great distances from their opponent, did the long-standing tactical application of close quarter combat between two floating castles end. The proverbial land battle fought at sea depicts the fact that the initial line of homeland defense to any island or coastal nation was frequently a nation's navy, which in the case of England gave rise to the expression "England's wooden walls."[74] This prompted great pride and identity in England's ability to stave off invasion from the sea.

[72] Dana 1964, 12.
[73] Melville 1850, 118.
[74] Rodstock 1806

Another example is the Skuldelev blockage in Roskilde Fjord that was created to protect Roskilde, then the capital of Denmark, against attack by sea.[75]

Life Rafts

The notion of using a small raft or boat to escape a catastrophic event on a larger vessel is a concept that is easy for our safety conscious culture to understand. Historically, especially in 18th- and 19th-century United States and Europe, going to sea was often seen as a remedy when one was "growing grim about the mouth" or when faced with "a damp drizzly November in [the] soul"[76] A life at sea could provide the freedom of escape from the sedate, bucolic and often boring existence offered by farming or life in a town where there may be little chance for advancement.

> Oh, give me again the rover's life–the joy, the thrill, the whirl! Let me feel that again, old sea! That means leap into thy saddle once more. I am sick of these terra-firma toils and cares; sick of the dust and the reek of towns. Let me hear the clatter of hailstones on icebergs, and not the dull tramp of these plodders, plodding their dull way from their cares to their graves.[77]

In these cases, watercraft acted as a life raft and mode of escape from life on land. It could also be said that migrants that boarded a ship for a different land and the prospect of a new life, using the ship as a form of life raft to escape persecution and conflict for the chance at a more prosperous future.

Coffins

Over the last 150 years, archaeological investigations across Northern Europe have frequently uncovered ships and boats used as sepulchers to bury prominent

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[75] Olsen and Crumlin-Pedersen 1968.
[76] Melville 1964, 1.
[77] Melville 1850, 84.

individuals. Examples including the Sutton Hoo Ship Burial Mound #1in England,[78] and the Oseberg, Goksad, and Tune sites in Norway[79] all illustrate the conversion of watercraft into coffins. Numerous excavations have also yielded the charred remains of wood and fasteners indicating the use of watercraft as part of the funeral pyre in these cultures. In contemporary culture, the connotation of the word coffin immediately communicates death, and during the 19th- and 20th-centuries the word "coffin" was utilized repeatedly in association with the word ship to impart several disastrous occurrences. During the Irish Potato Famine (1845-1852), the massive number of emigrants boarding vessels (life rafts) in western Ireland to escape the food crisis quickly overwhelmed available merchant shipping.[80] Overcrowded ships left Ireland with cargoes of humans already weakened by malnourishment and cramped in squalid conditions. With limited food and water for the voyage across the Atlantic many perished, and the estimated mortality rate during the exodus was approximately 30%.[81]

Another adaptation of the word "coffin ship" could possibly be asserted by anyone on an old, ill-maintained ship or boat out of sight of land. Around the turn of the 20th century, the pressure to design and construct merchant ships that could economically compete led to the design and construction of grossly inadequate vessels for the intended functions. There are many documented accounts of ships capsizing due to instability or following collision.82 The lack of safety standards prompted governments around the

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[78] Bruce-Mitford et al. 1975.
[79] Durham 2002.
[80] Laxton 1997.
[81] Coogan 2012.
[82] Stilgoe 2003, 155-156.

world to establish or strengthen laws and conventions to govern merchant shipping and enforce safer practices.

Factories

For people who have occupations that take them onto the water, the ship or boat is their place of work, “office” or “factory.” Pelagic fishing and whaling, however transforms the ship into a factory, or more specifically, a factory processing plant, home, and community while at sea. The earliest European pelagic fisheries utilized the remote shorelines of Spitsbergen, which is part of the Svalbard archipelago in northern Norway, Iceland, and the coast of Newfoundland on a seasonal basis to construct temporary camps and process the catch and primarily employed the main ship as a storehouse. Over time, the changing migratory patterns of whales and the depletion of fish stocks drove these ships far offshore for months at a time. The need to combine all aspects of the fishery, from catching the fish and on board processing, required the construction of large, specialized ships that were essentially floating factories. Today, even larger ships, some the size of a factory on land, roam the world’s oceans in the pursuit of efficiently harvesting the marine resource.

Romantic Notions

Physical geography divides the earth into three spheres of influence: the lithosphere (land), the hydrosphere (water), and the atmosphere (air); and humans can only inhabit the land. We cannot venture into either of the two other realms without constructing the mechanical means to do so. This is the universal purpose for watercraft: to provide humans access to a region where we cannot normally endure. All other related uses, whether that it be as home, fortress, coffin or metaphysical manifestations, build connections but are derivations from the *raison d'être*. Although the ease and access of long-distance travel have removed some of the novelty and mystique of watercraft this is the one point that cannot be understated. Oceans, seas, lakes and rivers have often been perceived as a frontier boundary, a barrier and a bridge.[83] It is a world that is alien to us,and watercraft have been humanity's portal for interacting with this foreign world– ships and boats are the building blocks of that bridge.

As of 2009, 38% of the world's population lived within the coastal zone (100 km) of the coast or estuaries, and 44% live within 150 kilometers of the coast.[84] According to the U.S. National Oceanic and Atmospheric Administration (NOAA), in 2010 approximately 123.3 million people, 39% of the U.S. population , lived in coastal shoreline counties.[85] Eight of the 10 largest cities in the world are built directly on the coastline.[86] Human migration to and the historical development of these cities is a result of their acting as principal nodes of economic possibility through the rise of prominence as port cities, exemplified by the expansion in size and prominence of New York City.[87] Oceans provide sustenance, help to regulate global climate and, as has become the case for over the last 150 years, are a preferred leisure and recreational destination.

Those adventurous souls who fled the land, and were fortunate enough to survive, returned from sea with stories, many embellished, of the different sights, sounds and smells in far-off lands. Romantic notions flourished, crafted by unknowing minds that

[83] Labaree 1975.
[84] Stewart 2009.
[85] NOAA 2013, 4.
[86] United Nations 2013.
[87] Albion 1984.

created excitement in many for the opportunity to challenge the human condition against unrelenting natural forces, life-and-death situations, or the intense solitude associated with being out of sight of land. These notions have been perpetuated and even strengthened as the years have passed, forming an emotional linkage with a contrived image of life at sea on watercraft.

In the 21st century, mostly in Western cultures but growing in acceptance globally, boats are usually considered a novelty or a form of recreation during leisure time. Apart from some niche industries, large factory and container ships have assumed much of the role for transportation and harvesting of the seas. Those of us who do take to the water usually use personal watercraft for perhaps a couple of hours, for maybe overnight or a week, and return home, never venturing too far from our daily routine and the safety of our home port. Some gain access by taking holidays on cruise lines that incorporate all of the trappings of theme parks, shopping malls and Las Vegas. Even though immense, highly engineered watercraft that represent the pinnacle of modern engineering travel the oceans daily, few are able to experience, or even observe their movements, as most people, at least in the West, have moved away to reside in places other than near a commercial waterfront. By chance, we observe them on the horizon departing or steaming back into port, but most of the world's population does not depend on them for individual transport, and thus they no longer linger within the realm of our daily experience or cognition. All that is left are preconceived notions of what a sea voyage should be, which in essence is euphoric recall regarding the way that many of us use watercraft today, and which have been influenced by the books and visual arts formulated with strong romantic bias.[88]

Before air travel allowed for the rapid movement of people and ideas from one region to another, travel across long expanses of ocean was not an easy or inexpensive undertaking. Conjured images of the different sights, sounds and smells from distant lands held a strong attraction and people thought of watercraft as vehicles that could allow them to make long journeys. Romantic notions flourished around mystery, adventure and “otherness” of distant lands.

> Particularly, I remembered standing with my father on the wharf when a large ship was getting under way, and rounding the head of the pier. I remembered the*yo heave ho!* of the sailors, as they just showed their woolen caps above the high bulwarks. I remembered how I thought of their crossing the great ocean; and that that very ship, and those very sailors, so near to me then, would after a time be actually in Europe. [89]

Herman Melville fictionalized everyday experiences from his own life and *Redburn* is a partial account of this first voyage on a Liverpool packet ship in 1849.[90] The screen roles of a swashbuckling Errol Flynn or the more modern representation developed by the recent films *Pirates of the Caribbean* or *Master and Commander* perpetuate the formation of intense imagery. Regardless of authenticity, these messages propagate romantic stereotypes of shipboard life and the thrill of sea life (Figure 2.3). They create a “siren’s song” that generates enough charismatic energy to pull people toward a life quite different from their normal, daily practice. After all what could be better to sell spiced rum than a charismatic pirate and a happy-go-lucky crew who, at

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[88] Isham 2004.
[89] Melville 1850, 15.
[90] Newton 2002.

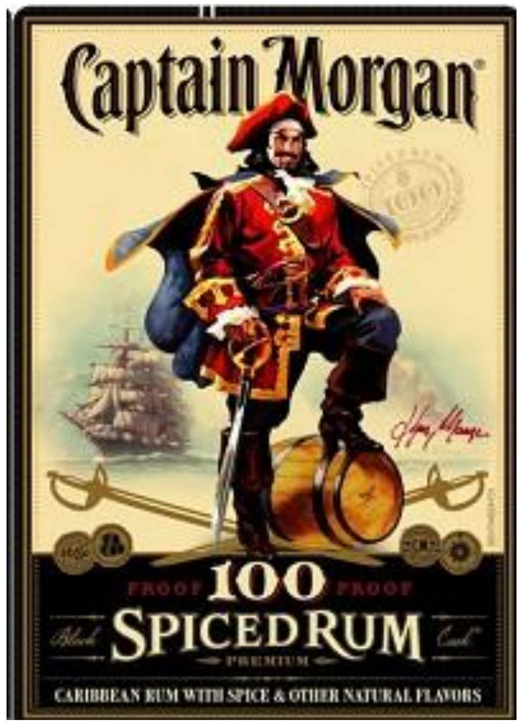

Figure 2.3. Above, the charismatic image of the swashbuckling Morgan on a bottle label stands guard over a cask of what the consumer can only assume is spiced rum. Below, the “LEGO” box cover illustrates that even at age 6 young minds can understand the romantic notion of the pirate. Products of the Captain Morgan Rum Company, www.captainmorgan.com, and the The LEGO® Group, www.lego.com/en-us/aboutus/lego-group.

least in the TV commercials, always thwart their adversaries with mischievous cunning. In young eyes, every museum ship[91] is a pirate ship and the indoctrination to the romanticized world of Caribbean swashbuckling begins at ages “6-12.”

For many scholars it is a frustrating circumstance that romantic notions frequently envelop historical and archaeological evidence. Perhaps the closest similarity to the seafaring pirate, albeit partly due to nationalistic fundamentals, is that of the “Viking.”[92] Melville’s “oaken box,” the USS *Neversink,* is a characterization of his life aboard the United States Frigate *United States.* This walled city, three stories high, 250 feet long and 40 feet wide, with 4 inches of oak plank separating the residents from unimaginable peril contained 450 men and boys. A repository wherein resided a mass of humanity greater than many towns of the day. Bodies crammed into an area only a fraction the size of most town squares; eating, sleeping and working unceasingly within a few apportioned square feet for months, if not years, on end. Death, misery, and boredom were commonplace to this way of life. A life that required total subjugation to one ruler, one man with definitive power over life and death, and one man with the final authority to administer either humane or sadistic forms of treatment and punishment for the slightest infraction. An existence that in many ways fulfilled the Hobbesian premise that life is “nasty, brutish, and short.” These facts transmitted authentic shipboard life and a life at sea through the millennia, up and into our current century. This truth lies in direct

[91] Between 1981 and 1988, while working as a maritime history interpreter on numerous museum vessels at least two or three times a day the question "Is this a pirate ship?" was posed by visitors of all ages but especially small children. This is not a phenomenon specific to North America. In the interceding 25 years, I have heard this question countless times and read many descriptive museum labels attempting to correct false notions throughout Europe.

[92] Cederlund 2011.

contrast to the previously discussed notions regarding freedom. Regardless of the reality, people flock to the dockside or museums in order to experience the object.

Apart from those travelers with the ability to book first class passage, it was not until well into the late 19th and early 20th centuries that passengers aboard ships enjoyed better living conditions than the crew of a man-of-war, coastal trader, or packet ship. The classic literary works by Melville, Conrad, Kipling and Dana all portray abysmal living conditions, brutality and a resigned complacency that one's own life could end at any moment and in absolute solitude far from the sight of land. Nonetheless, contemporary culture retains a romantic appeal to this lifestyle, regardless of the testimony gleaned from historic documents or archaeological sources. They forget the realities of a sea voyage and honor the memory of those who failed to return, and the mode of transport on which they departed.

Watercraft Signs and Messages

Symbolism is not a question of a developed versus a primitive form of thinking as there is an evolved social and psychological meaning to signs. The fact that watercraft messages continue to appear for interpretation signifies the importance of the object through to the present day. The selection of the particular gender pronoun is one of the best examples to highlight the elevation of the object above all others. Of all the "things" that surround us daily, watercraft are part of an infinitely small group of objects that receive the feminine pronoun "she" in romantic languages.[93] In selecting subjects for his paintings, Igor Medveldev-Mead was "partial in selecting those boats that appealed to

[93] Mellefont 2000.

[him] in their aesthetic order and in the privacy of the oval, feminine shape. There was mystery to that shape."[94] Jeffrey Mellefont, in researching his article *Heirlooms and Tea Towels*, searched for early literary references for the personification of watercraft by the feminine pronoun and noted that 1375 was the earliest recorded use by the *Oxford English Dictionary.*[95] Some scholars contend that the attachment occurred long ago and the special association formed between watercraft and humans revolves around the belief system and worship of the "Great Mother"–the feminine vessel from where life originates.[96] Neumann notes that in many languages the terms for ship and vessel are one and the same,[97] indicating a much greater significance in the selection of terms.

Along with the general acceptance of feminine personification, watercraft and seafaring metaphors, allegories, similes, sayings and witticisms permeate usage in the English language every day. How often do people, with little or no seafaring experience, who perhaps have never even been in close contact with a boat, use the terms "on an even keel," "we're all in the same boat," or "I've taken some wind from their sails?" To say, "we are all in the same car, cart or airplane," simply does not bring the same depth of meaning to the phrase. There are few who would not understand the phrase, "the rats are leaving the ship" (Figure 2.4). Moreover, in a figurative manner, if someone desired to communicate a negative impression of an event he or she might create an image of a ship striking an iceberg to suggest the sinking of HMS *Titanic* (Figure 2.5). Although most people around the world go weeks or months without ever seeing any form of

[94] Medveldev-Mead 2005, 11.
[95] Mellefont 2000, 5. The author searched as well but could locate no earlier written usage of the female pronoun as applied to ships and boats.
[96] Gimbutas 1989, 249; Schnier 1951.
[97] Neumann 1955.

Figure 2.4. "Rats leaving the ship" 2009. Palestinianpundit, http://palestinianpundit.blogspot.com/2013_08_25_archive.html. Accessed October 2013.

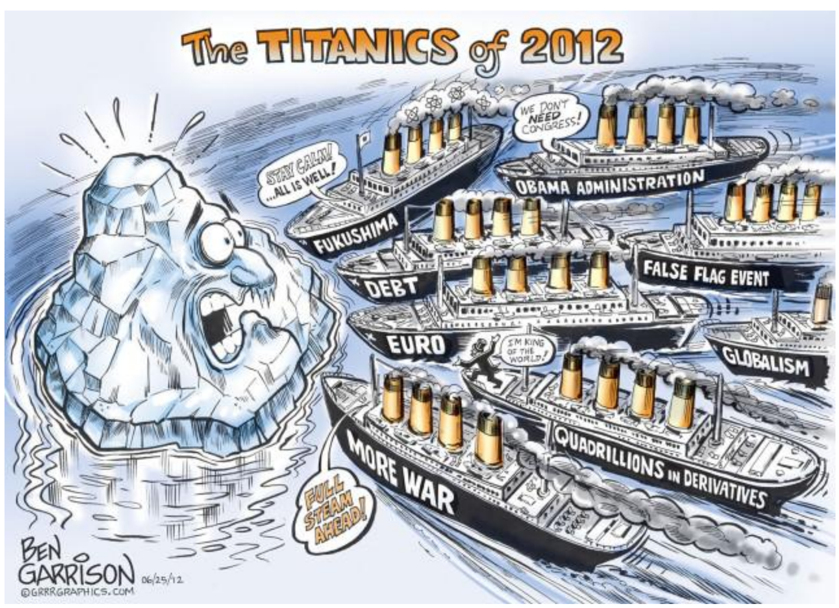

Figure 2.5. "Titanics of 2012"   GrrrGraphics. http://grrrgraphics.wordpress.com/page/2/. Accessed May 2013.

actual watercraft, signs that alert us to their presence encompass most spaces. So, commonplace, in fact, that an individual or society seldom takes notice. The current use and representation of watercraft is not unique to the 21st century; it has occurred in the written word over the last two millennia.

The messages projected by watercraft are so easily decoded that some of the greatest minds in history communicated through ship metaphors. Leonardo da Vinci (1452–1519) employed a combination of simple ship terms to convey the ethos of his approach to creative thought. "He who loves practice without theory is like the sailor who boards a ship without a rudder and compass and never knows where he may cast."[98] Benjamin Franklin, perhaps best known for advising his readers in *Poor Richard's Alamanac* "that a penny saved is a penny earned," also summoned watercraft imagery to suggest thoughts on other aspects of personal finance. "Beware of little expenses. A small leak will sink a great ship."[99] Icons of pop culture, including John Lennon, are included in the group, used ship imagery when he exemplified *The Beatles* pinnacle role within rgw "60s Movement." He reflected, "We were all on this ship in the sixties, our generation, a ship going to discover the New World. And the Beatles were in the crow's nest of that ship."[100] The use of ship imagery in symbolism is not however, only a tool for the Modern, Postmodern or Postcolonial periods. The Stoic Greek philosopher Epictetus (55–135) wrote, "we should not moor a ship with one anchor, or our life with one hope."[101] Ship allegories and metaphors pertaining to "the age-old symbol of man's

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[98] Kline 1972, 224.
[99] Franklin 1745.
[100] Miles 2009, 298.
[101] Harbottle 1906, 424.

ship on the voyage of life" were commonly used between 1500 and 1800 to characterize the psychological differences between stoicism and emotion.[102]

The exploitation of ships and seafaring to summon fiery, passionate images in the sermons of 16th and 17th-century Protestant ministers provided both hope and a sense of foreboding that kept parishioners along the desired path. John Calvin (1509-1564) offered comfort when he wrote, "Although we may be severely buffeted hither and thither by many tempests, yet, seeing that a Pilot steers the ship in which we sail, who will never allow us to perish even in the midst of shipwrecks, there is no reason why our minds should be overwhelmed with fear and overcome with weariness."[103] A century later, and an ocean away in the British North American plantation colony of Connecticut, the Reverend Thomas Hooker (1586-1647) selected words such as "Rocks and Sands" and referred to "a Ship that is foundred" and "Shipwrck" (sic.), all in an effort to offer rebuke and control over his congregation.[104] "Temptations," he intoned, "are as violent and boisterous winds, and raging waves, [which] Force the Vessel Out of the Channel and lift it upon the shore and shelves, where it is set on ground, if not split."[105]

Literary conventions, such as those introduced in the previous paragraphs, and pages, cartoons, paintings and musical lyrics are all components within the linguistic study of icons and symbols that comprises the sub-field of linguistics, semiology. By its nature, a symbol is a nebulous concept, dependent upon the laws or conventions governing the "interpretant" for understanding. The focus of symbolism is the

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[102] Grange 1962, 512.
[103] Dales 1862, 329.
[104] Carrol 1969, 38.

interpretation of the sign, which includes factors of placement and the surrounding environment, manner of use, shape and even color. Ships and boats signs have and continue to play a significant symbolic role in the extension of national or state interests, and the articulation of belief systems in many different cultures; from aspects of fertility and regeneration to mortuary rituals and votive offerings. All of which continue to form linkages, increase the value of artifact "singulariazation," and promote saving of watercraft

Inventory of Watercraft from Archaeological Contexts

A catalog of watercraft, compiled from a multitude of sources, relied heavily on published material, internet websites, correspondence, and where possible, direct personal contact. The greatest challenge to the data collection was the lack of communication concerning the material stabilization of many projects. Scattered references appear in numerous locations and the stabilization of the recovered object frequently receives little more than a passing mention.

Even harder to establish was the final depository for the material remains. Since the 1960s, archaeologists have produced commutative lists of watercraft for comparative analysis of type and construction techniques by citing reports, articles and unpublished manuscripts. Unfortunately, very seldom do any of these establish the artifact's final disposition or the location of a depository. With representative craft from 34 countries (Table 2.1), the catalog is extensive, but due to the aforementioned lapses in documentation and the sheer number of scantily published small craft in storage, it falls well short of representing a complete inventory. In the storerooms of institutions worldwide, there are considerably more disarticulated timber remains and structures in varying stages of preservation. Regardless, the inventory provides a very good representative cross-section and accurate sample of saved watercraft worldwide.

Sample Watercraft Saved From Archaeological Contexts

Country		Country	
Australia	1	North Vietnam	1
Belgium	7	Norway	10
Canada	10	Philippines	5
China	6	Poland	10
Croatia	4	Portugal	7
Cyprus	1	Slovenia	1
Denmark	18	Spain	1
Egypt	7	Sweden	10
Estonia	1	Switzerland	5
Falkland Islands	1	Turkey	40
France	19	Ukraine	2
Germany	20	United Kingdom - Channel Islands	2
Ireland	3	United Kingdom - England	37
Israel	2	United Kingdom - Scotland	3
Italy	13	United Kingdom - Wales	8
Korea	1	United States	27
Netherlands	29		
Nigeria	1		

Table 2.1. A sample of watercraft saved from archaeological contexts based on data queried from manuscript on file with the Conservation Research Laboratory, Texas A&M University.

Archaeology, Heritage and National Identity

Gibbons and Adams suggested that evolutionary development of maritime archaeology paralleled that of the rest of the field except for the fact that "the evolution from antiquities to connoisseurship to scientific wreck archaeology" was very compressed.[106] Almost a century before George Bass excavated Cape Galydonia, and the

[106] Gibbons and Adams 2001, 284.

recovery of the Bremen cog (1962), the watercraft from the Skuldelev blockage (1962), and the *Vasa* (1961), ships and boats were being professionally excavated and the public continued to locate artifacts along rivers, streams and during public works and private construction projects. Excavations of the bog at Nydam (South Jutland, Denmark) undertaken on three boats by Conrad Engelhardt between 1859 and 1863 was perhaps the first example of maritime/nautical archaeology and the first boat saved as a result of an archaeological excavation.

The discovery of a ship or boat does not automatically result in the saving of the artifact, but what is saved and what is passed on for reburial or destruction opens a window for further understanding the collective (state) and individual (personal) beliefs of that particular culture. The catalog indicates that the quantity of watercraft collected by a particular country (see Table 2.1) follows a predictable path based on national identity, and linkage to common usage, a specific person, event, location or type. In addition, the past maritime hegemonic powers of northern Europe, followed by the United Kingdom, constitute the greatest collections by number of vessels. The North American countries of the United States and Canada possess sizable collections but rank further down the list for understandable reasons. As younger nations, groups or institutions in both the United States and Canada have focused on building collections by recovering ships and boats through historic preservation rather than archaeology. Apart from Native American dugout canoes, which account for the overwhelming majority of collected archaeological watercraft, the record of use in the "New World" is much more recent than that of Europe.

Serving as the current or former maritime hegemon enhances identity but is not the only manner of creating connections with watercraft, a point supported by the recent excavation and collection of the Yenikapi shipwrecks (38 since 2005) in Istanbul, Turkey. Turkish interaction with the waters that border its lands has created a cultural maritime landscape, which manifested in the identification with watercraft, and leads to the collection of examples of that collective personality. This is a feeling that holds true for both the more powerful and traditionally weaker maritime nations. The 1979 discovery of nine *balanghay* boats in the Philippines "[drew] breathtaking attention among the Filipinos as they represented the relics of the main means of transportation in the islands many thousands of years ago and they are unparalleled in Southeast Asia."[107] The author of the statement triumphs the discovery of the small craft in his country. By using the expressions "breathtaking" and "unparalleled," he elevates the sense of national accomplishment.

Of the more than 300 watercraft catalogued to date, a little over a quarter are dugout canoes. If future research can establish better provenance for many watercraft that could not be included in the catalog at this time the percentage of the total would most likely nearly double. The three main reasons why the dugout canoe is singularly the most often saved form of watercraft are age, primitiveness and logistical ease. Everybody wants to be first, and the dugout represents one of the earliest structural marine forms. In countries where the current population can trace its collective ancestry back over the millennia, the collection of what could be the oldest bolsters connections with the

[107] Abinion 1989.

advancement of earlier cultures, which reflect back to the current culture in a positive light, elevating national esteem. In countries that were once colonies, the reverse psychology applies. The collection and display of unearthed indigenous artifacts considered "primitive" by the overtaking culture elevates the invader while debasing the indigenous population, allowing for a more palatable, or at least easier subjugation, acculturation or removal of the original residents.[108] The United Kingdom and her former North American colonies are ideal examples of collecting to establish pride in ancestral linkage (United Kingdom)[109] and colonial acculturation (United States, and to a lesser extent Canada). The abundance of these canoes along shorelines and riverbanks has greatly increased the probability of detection and ease of recovery. Finally, the size of the dugout, generally ranging from 3 to 10 meters, is the limit that most small institutions can afford, either financially or in the allocation of exhibit space. But by contributing what they can, in this manner, they too can participate in presenting the tangible evidence of their past.

In Scandinavian countries (Sweden, Denmark and Norway), the largest number of collected watercraft type are the Nordic cargo and military ships and boats representing the Viking period, followed by cogs (kogges) from the period dominated by the Hanseatic League. However, collections in Germany, the Netherlands and Belgium seem to be dominated by the dugout canoe followed by Roman-period river craft and cogs. In North America, after the dugout canoe, colonial period craft and examples from the two primary early conflicts, the United States Revolutionary War (1776-1783) and

[108] Trigger 1984.
[109] Fowler 1987.

the United States Civil War (1861-1865), prevail. It is the connection created by cultural artifact biography that creates the linkage between person and artifact, which in turn excites stakeholders and prompts the saving of watercraft. Certainly, many boats of alternative styles and types have been located through the years, but the range of what has been saved appears to be very limited.

The Impact of Cultural Resource Management

The emotions brought about by national pride and heritage linkage are important factors for saving watercraft. One perspective, expressed by Charles, Prince of Wales, in his "Foreword" to Margaret Rule's *The Mary Rose,* looks at the saving of tangible representations of heritage as a means to better understand modern society.

> The result of all this hard work and expertise is that future generations, we hope, will be able to glimpse a small part of Britain's maritime heritage; will be able to see history 'come alive' and to step, as it were, into the shoes of a Tutor seaman in the reign of Henry VIII. The only real way of understanding and coping with the present is, I believe, through the adequate knowledge and interpretation of the past.[110]

Another point of view, provided by former U.S. President Theodore Roosevelt (1858-1919), characterized humanity's impulse to save objects from the past, as a mark of that civilization.[111] That is, the care and the thought society devotes to the next generation, the people that have yet to come. Through preservation management regulations, nations have set standards and guidelines for managing cultural property when located in potential archaeological context, but no law specifically states that anything absolutely has to be saved. The decision to save watercraft is frequently an

[110] Rule 1982, Foreword.
[111] Kortum 1987, 30.

impulse act, one that is later rationalized and intellectually argued in justification of the act.[112] In fact, most preserved or recovered artifacts are the result of small groups of individuals working on behalf of personal conviction, not as President Roosevelt or the Prince of Wales proclaimed, with the care and thought of who else's heritage they were preserving with that piece of material culture. Heritage is very individualized, and occurs more habitually on a local or regional scale than on the national or international stage.[113]

One of the earliest ships found in an archaeological context, saved and placed on display, occurred in the United Kingdom around 1820. "Found in 1823 in an old channel of the River Rother at the west end of the Isle of Oxney, buried in 19 feet of deposit," it was hypothesized at the time that she was lost in the great storm of 1287, when Old Winchelsea was destroyed and the course of the Rother changed.[114] Sean McGrail noted, "after being excavated, lifted and put on display, it was destroyed when it no longer made a profit."[115] Although the manner of disposal would not be advocated today, the exposure of the watercraft in the riverbank is similar to the discovery of countless ship and boat finds. Of the examples recorded in the database, over 70% were "unintentional finds" (Figure 2.6). Since it was located as part of a dredging project, had the boat from the River Rother survived, like similar finds it would have been classified under the subheading "unintentional–civil/commercial projects". This category accounts for almost half of the watercraft catalog, and approximately 44% of the total of all entries discovered between 1950 and 2013 during civil or commercial projects.

[112] Alford 1989; Dodd 2001.
[113] Maarleveld 2012.
[114] Barnard 1902, 166.
[115] McGrail 1983, 9.

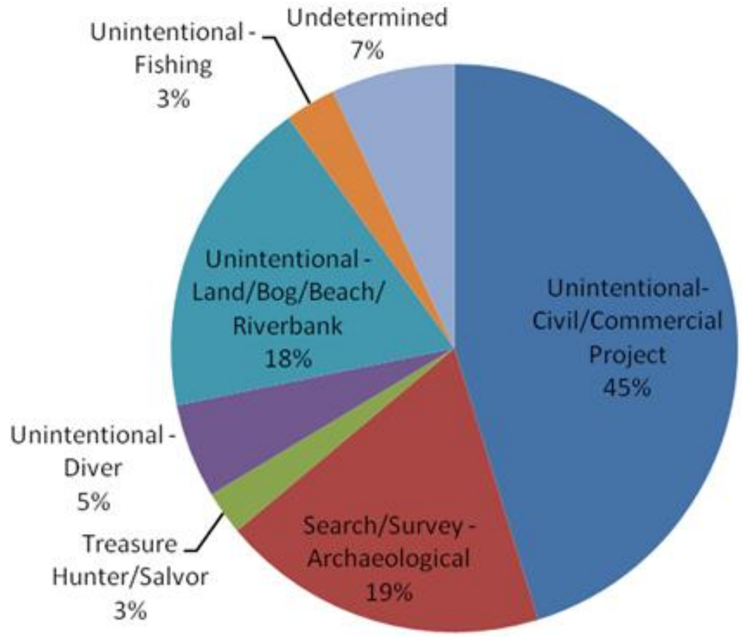

Figure 2.6. Chart illustrating the breakdown into the manner in which watercraft have been discovered.

What is truly unique for 1823 is that someone decided to save the 200-ton ship at all. One can only imagine that it must have been in nearly pristine condition for directors of the salvage crew to associate the discovered wreckage with an economic opportunity. Until perceptions regarding the value of cultural patrimony, and in particular watercraft, changed around the middle of the 20th century, most uncovered shipwrecks were seen as a hindrance to progress and a potential for lost revenue due to work stoppage. Such was the fate of the Bruges Vessel in Belgium.[116] In August 1899, while digging a canal in

[116] Marsden 1976.

Bruges, mechanical excavators uncovered a shipwreck, dated to the Roman period.[117] A Mr. Rutot along with a Baron A. de Loé representing the Museum of Decorative Arts visited the site and found the wreck only slightly damaged but otherwise in very good condition.

> They tried immediately to arrange for the preservation of the boat, but having been away from the site for only about one hour, on the return they were extremely astonished to find that the mechanical excavator, which, that morning had been over 100 m away from the site of the boat, had been brought up to the site in haste and had just reduced what was left to dust.[118]

Again, no national or international legislation forces individuals to save watercraft, only that they provide some form of mitigation. In fact, since the 1990s there has been considerable push for reburial and *in situ* preservation. Yet, the quantity of

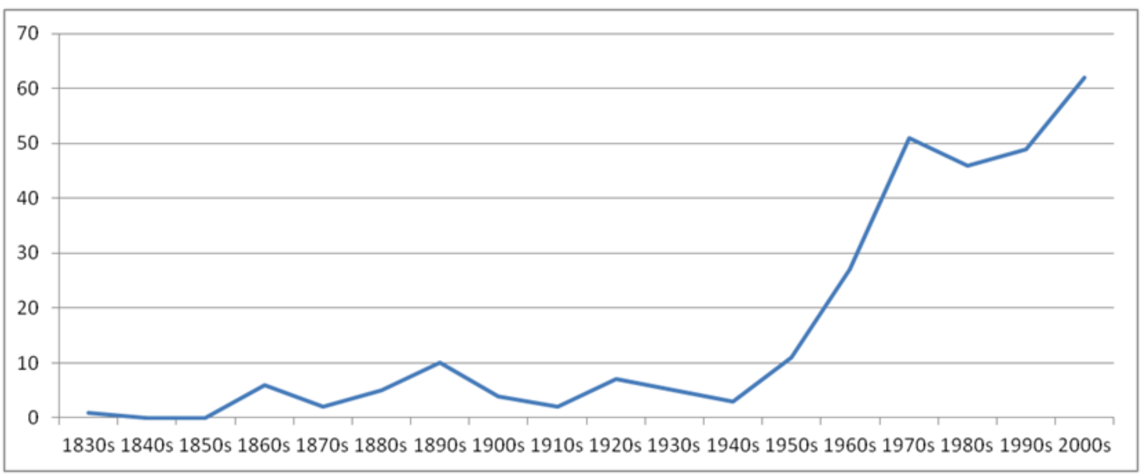

Figure 2.7. The graph illustrates the collection of watercraft by decade beginning at 1830 and ending in 2010. It illustrates the impact of cultural heritage management legislation on the collection of watercraft.

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[117] C-14 dating surviving fragments establishes that the hull is from the 2nd - century CE.
[118] Marsden 1976, 23.

saved watercraft, stabilized and placed on display continues at extraordinarily high levels. Of the total number of boats in the database, 73% were recovered since 1950 (Figure 2.7). The fact that nearly half of that number were found by "surprise" in the course of civil or commercial excavation projects demonstrates that emotion plays a pinnacle role in saving watercraft. Once uncovered, the artifact is suddenly elevated to the status of buried treasure or considered a major hindrance and an extra cost for a construction project.

The incredible amount of growth in the number of recovered watercraft between 1950 and 1970 is the result of a combination of factors. First, the linkages and connections discussed throughout this chapter concerning cultural artifact biography. In most people, many of these emotions remain dormant or hidden just below the surface. That is until stirred up when timbers emerge from the bucket of a mechanical excavator, when they strike with a impact similar to that of finding buried treasure (Figure 2.8). The buried treasure affect heightens curiosity, focuses fascination and stirs romantic images, which account for the second piece of the puzzle. The third factor stems from cultural resource management laws. Unlike the Bruges vessel in 1899, since the 1960s (in the United States for example but with similar occurrence selsewhere around the world) the discovery of a large archaeological find halts work in the immediate vicinity in order to determine "significance."[119] In the United States just about every watercraft found in that context could be classified "significant" under the legislation of the National Historic Preservation Act 1966, as amended. The longer the artifact receives exposure to the news

[119] National Historic Preservation Act (NHPA; Public Law 89-665; 16 U.S.C. 470)

media and public the more likely connections and attachments to that artifact will form, and before too much time passes someone will suggest that perhaps the structure should be saved.

Most archaeological watercraft have some amount of tourist value and frequently interested stakeholders use that notion as a justification for investing in the required preservation program. The narrative surrounding the saving for display of the Newport, Wales ship illustrates many of the principles discussed in this chapter. Shortly after the remains of the well-preserved medieval ship were discovered on a construction site in 2002, interest in saving the oldest medieval ship found in the United Kingdom for display began to be voiced.

> Officials are currently looking for a suitable lake or tank in which to store the timbers while they are investigated by archaeologists. But local businessman Charlie Ferris wants the ship put on display in the city, believing it could become a major attraction for tourists. 'It is like saying what price the Mona Lisa? It is a wonderful opportunity for Newport,' he said. 'It is a gift for the town and we should protect our heritage.' He added: 'We have had interest in this from Cincinnati and San Francisco - this artefact belongs to the world.[120]

For weeks, the Welsh campaign to "Save Our Ship" put considerable pressure on local authorities until it gained enough support to move forward with the project including standing a 24-hour vigil over the site to ensure no damage came to the ship and a small flotilla of pleasure craft sailed up the river to draw attention to the campaign. In the words of Welsh Finance Minister Edwina Hart, "the discovery of this rare national treasure has brought Newport to the forefront of national and international interest. The

[120] Anonymous BBC Online 14 August 2002.

ship will be a fitting symbol of the vibrant history and the culture of our newest city and Wales as a maritime nation."[121]

Figure 2.8. During building excavation at 300 Spear Street, San Fransico, Ca, the partial remains of a whaleship were uncovered, and the stern saved for future display. From Strother 2007, 82.

From several sources, 3.5 million British pounds were provided to the project for excavation, conservation, reconstruction and study through government appropriation.[122] Part of the funding included plans for a 280 square meter basement to be built under the

[121] Anonymous BBC Online 23 August 2002.
[122] Allocations were made through England's Heritage Lottery Fund.

ground floor gallery and main foyer of the new arts center where visitors would be able to view the ship through a glass floor, and through a viewing gallery on the lower level.

However, by 2013 those initial funds were nearly been exhausted, one year shy of completing the stabilization process of the waterlogged timbers.[123] A staff of 14 has been reduced to two or three people,[124] and if additional funding cannot be appropriated, or acquired in some manner, the artifact's future is most probably in jeopardy. If the course continues on the current track, at best the presumed protocol would be to dehydrate the timbers through lyophilization and then crate the final product, to be stored away from public view, or for some portion of the structure to be utilized for a minimalist display. The project was not mismanaged! For a waterlogged structure of its size, the fact that the documentation and conservation were almost completed after 11 years is evidence in support of this opinion. Yet, the project is in jeopardy. If a 12-year project cannot be sustained, how will the industry manage the 20 to 30 years required for a larger vessel project?

Undoubtedly, the required funding to complete the Newport Ship project will be developed but this is not always the case. In 1999, when the propeller wash of large vessels navigating St. Peter Port, Guernsey in the Channel Islands threatened the timbers of a Gallo-Roman shipwreck called *Asterix*, a rescue operation was undertaken to excavate and recover the ship remains. The timbers were transported to England for conservation but following stabilization there was no money available to pay for return

[123] Deans 2013
[124] Personal communication between Peter Fix, Nigel Naying and Toby Jones, April 2013.

shipping.[125] A similar circumstance occurred with a large portion of the stern that belonged to the whale ship *Candace*, rescued in 2006 after exposure during a public works in San Francisco California. The initial plan for the structural remains was to place them on display at a museum dedicated to the history of San Francisco. Failing to secure funds for the elaborate plans, the ship was put up for auction in August 2013 (Figure 2.9).

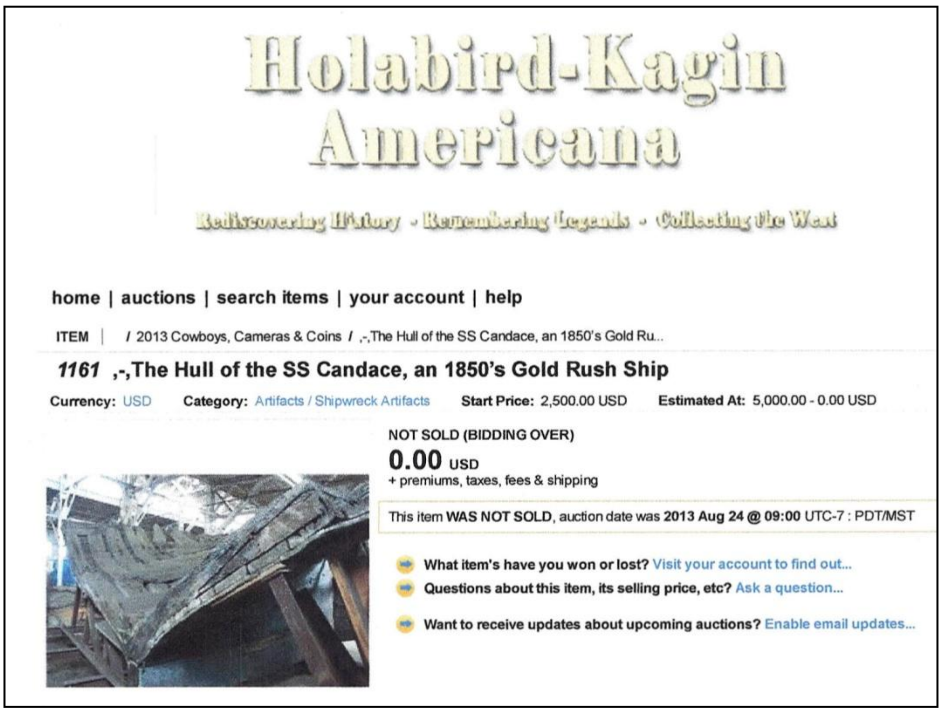

Figure 2.9. The online auction form for the whaler *Candace* showing a reserve price of $2,500 that was not met at auction. Internet download, http://www.icollector.com/-The-Hull-of-the-SS-Candace-an-1850-s-Gold-Rush-Ship_i16987167. Accessed Janruary 2014.

[125] Anonymous BBC Online 27 January2010,

Conclusion

An artifact biography constructed for watercraft, the specialized cultural traits formed by communities living along waterways or oceans, the potential influence of genotypes and phenotypes, and the allure of romanticism and heritage identity, all demonstrate the special relationship that developed between humans and watercraft over the millennia. While it may be true that watercraft are important socioeconomic vehicles for any given society, evidence of this special relationship elevates watercraft to something more than just ocean-going objects–they ascend to “singular” status. The sinuous bonds of attraction formed through these relationships have spread through everyday life from the earliest period dated by archaeological investigation and saved for posterity. The manner of attachment, ceremonial, secular and ritualistic, expressed by signs, continued to keep the importance of the object in a dominant place position during each successive cultural generation. Just as if on billboards by the side of the road, signs of the attachment are everywhere.

CHAPTER III

THE FOREST AND THE TREES:

THE STABILIZATION OF WATERLOGGED ARCHAEOLOGICAL WOOD

Introduction

Due to its degraded nature, the conservation of waterlogged archaeological wood is a reactionary function requiring invasive action that in many disciplines could be misconstrued as an industry in a state of perpetual crisis management. Without significant intervention, however, to offset the deleterious effects of a long-term immersion in a marine environment, the material would most likely be lost. From the moment of recovery, the item must remain wet, but it cannot remain in long-term wet storage indefinitely. That action only maintains the status quo, elevates long-term costs, promotes risk, continuing deterioration and the possibility of catastrophic loss. Decades of research into the act of reburial and *in situ* preservation show promise as potential depositories of the future by re-creating a suitable storage environment, but even these do not ensure long-term stability for the myriad of discovered resources, and just because an artifact assemblage is out of sight does not alleviate the costs associated with perpetual monitoring. Although the rate of deterioration in an anaerobic burial environment will be reduced, deterioration does not completely cease. When deemed special, of a particular age, or found as part of a “rescue operation” where the structure might be destroyed, seldom is an ancient structure relocated and reburied, or left in place as highlighted in the previous chapter by the 2012 discovery of whaling vessels in a Western Australia parking lot. Instead, all or a portion of the structure is transported to a conservation lab for stabilization, and eventual installation in a museum display or placed in long-term storage. Yet with the wide disparity between museum environments, once on display or in storage there is no guarantee of preservation and many substandard museum storage environments have proven inadequate and destructive to the watercraft artifact.

Although the focus of this analysis is the conservation of wooden watercraft, due to the primary construction material and the manner in which the conservation community has grouped large structures and small artifacts or fragments together, no assessment would be complete without a general discussion of waterlogged wood conservation. In order to tie together general conservation issues with watercraft, the literature review that appears within this chapter reveals the ethos and development of professional practices concerning the conservation of archaeological waterlogged wood over the last 150 to 160 years.

Even though there are many differences between a large timber that must respond accordingly within an integrated system and small, lightweight objects or fragments, the conservation community traditionally applied the same philosophical approach to the two categories. That is to focus on the dimensional stabilization of the artifact.[126] The potentially adverse side of this discussion is that, ultimately, the requirements become significantly different and it is often very difficult to scale-up a procedure that worked in the lab to a large integrated structure. The task of stabilizing waterlogged wood, while a

[126] Christensen 1970.

seemingly simple process, is in fact very difficult to achieve with 100% accuracy and precision.

From its inception as a field of study in the early 1860s, conservators, conservation scientists, wood technologists, chemists, physicists, archaeologists and engineers have tried to tackle the issue of conservation and produce consistent satisfactory results. Well into the second century of approaching the subject through scholarship and the scientific method a considerable amount of work has gone into understanding how hydrolysis of wood occurs and how microbial and zoological organisms degrade the chemical and physical constituents of the polymorphic structure, and in developing methodologies to counteract the natural forces. In 2014, stabilization methods are generally more reliable than in previous decades; nevertheless, few in the conservation field would suggest for one reason or another that there is 100% satisfaction with any one particular method or material, and most agree that the need for new methods and materials exploration is a continuing requirement.

Wood Composition and Decay in the Marine Environment

Wood is a natural composite material, formed by the generation of polysaccharide and polyphenolic chemical chains that take the character of long tubular-shaped hollow cells. Wood cells have two major functions. While the tree grows, the cells in the sapwood transport moisture and nutrients from the roots at the bottom to the canopy of leaves at the top. In the leaves, the combination of moisture, carbon dioxide and sunlight generate sugars through photosynthesis that aid in the growth of more fibrous, cellular materials. The second function of the wood cells, situated between the sapwood and the pith, is to store moisture and physically support the structure of the tree. The polyphenolics form lignins and act as a matrix for the long, high tensile strength polysaccharide chains of cellulose. Within the ultrastructure of the cell wall cellulose, hemicellulose and lignin form four primary layers with the fibrillae of each layer designated S_1, S_2 and S_3 oriented in a different direction. In cross-section, the wood cells appear as a stiffened bundle of pipes; strong and rigid, yet hollow and light. This chemical and physical structure produces the high strength to weight ratio characterized by wood.

The moment felled by saw or ax, the tree dies and wood decay processes commence. The rate of decay is a function of the wood species and the depositional environment. When immersed in marine surroundings wood decays by three primary processes–zoological, microbial and cellulolysis, a form of hydrolysis. Wood exposed to an aerobic water column will most likely undergo rapid decay, especially in sea environments, because of the voracious appetite of the common shipworm (*Teredo navalis*). A marine bivalve mollusk shaped like the common earthworm, the animal possesses two calcareous plates on its leading end that act as valves to rasp at the wood and enlarge its burrowing tunnel. The mollusk's movement through the wood is rapid, and within months or a few years, very little of the wood's original mass or volume may remain. As the boring progresses, the animal secretes a thin calcareous shell around its body. When the animal dies, all that remains is a circular tapering calcareous lined tunnel winding deep into the wood and ranging in diameter from a few millimeters up to perhaps 2 centimeters. The remaining integrity of the adjacent wood fabric is, to some extent, maintained by this calcareous lining, but the riddling of the wood, like Swiss cheese in cross-section, perforates and decreases the density and therefore the physical strength of the wood. Very often, if the calcareous material were removed the macrostructure of the wood could easily collapse.

The first stories, recounting the boring marine bivalve's depredations to ships sailing in temperate waters, date to the earliest European voyages to the New World.[127] It was a Mr. Wilcox of His Majesty's Dockyard at Portsmouth in 1833, however, that relayed one of the most poignant observations to the potential devastation wrought by the animal's tunneling.

> I have never witnessed any that evinced more clearly the danger to be apprehended from them, than in the instance of their attack on this ship. I have invariably found, on examining defects occasioned by the teredo, that the perforation approached the inner surface of the timber to within even the thickness of a wafer.[128]

Exposed shipwreck timber will be degraded by *Teredo navalis* as long as it remains in an anaerobic environment. At a certain depth, oxygen depletion under the silt reaches a point where the animal can no longer survive, but depending on sediment morphology and compaction, that could be several inches beneath the sediment surface. Coupled with periods of scouring and reburial of the wreck, the depth of penetration in recovered archaeological wood results in a material where, even though buried, not only the natural composite material has degraded, but also the internal volume is considerably less than indicated by measuring the exterior elevations.

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[127] Morison 1970, 633.
[128] Wilcox 1933, 280.

Burial in an anaerobic, or minimal oxygen environment, may protect the wood from marine mollusks, but where there is at least some available oxygen, internal decay may continue on the microscopic level.[129] Erosion bacteria generally attack the cellulose and hemicellulose on the inner layer of the cell wall and over time; they migrate to the outer layer as well. The microscopic perforations left by this metabolization process fill with water, which acts as the internal support for the remaining polymer structure. Without gentle removal of the water and replacement of lost material, the cell wall will shrink and possibly collapse. Therefore, moisture content is the primary parameter to measure decay in archaeological wood by determining the amount of moisture held within the cells and voids. The greater the moisture content the more degraded the polymorphic structure. This method of analysis provides one of the best analytical tools for determining the extent of wood degradation. The procedure presumes that as cellulose and hemicellulose disappear from the cell wall water enters and fills all voids. The process follows along the same lines as determining moisture content of wood for everyday use.[130] By weighing a sample of waterlogged wood, oven-drying the material to drive off any remaining free water in the sample, and then re-weighing the oven-dried product, it is possible to determine the moisture content as a percentage of weight. The formula follows–waterlogged weight (-) oven dried weight (/) by waterlogged weight (x) 100 (=) moisture content (also known as Umax). Through the development of moisture content, a rating system for degraded waterlogged archaeological wood was devised and

[129] Nilsson 1999.
[130] American Society of Materials Testing- D4442-92, 2003.

continues in use today as a means of communication amongst conservators.[131] This system divided waterlogged wood into three categories. Category or Class I accounts for wood with moisture content over 400%. Class II waterlogged wood ranged between 185% and 400%. Finally, Class III, the least degraded material, encompasses waterlogged wood with moisture content less than 185%.

Deterioration by erosion bacteria and cellulolysis occurs from the exterior surface toward the interior. This action creates non-homogeneous degradation patterns causing the artifact to act as if it were made from two distinctive composite materials, and focusing a treatment regime on one may cause shrinkage, collapse and damage to another. Coring samples for moisture content analysis is a very destructive process and depending on the watercraft's scantlings could pose aesthetic issues if the structure is subjected to too many large perforations. The procedure is also very time-consuming, in particular if dealing with medium-sized or large artifacts.

In order to detect the interface between the more solid core and degraded outer layer, a simple pin test described by Christensen[132] has been used for analytical purposes on numerous projects.[133] By pushing a straight pin into the timber one person can quickly learn to gauge the level of extreme deterioration and map degradation patterns. The test is effective but only provides qualitative analysis. Following a similar principle, a rapid nondestructive method introduced by Clark and Squirrell in 1985[134] utilized a Pilodyn® wood density meter to assess the timbers of the *Mary Rose*. The methodology is similar

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[131] De Jong 1978, 5.
[132] Christensen 1970.
[133] Terfve, 2002.
[134] Clarke and Squirrell 1985.

to the manual pin test but the density meter provides an actual number for resistance and therefore testing is both rapid and quantitative. In the case of the *Mary Rose*, the instrument was employed under water before timber recovery and following 10 years of wet storage while preparations were made for the stabilization process to detect microbial deterioration.[135] It has been applied on other projects,[136] and subsequent work has been conducted to determine standard practice as it applies to waterlogged degraded wood.[137] When used in conjunction with core samples for moisture content analysis and a Sibert decay detecting drill[138] a very good understanding of the deterioration in the wood can be achieved on many levels in order to select the most favorable stabilization materials and methods in order to maintain the dimensional stability of the artifact.

Doctrine Governing General Method and Practice

The guiding principles that direct the manner in which conservators approach the stabilization of waterlogged archaeological wood evolved from a combination of physio-chemical requirements and socio-cultural desires. In Collin Pearson's *Conservation of Maritime Archaeological Objects* (1987), David Grattan and Richard Clarke listed four underlying principles that continue to govern methodological practice to the present day. To Grattan and Clark, the stabilization of archaeological wood required that the article (1) retain its waterlogged, swollen shape,; (2) be durable,; (3) be reversible; and (4) the process constitute minimal intervention.[139] With the inclusion of (5) a fifth principle proposed by Collin Pearson several years earlier, "only if the technique for small objects

[135] Mouzouras 1987a; Mouzouras 1987b; Also Mouzouras, et al. 1990.
[136] Clarke, Squirrell, and Gregson 1986.
[137] Gregory et al. 2007.
[138] Panter and Spriggs 1997.
[139] Grattan and Clarke 1987, 164.

can be upgraded for large objects should they be considered,"[140] these principles form the blueprint concerning the conservation of waterlogged archaeological wood since the 1960s, with aspects extending as far back as 1860. Each of these five principles is discussed in detail below.

Although not frequently or formally enumerated in published materials additional requirements influencing the manner in which individuals choose to select a particular conservation approach include (6) the notion that conservation materials should have a low mammalian toxicity, (7) exhibit ease of use, and (8) be as cost-effective as possible. Standing on a platform constructed by these beliefs, in 1981 Collin Pearson[141] reminded the assembled participants at the First International Council of Museums-Conservation Committee, (ICOM-CC) working group for Wet Organic Archaeological Materials (WOAM), held in Ottawa, of the research initiatives adopted at a 1978 Zagreb meeting:

1. "Use of detergents in the conservation of waterlogged wood.
2. Use of tetraethyl ortho silicate.
3. Problems connected with the salvage of waterlogged wood.
4. Freeze-drying.
5. Methods of analysis of PEG in waterlogged wood.
6. Use of sucrose.
7. Use of organic polymers.
8. Irradiation techniques.

Further activities have been added via the [WOAM] Newsletter, including;

9. Analysis and research.
10. Treatment of large ship' timbers.
11. Acetone/Rosin process.
12. Controlled drying.

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[140] Pearson 1981; 56. Pearson's statement arose from discussions held at a 1977conference at The Hague regarding the possible recovery in conservation of the Dutch East Indiaman *Amsterdam*.

[141] Pearson 1982; 7-8.

13. PEG impregnation.
14. General interest.

During the 30 years since Pearson penned this list, the conservation community has continually introduced and tested new materials and methods, and judging their efficacy using the parameters governed by the aforementioned principles. Many of the materials tested have quickly fallen into disfavor due to ineffectiveness at meeting the physio-chemical requirements. Other materials, although proven to be viable, at least in the short-term, became unpopular due to biases generated by adherence to social standards. In their place, conservators and conservation scientists presented new materials and methods for evaluation, and scrutinized and compared the new with established methods. Slowly the available number of treatments grew, but the search to find better materials and methods continues. Interest in many of the original topics presented by Pearson's list has dwindled over the years, replaced by new topics that reflected the needs of changing societal expectations–but the base principles remain.

Principle #1–Dimensional Stabilization of Wood in the Swollen State

Maintaining dimensional stability, i.e., guarding against shrinkage and collapse, has been the all-encompassing goal of waterlogged archaeological wood conservation from its earliest inception. The desire to maintain the shape of the waterlogged form in its swollen state derives from three specific criteria: (1) "avoid collapse caused by capillary forces," (2) "avoid shrinkage by substituting the hygroscopically bound water in the cell wall by a bulking agent," and (3) "support and stabilize the degraded wooden structure at a macroscopic and microscopic level."[142] David Grattan expressed his thoughts on the subject of maintaining the swollen volume of wood in his 1982 comparative study of treatments.

> However, there are two very clear advantages in maintaining the swollen condition. Wood which has been seasoned to a low RH before saturation is forced to expand on waterlogging in what is essentially a restrained condition. The compressive forces produce irreversible cell damage at this time, which means that should the wood be returned to the original RH, checks and shakes will appear. The treatment which aims to produce a wood with something less than the swollen dimensions would be inclined to favour the formation of cracks the swollen state can be thought of as a reference condition, from which the original dimension can be approximated if desired.[143]

Grattan's statement expresses a specific intent to devise a treatment to stabilize waterlogged wood in its swollen form. The underlying premise of design, however, is compromise, and the maintenance of wood in the swollen volume while understandable, elevates that particular criterion. The promotion of one criterion leads to the demotion or the giving up of some other property or characteristic. In the case of waterlogged archaeological wood, the ultimate strength of the conserved wood has frequently been sacrificed for dimensional stability in the swollen state and the prospect of reversibility. This resulted in heavy, often overbuilt support structures that appear to float the hull on a forest of steel, or structures insufficient to support the weight of the integrated material that led to structural deformation.

The attempt to retain dimensional integrity is the oldest and most enduring of all of the five principles. It was the requisite goal of Danish researchers from Denmark's National Museum during the early 1860s, who were confronted with a large number of

[142] Jensen, Jørgensen, and Schnell 2002; 328.
[143] Grattan 1982, 124-125.

waterlogged antiquities unearthed in the process of cutting into peat bogs for the acquisition of fuel. "As the wood was quite spongy and full of water, the problem was to find a substance which could simultaneously displace the water and fill the pores of the wood with a mass that would congeal and thereby impede the shrinkage of the wood when drying."[144] In 1861, C. F. Herbst published the first known article on the subject, appearing in *Antiquarisk Tidskift* under the translated title "On the Conservation of Antiquities of Wood Found in Peat-Bogs." The material examined and selected by Herbst was potassium aluminum sulfate *dodecahydrate* – ($KAl\ (SO_4)_2{\bullet}12\ H_20$), also known as the alum treatment method. For the Danes in 1861, alum seemed to meet their criteria and solve the challenge of stabilizing waterlogged wood. Boiling the wood in a supersaturated solution of alum followed by drying and applications of a coating of linseed oil effectively displaced the water held in the wood pores and maintained a reasonably good shape with little shrinkage. The process was successful enough that both the original treatment and adaptations of the process continued in use around Scandinavia until serious issues concerning the treatment's long-term stability became evident in the late 1940s, which prompted widespread discontinuation of its use in the 1950s and 1960s.

The conservation community has been so intent on maintaining dimensional stability that nearly every experiment and treatment evaluates the performance of a chemical or method by calculating the shrinkage parameter known as anti-shrink

[144] Christenson 1970

efficiency (ASE).[145] The general rule for its application is to separate a sample of waterlogged wood before treatment and then air-drying it to assess and measure shrinkage of the control piece. This is followed by a standard course of treatment for the second sample (S_2) and then measuring the amount of its shrinkage. A quantitative percentage for anti-shrink efficiency can be calculated by the formula, S_1- S_2/ S_1 x 100. Shrinkage and dimensional stabilization are of course imperative criteria; however, as previously mentioned engineering design is always a compromise and the strong focus on volume retention shifts focus away from other important aspects including the general decrease in strength of the material or alteration of known properties for which the material was originally selected. With small artifacts or fragments, this condition may not constitute a significant issue. The greater the quantity of required chemicals, however, when coupled with a more complicated composite assemblage of materials, the more crucial issues of increased mass, strength requirements, or other physical properties may become.

Principle #2–Durability

The degraded nature of waterlogged archaeological wood requires that a treatment not only retain the swollen volume, a state of nature where the composite material is weakest, but also adds strength and cohesion to the final product.[146] At the same time, the stabilizing material must have certain longevity to ensure that the measures undertaken to stabilize and conserve the object do not ultimately degrade and cause irreparable damage to the artifact. This portion of the concept has led to issues in

[145] Giachia et al. 2010; Barbour 1985; Imazu, Morgôs, and Sakai 1999.
[146] Morlat-Thésis et al. 2007; Also, Christensen 1970.

some cases regarding the inappropriate selection of materials. Some chemicals once thought to be completely innocuous, or at least relatively reversible, are beginning to degrade after less than 50 years of service life. The byproducts of the deterioration process may pose risks to the historic integrity of the conserved substrate, or documented interaction with moisture and oxygen in the environment that altered the overall character of the conservation medium (i.e., the alum method, acetone rosin and tetraethyl ortho silicate). Durability also creates issues of scalability in that what may be a reasonable risk on a small scale may expand geometrically when subjected to a large artifact.

Principle #3–Reversibility

To understand the theory behind the "reversibility" standard in conservation, one must refer to the founding period of modern preservation practice. In 1903, Alois Riegl, an accomplished Viennese art historian, published his seminal work *Der moderne Denkmalkultus. Sein Wesen und seine Entstehung*, which translates into English as *The modern cult of monuments: Its nature and origin*. The work was the culmination of decades of philosophical thought concerning the treatment of heritage monuments from the perspective of the "anti-scrapers." Riegl's assertions represented the thoughts of many in the 19th century who opposed the heavy-handed restoration treatments of European cathedrals and medieval architecture by the Romantic Nationalists of the Second Empire ("Scrapers") and their leader, the architect and writer, Eugène Emmanuel Viollet-le-Duc (1814-1879). Viollet-le-Duc supported a restoration philosophy that sought "to establish a completed state which may never have existed at any particular time."[147] Other notable opponents to the "scrapers," whose published works created the context in which the *Cult of Monuments* could be written, included John Ruskin (1819-1900), William Morris (1834-1896) and Adolphe Napoleon Didron (1806-1867).

In 1849, John Ruskin published *Seven Lamps of Architecture* in order to express a preservation ethos that future generations could follow. These seven lamps could as easily be, and on occasion are, referred to as the seven pillars–"sacrifice," "truth," "power," "beauty," "life," "memory," and "obedience"[148] of preservation. William Morris was one of the principal founders of the Society for the Protection of Ancient Buildings, which sought to advocate for the preservation of buildings in order to contest the alteration of the individual form. Finally, the French art historian and archaeologist Adolphe Napoleon Didron (1806-1867) in 1839 wrote, "it is better to preserve than to repair, better to repair than to restore, better to restore than to reconstruct,"[149] which has become the hierarchical configuration of contemporary applied preservation and conservation standards.[150] The philosophies of these men form the basis of modern contemporary theory and professional practice in most cultural preservation fields. Once their philosophical foundation cured, the 20th century became an environment primed to establish a definitive working ethos that attempted to respect the historic nature of the structure (whatever the form) and do no or as little harm as possible to the object.

The essence of an object, including evidence of its origins, construction details, the method of its manufacture, and protection of the object's character and integrity is a

[147] Viollet-le-Duc ([1854] 1990), 195.
[148] Ruskin ([1849]1989.
[149] Didron 1839.
[150] Preservation is preferable to restoration and both are favored over reconstruction.

bedrock principle throughout the discipline of art and antiquities conservation,[151] and manifests in the assumption that treatments are not everlasting. Many who comply with this objective contend, “reversibility requires discipline in the use of materials and the rejection of some, however convenient they may be. It recognizes the future and it’s yet unknown methodology.”[152]

Beginning in the late 1940s and lasting into the 1960s a myriad of modern chemical products entered the marketplace, a result of World War II research and development. Many conservators embraced the new materials, such as polymers requiring radiation or condensation to cross-link and polymerize inside heavily degraded artifacts. Concern arose over the use of these materials due to recently developed understanding regarding detrimental processes applied during the last half of the 19th and the first half of the 20thcentury, such as the repeated hydration and re-crystallization of alum in the interior of treated wood. In addition, surface treatments and adhesives including shellac, cellulose nitrate, acetate and plaster of Paris, aged differently and many of these products bonded to the friable objects that they were intended to protect. The numerous treatments made possible by the new chemistry brought about concern that unbridled enthusiasm for the modern products would lead the conservation field down previously untraveled paths and that, at least for the moment, perhaps only treatments that could be removed–“reversed”–should be considered for art and antiquities conservation.

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[151] Barclay 1999, 157.
[152] Warren 1996, 41.

Precisely when and where the term “reversibility” came into common vernacular as a professional standard remains uncertain. The term first appears in the 1961American Institute of Conservation (AIC) Code of Ethics, but little mention was made of the concept in conservation literature. A scan of abstracts in *Studies in Conservation* between 1952 and 1970 yielded only one 1967 reference to the possibility of reversing a treatment.[153] Paper conservator Richard Smith provided a definition of reversibility in his 1966 article entitled “Paper deacidification: a preliminary report,” as “the ability of the conservator to remove any residue introduced into the paper by preservation treatment.”[154] The word does not appear in the Venice Charter (1964) that laid the theoretical groundwork for much of the heritage legislation in the second half of the 20th century. No reference could be located in Howard Plenderleith’s seminal work *The Conservation of Antiquities and Works of Art*, 2nd Edition (1971). In 1972, Plenderleith however made mention of the concept without using the word in an opening address at the *Preservation and Conservation: Principles and Practice* regional conference. “In conservation work, there is a dictum that nothing should be done that cannot, if necessary, be undone easily in the future.”[155] Throughout the 1970s, reference to the word in publications became more prevalent, but by the date that the Grattan and Clarke chapter listing the four basic principles appeared in print, many in the conservation community had begun to acknowledge that no treatment was truly reversible. The concept was “an aspiration rather than an achievable aim,”[156] and although well

[153] Munnikenddan 1967.
[154] Smith 1966.
[155] Plenderleith and Werner 1972.
[156] Seeley 1999, 161.

developed and constructed with sound intent, "like the existence of God himself [was] not demonstratable," (sic) and "visually flawed."[157] The shift instead, focused on the pursuit of "retreatability."[158] Yet, even under a standard of retreatability, while many conservators acknowledge this paradigm, a great number continue to remain faithful to the concept of reversibility if possible.

> While no treatment is 100 percent reversible, Museum staff aim to come as close as possible to that standard. Since methods for cleaning, reassembly, and restoration are subject to periodic reevaluation because of technical innovations and changing values, it is important that work be reversible so as not to impede the efforts of future conservators.[159]

Realistic grounds for deviating from the reversibility/retreatability standards would be that the use of a non-reversible product outweighs the alternatives, which would be to replace the degraded material either in part or in whole. On occasion, waterlogged wood meets that criteria; but the overwhelming majority of conservators–in particular, those endeavoring to stabilize waterlogged archaeological wood–continue to search for chemical treatments and methods that would be theoretically reversible or at least re-treatable.[160] Some acknowledge the irreversibility aspects of certain methods proven successful, and choose to select reversible treatments, making exception only under the most rigid criteria.[161] While others acknowledge the drawbacks of previous treatments, upon final analysis they believe that for the cultural patrimony under their

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[157] Smith 1999, 100.
[158] Applebaum 1987. Pavelka 1999.
[159] J.P. Getty Museum explanation of reversibility 2013.
[160] Morlat-Thésis et al. 2007.
[161] Chaumet, Albino, and Tran 2011.

stewardship the prospect of retreatability with another chemical or method is an important objective to maintain.[162]

The concept of reversibility is an ethical decision based upon what the conservator believes is best to manage the material integrity of the object under his or her stewardship. Therefore, a range of approaches to the standard has developed over the years–from dogmatic acceptance to a case-by-case rejection and all out dismissal of the premise. Frequently a particular product or method will create a culture of acceptance concerning the irreversible aspects of a material and individuals or labs will widely sanction the use of that one product. One example is the continued use of melamine-formaldehyde resins (condensation polymers) to conserve Roman period river barges at Museum fuer Antike Schiffahrt (Museum of Ancient Seafaring) in Mainz, Germany, which is a division of the Römisch-Germanisches Zentralmuseum (Roman-Germanic Central Museum). Another example is the use of cross-linked silicone oil at the Conservation Research Laboratory and Archaeological Preservation Research Laboratory at Texas A&M University. In these cases, conservators have concluded that the product was sufficiently safe for long-term use and that the advantages of using the product outweigh the loss of ability to treat the artifact with another material. If necessary, both techniques allow for the treated object to be retreated in the future by the same process. Reversibility and retreatability will continue to remain integral aspects of the conservation field governing action and spurring healthy debate for many years into the future.

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[162] Hocker 2010.

Principle #4–Minimal Intervention

Although a well-intentioned goal, the degraded nature of waterlogged archaeological wood generally requires considerable "internal consolidation"[163] and bulking of the cellular structure with some sort of chemical medium. Therefore, one can hardly consider the general practice of treating waterlogged wood as "minimal." The problem with the concept of "minimal intervention" is that it is an ill-defined and ambiguous concept that entered the conservation vernacular in the late 1970s and 1980s as a corollary to the reversibility standard. The primary question that arises with the statement is what does "minimal" actually require? As exemplified in the first sentence of this paragraph, not all situations apply to a single item. In relation to the conservation of waterlogged organic artifacts, the phrase has generally applied to mean a well-informed approach toward the artifact. For example, the level of degradation and the patterns of decay should determine selection of the conservation treatment, keeping in mind that the best treatment known might not be the correct one for every situation. The method of intervention that least affects the character of the original material will be the best depending on the degree of decay and expectations of future performance. In reality, the conservation treatment may have only one successful chance to stabilize an artifact and that is during the first attempt. Thus, the conservator must try to select a treatment that produces the desired results and can be retreated in the future if required, not simply one that is "minimal."

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[163] Applebaum 1987.

Principle #5–Scaling-up

Many proposed treatments for the stabilization of waterlogged archaeological wood cannot be scaled-up to even the smallest sized watercraft, which limits their viability due to logistical and economic constraints, or human health implications. Integrated structures have different physical and engineering requirements at both the macro and microscopic level of the substrate. Apart from the dugout canoe, all watercraft are integrated structures, or components erected into a larger unit. Each element has its own role and requirements within the unit. In addition, the larger the object, the greater the difficulty when trying to re-treat the item if the wrong material was initially selected or improperly applied, leading to an unsatisfactory result.

In the case of the largest saved watercraft (the *Vasa* and the *Mary Rose*), when the artifact is so large to necessitate enclosing the final wall of the building after the object has been brought within the confines formed by the other three walls, the possibilities of future interventions are extremely limited. Therefore, the question arises whether scaling up treatments should be considered criteria for archaeological wood conservation in the future. Small objects have particular requirements as do larger watercraft. Therefore, the development of future theoretical thought and practice should focus on the ability to meet required standards for the specific integrated structure, not simply to "scale up" what has proven to work with smaller objects.

Conclusion

The breakdown of wood and the five underlying principles described in this chapter control much of the theory and methodological practice for the conservation of archaeological waterlogged wood. All are important criteria to manage the safe removal of water from the structure of the wood while imparting some semblance of consolidation. The fact remains however–in design, the selection of one criterion over another (for example, selecting volumetric stability over strength) demotes the latter property's impact on the outcome of a treatment regime. Wood is a natural polymer, and as such deterioration occurs heterogeneously. The focus on dimensional stabilization, durability, reversibility, minimal intervention and scaling up, while at the same time attempting to create dynamic displays that place stress on the integrated structure in ways that it was not designed for, will over time continue to create problems that will have to be managed. Stalwart adherence to these principles shaped the development of theory and practice of waterlogged archaeological wood conservation over the last 160 years and has been noted through a review of literature on the subject.

CHAPTER IV

TRENDS IN THE CONSERVATION OF WATERLOGGED WOOD

Introduction

One could approach a literature review of the immense body of work associated with the subject of waterlogged archaeological wood conservation from two directions. The first and more popular method, employed by most conservatories, is to list and discuss the principal materials and methodologies utilized during the stabilization process. What treatments were satisfactory, and which provided less than desirable results. Along with the 1987 Grattan and Clarke literature review already cited in Pearson (1987), several other authors have provided detailed descriptions of the different chemicals or processes used over time for the stabilization of waterlogged wood.[164] This manner of topic enumeration however, provides a very linear perspective that tends to highlight only the most frequently utilized treatments, making the literal mountain of documents on the subject difficult to synthesize. When only a couple of materials or treatments come to the forefront of any discussion, it is easy to lose sight of the industry's developed character and the amount of effort required to reach the current state of methodological practice. The alternative direction, taken in this chapter, attempts to codify the mountain of literature by looking at trends over time in search for the aforementioned developed character.

[164] Grattan and Clark 1987; Smith 2003; Margos et al. 2008.

To assess the complete picture of contemporary practice, from the late 1950s through to 2013, approximately 1,100 articles necessitated review, classification and cataloging into a database (manuscript on file at the Conservation Research Laboratory, Texas A&M University). The number does not constitute the entire body of work on the subject, but a substantial portion of published materials, particularly as they relate to watercraft conservation. Therefore, eliminated from consideration were articles concerning the conservation of waterlogged lacquer-ware, furniture, and many of the articles focusing on adhesives or the application of stabilizing media to other forms of waterlogged organic materials such as leather, wicker and cordage. In addition, since the selection of categories is the result of the author's qualitative judgment, results did not achieve 100% precision; however, there is sufficient accuracy to discern trends and formulate a reliable perspective on the conducted work.

Within the index, each article received a category classification based on its focus. The catalog divides the literature into three hierarchical levels. Level #1 classifies material based on the broadest terms and Level #3 on the most detailed. Level #1 only includes three categories "Analysis," "Treatment," and "Case Study" (Table 4.1). Since the focus of the original article directed its categorization, it was not always a simple task to determine topic headings because individual articles frequently referred to multiple subjects. This created crossover and the blurring of some lines between categories. One example of the duality between hierarchical levels is the literature concerning the microbial decay of wood. Although Level #3 included the category "microbial growth and control," the primary focus of the article was wood decay. Therefore, the category selected for the article was "wood deterioration." Individual treatments also frequently presented a dual focus, as exemplified by the 1983 Šimůnková, Šmejkalová, and Zelinger[165] article discussing certain monomers by focusing on "radiation polymerization" of those monomers, and therefore, that topic was selected when classifying the article (Table 4.1).

Table 4.1. Hierarchical Classification of Literature Topics Related to the Conservation of Waterlogged Archaeological Wood

Level 1	Level 2	Level 3
Treatment Case Study Analysis	*In Situ* Preservation/Reburial Conservation Materials and Methods Watercraft in Process/Results Wood	***Stabilization Chemical*** Acetone-rosin, Alum, Azelaic/palmitic acids, Cellosolve (1-ethoxy-2-propanol) and petroleum, Cellulose and Chitosan, Cellulose ethers, Chemical Dehydration, CO2 supercritical fluid, Cross-linked organic polymers, Epoxy and Acrylic polymers, Carboxylic acid, Formaldehyde resins, Glycol Methacrylate, Lignophenol, Keratin, Minsk Method (Phenol alcohol and maleic anhyyride), PEG (Polyethylene glycol, PAG (Polyalkylene glycol), Nonhygroscopic waxlike oligomers, Polypropylene glycols, Polybutyl methacrylate, Silanol-Terminated Polydimethylsiloxane, Silanes, Sodium bichromate followed by Chromic Anhydride and Linseed Oil, Soil Stabilizing Gel Media Solvent + Linseed oil, Colophony, and Carbolineum mixture, Soluble Nylon, Sugars, Sugar Alcohol, Tetra Ethyl Ortho Silicate: (TEOS), Zirconium Compounds ***Stabilization Method*** Comparative or Combined Methods, Controlled Dehydration, Freeze-drying (General), Freeze-drying (Vacuum), Freeze-drying (Vacuum) PEG Pretreatment Freeze-drying (Atmospheric), Freeze-drying (Atmospheric) PEG Pretreatment, Kiln

[165] Šimůnková, Šmejkalová, and Zelinger 1983.

Table 4.1 Continued

Level 1	Level 2	Level 3
		Drying, Radiation Polymerization, Vacuum Impregnation. ***General Topics*** Acid/Sulfur/Iron Corrosion, Adhesives, Characterization and Morphology, Display environment, Documentation, Investigative methods, Mechanical Properties, Microbial Growth and Control, Overview, Reassembly, PEG Antioxidants, PEG Degradation, Recovery/Transport, Wood deterioration and Wood storage

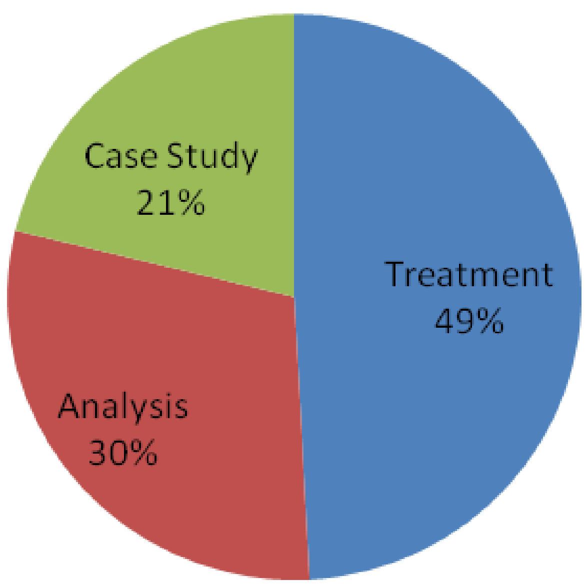

Figure 4.1. The division of literature over 60 years based on Level #1, topic classification with the broadest scope.

In the broadest terms, the classification system reveals a number of pertinent details concerning the focus of the conservation community over the last 60 years. Obviously, those materials utilized the most received the greatest amount of attention in the literature, but it was not as much as one might consider (Figure 4.1). While polyethylene glycol (PEG) has been the most prolific stabilization medium, it accounts for only 36% of the reviewed material. Looking at the combined corpus of work over the last 60 years, an overwhelming percentage of effort has gone to direct treatment and evaluation. Since a large proportion of catalogued case studies also focused on treatment methods, the percentage of effort, nearly 70%, dedicated toward creating a stable product certainly

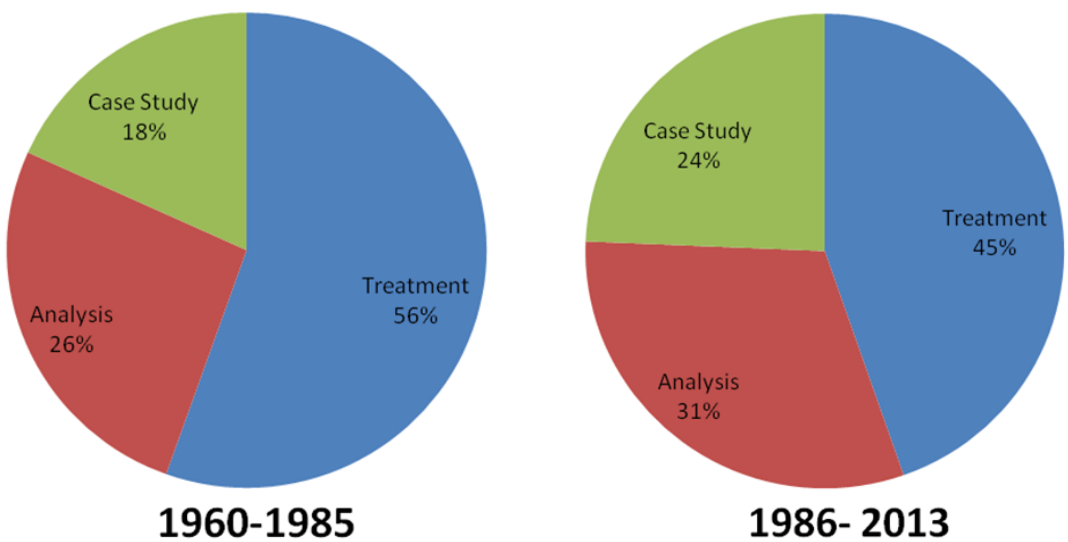

Figure 4.2. Side-by-side graphs illustrating the changing trends in the conservation of waterlogged archaeological wood between 1960 and 2013.

dominated field study.

Overall, the findings support earlier statements regarding the practice of waterlogged wood conservation being in a state of perpetual crisis management as it continues to search for the best materials and methods. When the date range is divided into roughly two equal blocks, 1960-1985 and 1986-2013, a slightly different picture emerges (Figure 4.2). The most notable change is a shift from general treatment and qualitative evaluation toward more analytical work, and while the portion dedicated to case studies also increases, the rise occurs as a result of the growth in the number of watercraft conservation projects.

Four Major Periods in Waterlogged Wood Conservation

Grouping the publications by classification allows for the development of a subject historiography that would be difficult to achieve by other means of review. In fact, the trends in the conservation of waterlogged archaeological wood create four distinct phases of research and publication. The first phase (1955-1969) was exploratory, based on the need to develop new materials or methods for the stabilization of waterlogged wooden archaeological materials. This created essentially a process-based publication expressing experimental results in the form of a “how-to” recipe. The second phase (1970-1984) was laden with dissenting articles concerning the inability to maintain satisfactory results with some of the early selected internal consolidants, and thus constituted a refinement period, whereby the initial conservation methods were defined, reworked and compared to the prospect of using alternative materials. The third phase (1985-1999) illustrates a considerable push to take a step back and reevaluate the substrate material and bulking chemicals at the base level in order to better understand the manner of deterioration or long-term durability of the impregnated substance. During this period, the growth in the number of excavations undertaken meant considerable quantities of waterlogged materials began to overload labs,, especially in the United Kingdom and Europe. To mitigate this problem, methods of *in situ* preservation and reburial gained considerable attention. The conservation community is currently approaching the end of the fourth major phase of industry development (2000-present). This phase may be best characterized as a true state of continual crisis management. Chemical interactions involving acid, sulfur, and ferrous corrosion, creating the potential to damage the macro and micro structure of the wood, and changes to the physical characteristics of wood impregnated with deteriorating polyethylene glycol have jeopardized the continued stewardship of several important archaeological watercraft and the conservation community has applied considerable effort to better understand these occurrences.

The number of articles, when divided by the four periods (Figure 4.3), illustrates a corresponding reaction to the number of shipwreck conservation projects and a graph of publication dates closely resembles Figure 2.7. The number of articles that appeared in the first 15 years were few in number and many during this period represent supporting documentation from wood technologists. The greatest rate of growth occurred between 1970 and 1985, but since then the output has remained relatively consistent. The decline noted between 2001 and 2013 is an aberration based on a shortened time span. When the Wet Organic Working Group of ICOM publishes its most recent proceedings (2013) sometime in 2014 that will elevate the number of articles in the final group above 300, and more in line with the previous two periods. The dates of division are obviously arbitrary separators chosen due to the manner in which the literature seemed to naturally fall into specific groupings. Frequently, research conducted late in one period overlapped and appeared in publications during the next phase.

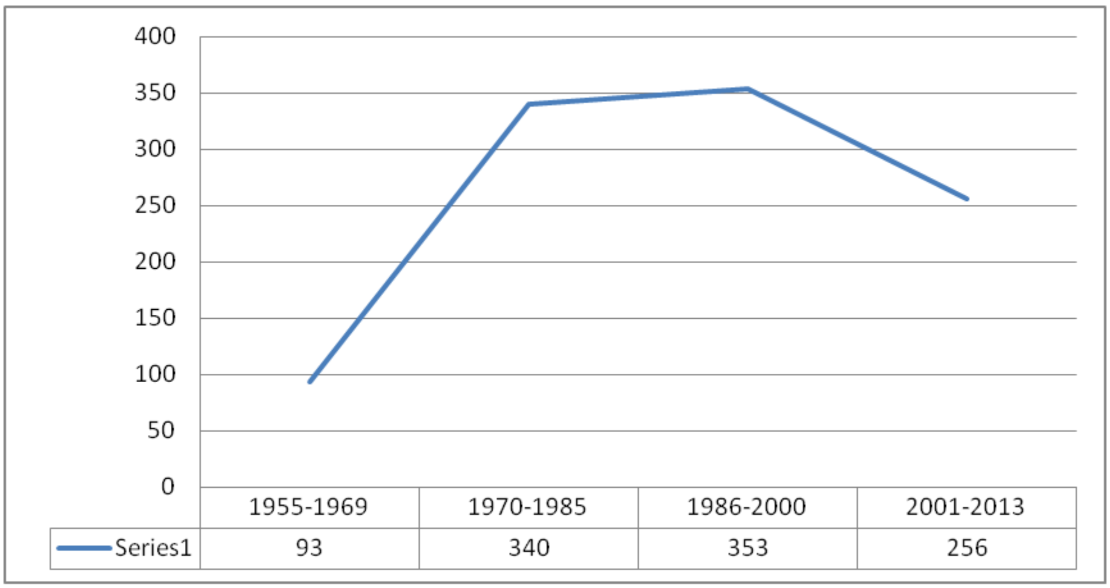

Figure 4.3. Graph illustrating the growth of the industry by number of published articles over the four periods of development. Graph closely mimics the graph in figure 2.6 illustrating the number of saved watercraft by decade.

Finally, more topics exist than are outlined in this review. Those selected for the general literature review of waterlogged wood stabilization focus the discussion on major trends, methods, or means of consolidation. Many topics, or case studies, that directly apply to watercraft conservation appear in chapters 4-10, which are specifically devoted to different aspects of watercraft conservation.

1955-1969–The Search for Internal Consolidants

The dissatisfaction with the alum method and surface applied formulations created by different percentages of turpentine, linseed oil, colophony and carbolinium,[166] coupled with the introduction of new chemicals developed during World War II, and a euphoric belief in the benefits of technology following the war, prompted the search and experimentation on new materials and methods that could serve the role of maintaining dimensional stabilization. During this first phase, many parallels can be drawn between research undertaken for the commercial wood industry and the conservation of waterlogged wooden antiquities. Wood scientists, primarily publishing through the *Forest Products Journal*, also began to detail scientific experiments concerning efforts to understand and manage the dimensional stabilization of commercially cut timber.[167]

One of the new chemicals, polyethylene glycol (PEG), introduced by Morén and Centerwall in 1952,[168] proved promising in trying to solve the problems associated with movement and shrinkage of green wood, and many began to experiment with PEG as a medium of dimensional stabilization of wood, a chemical seasoning agent, and a method to abate decay.[169] Within six years of its introduction the use of the chemical spread around the world, and found use in both in the commercial wood industry and in the preservation of waterlogged antiquities.[170]

Due to a lack of cohesion amongst conservation labs, stalwart loyalty by some to established materials, different levels of financial resources and a general lack of

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[166] Rosenqvist 1959, 15.
[167] Pentony 1953; Erickson 1955; Risi and Arseneau 1957; Resch and Eckund 1964.
[168] Morén, and Centerwall 1960.
[169] Stamm 1956; Stamm 1959; Anonymous 1961; Kenaga 1963; Stamm 1964.
[170] Organ 1959; Werner 1959; Frison 1960; Lefever 1961; Mitchell and Forbes 1962.

communication, the transition to more modern approaches of internal consolidation during the 1950s and 1960s was very slow in places. Some conservators continued to use topical treatments,[171] especially for watercraft conservation, and use of the alum treatment lasted until the early 1970s.[172] In 1962, the ship remains from the Skuldelev blockage were originally intended to be stabilized with the alum process, but the success experienced by conservators of the small finds from the *Vasa* prompted a shift to polyethylene glycol.[173] For larger objects, especially watercraft, PEG quickly became the standard treatment, and a number of projects employed the material for wood stabilization. Seborg and Inverarity discussed their success with PEG 1000 impregnation of timbers from colonial bateau recovered from Lake George, New York after only a couple days of soaking in a 50% aqueous solution.[174] German conservators responsible for the Bremen Cog also looked to PEG 1000 for stabilization of the 40 tons of waterlogged material associated with that artifact.[175]

The Morén and Centerwall PEG process called for the slow buildup of “half-solid or solid” PEGs in molecular weights of 1,000 and 4,000,[176] in an aqueous solution. As more conservators began to use the process problems arose when acceptable results could not be consistently replicated and treatments required a considerable amount of time to slowly build up the appropriate percentages of PEG in the aqueous solution. For example, larger objects such as the Bremen Cog were calculated to require 15-20 years

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171 Garczynski 1959.
172 Lehman 1972.
173 Jensen, Hjelm and Straetkvern 2011; 17.
174 Seborg and Inverarity 1962.
175 Noack 1969.
176 Morén, and Centerwall 1960, 178.

for impregnation of PEG 1000.[177] Christensen discovered that the high molecular weight PEG 4000 (commonly referred to as PEG 3350 in the United States) rapidly penetrated the softer degraded outer layers of the wood but created an osmotic gradient with the inner, less degraded core where the chemical could not as easily enter. This gradient caused water to be drawn away from the core, resulting in cellular collapse and "cupping" on the surface of the wood. In response, Christensen altered the PEG percentages based on degradation and chose not to heat the solution in the case of timber with a lesser-degraded core.

The inconsistency of results when treating different timbers coupled with the longer than desired treatment times associated with the penetration of PEG into wood prompted the search for other methods. In similar fashion to many treatments available to conservators for waterlogged archaeological wood during the period, wood scientists had been investigating the application of radiation polymerized impregnated monomers. The rapid penetration of low viscosity monomers and polymers followed by radiation polymerization began in the mid-1960s.[178] Another material introduced to the conservation community for internal consolidation in the late 1950s was the melamine-formaldehyde resin Arigal C (later repackaged as a similar product and sold under the names Lyofix DML and Kauramin). Originally developed "as a protection against rotting in cotton textiles," the resin was a water-soluble condensation polymer that was easy to use and effective at controlling dimensional stabilization.[179] Because of the irreversibility

[177] Hoffmann 1981, 42.
[178] Munnikendan 1967.
[179] Müller-Beck and Haas 1960, 150.

of the condensation polymer, however, acceptance and use of the process remained limited, mainly localized to the parts of Germany and Switzerland near its place of manufacture.

Non-bulking methods of stabilization appeared early during this period and attempted to use the expectation that the lower the capillary force a liquid exerts on the wood during dehydration, the less chance of shrinkage and cellular collapse. After considerable experimentation with many different solvents, the staff at the National Museum of Denmark selected a combination of ethyl/ether for solvent dehydration. Approaching the challenge of gently removing water by physical instead of chemical means, both wood scientists and conservators began to evaluate freeze-drying and the prospect of sublimating the water from wood.[180] To protect the fragile wood from ice crystal formation the water in the wood was exchanged for tertiary-butanol.[181] Sublimation proved very promising for small artifacts that could fit within the limited space of the lyophilizer product chamber and prompted new avenues of exploration to improve the process during the latter half of the 1960s. Even with these noted advances however, the first period ended very much as it started, with the conservation community searching for an inexpensive rapid panacea to stabilize waterlogged archaeological wood.

1970-1985–Dissatisfaction, Tinkering, Refinement and New Methods

Within the context of the 1960s and 1970s, as Europe and most of the world recovered and rebuilt from the devastating effects of World War II, national authorities could direct more resources toward the cultural needs of society. As a result of this

[180] Christensen 1970, 29-30; Erickson, Schmidt and Laing 1968.
[181] Christensen 1970, 30.

interest in preservation, coupled with cultural resource management laws, artifacts began to overload laboratories and methods that could simultaneously treat large quantities of artifacts became a necessity. At the time, PEG presented the best opportunity to accomplish these requirements.

In the early 1970s, a number of articles bridging the two periods appeared concerning chemical dehydration (dewatering) and advances in the process of freeze-drying. The continued frustration and dissatisfaction with the PEG method had some even “advocating [for the] complete abolition of use of the polyethylene glycol method,”[182] which launched a number of new treatments into use, with the specific goal of replacing PEG. Three specific processes included acetone-rosin, tetraethyl orthosilicate (TEOS) and Sodium bichromate, followed by chromic anhydride and linseed oil. Although not intended specifically to replace polyethylene glycol, wide-scale use of sugars for conservation purposes began to take hold during the early portion of this period and had moved beyond the nascent stages of development by the mid-1970s.[183]

Regardless of how some felt in respect to the deficiencies of the PEG treatment process, the synthetic wax continued to play a significant and ever-increasing role in the conservation of waterlogged wood. Like Christensen, Lars Barkman, working in Stockholm on the conservation of the *Vasa*, also experienced problems trying to stabilize multi-degraded timber with any regularity. He reached the same conclusion as his Danish counterpart, but instead of altering the Morén, and Centerwall method Barkman

[182] Bryce, Mackerrell, and Varsanyi 1975, 35.
[183] Stamm 1973.

determined that PEG-1500 would provide more uniform penetration,[184] which initiated further experimentation to determine how to utilize different molecular weights of PEG in an attempt to stabilize the inner and outer zones of timber with moderately or only slightly degraded cores.

Under the guidance presented by the pioneering work of Walter Ambrose (Canberra, Australia) great strides to make lyophilization a success occurred when he proposed to use a 10 to 15% solution of PEG–400 as a pretreatment to freeze-drying[185] in combination with a low vacuum.[186] The formation of a vacuum reduced the vapor pressure of the ice and avoided many of the surface checks and cracks observed by freeze-drying with no additives. In northern climates, months of dry, freezing winter temperatures afforded the possibility for a free source of sublimation, and many conservators in Canada and northern Europe investigated the opportunity.[187] Grattan, McCawley and Cook[188] confirmed Ambrose's assertions that a 15% pretreated solution of PEG-400 improved the freeze-dried product even at atmospheric pressures. During the course of the Canadian winter (approximately 3 months), roughly 50% of the water sublimated from the wood, which was sufficient to sustain dimensional stability, and adverting cellular collapse during controlled drying further reduced the percentage of water content.

With more readily available access to technology analytical studies expanded in the early 1970s. In 1965, the first commercially available scanning electron microscope,

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[184] Barkman 1975.
[185] Ambrose 1971; Ambrose 1972; Rosenqvist 1975.
[186] Ambrose 1976.
[187] Grattan and McCawley 1978.
[188] Grattan, McCawley and Cook 1980; also McCrawley, Grattan and Cook 1982.

(SEM) manufactured by the Cambridge Scientific Instrument Company (Cambridge, United Kingdom), allowed for the first visual microscopic investigation of waterlogged wood. By 1970, Karl Borgin had already completed his first SEM article on "the use of the scanning electron microscope for the study of weathering wood."[189] Further investigations provided by Bravery provided insight into microscopic aspects of wood decay.[190] By the end of the 1970s, Hanna and Côté were able to provide a summary of the different applications of SEM analysis as it related to wood, which confirmed the prospect of this analytical tool for assessing archaeological wood.CITE The use of advanced instrumentation allowed researchers to devote considerably more time to the analysis and characterization of wood, and less on trial and error methods.[191] This led to a complete paradigm shift involving a greater technical approach to the conservation of waterlogged wooden archaeological objects.[192]

1986-2000–Closer Analysis, Continued Refinement and Search for Better Methods

The emphasis placed on enhanced analytical approach to characterize waterlogged archaeological wood that began in the 1970s and early 1980s intensified during the third phase of development between 1986 and 2000.[193] The introduction and application of analytical techniques and greater accessibility to sophisticated instrumentation allowed researchers, in essence, to take a step back and more closely evaluate the root causes and mechanisms of wood deterioration and chemical interactions

[189] Borgin 1970.
[190] Bravery 1971
[191] Hoffmann 1982
[192] Barbour 1983.
[193] Grattan and Mathias 1986; Young 1990.

between composite materials and to better characterize the chemicals used for dimensional stabilization. PEG remained the predominant consolidant throughout the period, but researchers divided investigations of the chemical into a number of different directions. The first group focused their investigations on methods that would achieve a better understanding of PEG interaction with treated archaeological wood, the properties of the chemical and possible causes for its deterioration, and the best practical applications for the product. The second group worked to better understand PEG as a pretreatment for freeze-drying and the physical science involved with the sublimation of water from a PEG, water, wood system, including the use of the Antarctic climate for atmospheric sublimation of large timbers.

Finally the segment of the conservation community dissatisfied with the inconsistent results of PEG treatments continued to outline the problems associated with PEG treated artifacts,[194] and considerable effort continue to be placed on investigating new materials and methods that could potentially replace PEG with sugars, sugar alcohols, and cross-linked silicone polymers, to name only a few of the proposed substitutes. Another line of investigation evaluated the microstructure of degraded and deterioration waterlogged wood to comprehend the mechanisms taking place in the process of decay and what form of material, both quality and quantity, was actually left to stabilize. This information proved invaluable data for stabilization purposes and for researchers trying to determine appropriate methods of *in situ* preservation and the

[194] Bucsa 1989.

possibility of reburying archaeological organic materials instead of stabilizing them in the lab.

During the early 1980s, many in the conservation community concluded that there were considerable limitations and deficiencies when applying only moisture content analysis of core samples or simple pin tests in selection of a conservation regime. In order to formulate comprehensive conservation strategies that were appropriate to particular objects, a range of new quantitative and qualitative techniques were a requirement.[195] In creating these strategies, analytical techniques and advanced instrumentation were employed to assess several aspects of waterlogged archaeological wood conservation, principally the degradation of the material and characterization of the chemistry once impregnated into the waterlogged wood.

Along with the use of scanning electron microscopy (SEM) to visualize the level and patterns of preservation, thereby gaining insight into aspects of decay, researchers began to use microscopy to evaluate how the microstructure of archaeological wood could be altered by the impregnation of different consolidation treatments.[196] Nuclear magnetic resonance imaging (NMR) allowed for the characterization of water concentration, distribution and movement in wood.[197] The search for a better understanding of PEG treatments prompted Hoffmann to utilize high-performance liquid chromatography (HPLC) to follow the penetration of polyethylene glycol into the cell structure and assess what molecular size molecule of the polymer could penetrate a

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[195] Panter and Spriggs 1997.
[196] Hatchfield and Koestler 1987.
[197] Menon et al. 1987; Cole-Hamilton, Chudek and Martin 1990.

particular level of degraded wood.[198] Hoffmann's study on PEG penetration based on molecular size and degradation highlights a topic of considerable investigation during the late 1980s, using multiple techniques including fluorescence microscopy to assess distribution of PEG in wood as a relationship to molecular size. To better characterize waterlogged wood, detailed investigations concerning its physical and mechanical properties were conducted by infrared (IR) spectroscopy and thermomechanical analysis and were compared with sound contemporary European oak wood to determine their chemical composition.[199] The result of these investigations and many like them helped to form a detailed image concerning the loss of cellulose, hemicellulose, holocellulose and the changes in the lignin-carbohydrate complex of degraded archaeological wood. To assess the chemical properties of PEG, analytical reverse phase high-performance liquid chromatography was utilized to characterize the separation of oligomeric and polymeric ethylene glycols.[200]

One of the most significant applications of these advanced analytical studies, especially SEM,[201] was to gain a thorough understanding of the role that bacteria (tunneling, scavenging and erosion)[202] and different species of fungi[203] played in the decay process of buried archaeological wood. The concept behind the investigations was simple. If one could determine the mechanisms of deterioration and the result, there was a strong likelihood of successful implementation of better stabilizing agents or

[198] Hoffmann 1989.
[199] Mikolajchuk et al. 1989
[200] Barka and Hoffmann 1987
[201] Blanchette and Hoffmann 1994.
[202] Mouzouras et al 1986; Singh, Nilsson and Daniel 1987; Young 1988; Singh 1989; Daniel and Nilsson 1989; Eriksson, Blanchette and Ander 1990.
[203] Eaton 1986

methodologies. In regards to fungi, focused research assessed the decay of lignin by white rot Basidiomycetes,[204] soft rot fungi[205] and brown rot fungi that influenced the degradation of cellulose.[206] Most evaluation of fungi centered on degradation occurring in the natural environment, but Mouzouras, studying disarticulated timbers from the *Mary Rose* in wet storage, noted 14 marine and 2 terrestrial fungi on 134 sample timbers, and emphasized the need for enhanced bacterial control in the storage environment.[207] Examination into the role specifically played by bacterial attack[208] provided insight into the degradation of wood cell walls,[209] and particularly the destruction of the S2 layer of the cell wall.

By the mid-1990s, the growing body of work demonstrated that degradation of the polymorphic structure of wood was the result of bacteria and fungi, and not by chemical action such as hydrolysis as had been a widely held belief until that time.[210] Theoretically, hydrolysis and chemical decomposition should occur to degrade the complex polymers comprising the wood cell, but investigations under laboratory conditions could not substantiate the theory. By the end of the third period of development, the considerable advances achieved in understanding the major forms of fungal and bacterial attack allowed for better characterization of individual artifacts.[211]

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[204] Blanchette, Otjen and Carlso 1987.
[205] Daniel and Nilsson 1989.
[206] Highley and Illman 1991.
[207] Mouzouras 1987b.
[208] Singh, Nilsson and Daniel 1990.
[209] Singh, and Butcher 1991.
[210] Kim, and Singh 1994.
[211] Nilsson 1999.

Nowhere were these advances in understanding microbial and fungal degradation required more than in a relatively new area of study, *in situ* preservation and reburial.

Early proposals for *in situ* preservation and reburial for long-term storage following lab analysis and documentation[212] were the result of the costs associated with conservation and long-term stewardship coupled with the continuing accumulation of excavated archaeological resources. It was not until the early 1990s, however, that heritage managers such as English Heritage began to set policy focused on *in situ* preservation.[213] With the shifting policies, the number of dedicated research projects investigating this "new" topic began to grow. By the end of the 1990s, and the third period of development, a number of initial studies were in print. Investigation into *in situ* preservation and reburial followed along three general paths: (1) empirical studies characterizing the physical, chemical and microbiological aspects of the burial environment; (2) results of reburial experiments; and (3) practical evaluation of methods or materials to create an acceptable long-term stable setting.

Assessment of reburied timbers from Lynæs Sands, Denmark by Gregory,[214] and at the *Mary Rose* excavation site by Pointing, Jones and Jones[215] demonstrated that most marine burial settings were anaerobic-reducing environments (neutral pH, low Eh and free of dissolved oxygen), revealing the potential for using the technique as a means of aiding long-term storage. Further empirical study of the physical and chemical characteristics reburial sediments in relation to the deterioration illustrated a correlation

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[212] De Jong 1981; Jespersen 1985.
[213] Caple 1994.
[214] Gregory 1998.
[215] Pointing, Jones and Jones 1997.

between certain parameters that could aid in the selection or monitoring of the site. Specifically that there appeared to be a correlation between carbon to nitrogen ratio with the rate of deterioration and the mode of microbial attack.[216]

Researchers acknowledged that all results were preliminary and called for more study, and with growing interest in the topic the opportunity to study the subject increased. By evaluating 26 previously excavated and reburied wrecks sites (1991-1996), Pomey observed that the quality of preservation varied between locations and generally depended upon specific site conditions.[217] In particular, the type of bottom, depth and topography weighed heavily in keeping the sediments on top of the burial mound. Apart from these natural conditions the study of these sites also concluded that human impacts of search and looting continued to disturb the established equilibrium of the site, creating a poor depositional environment. To maintain the site, investigations were undertaken to determine if certain manufactured materials incorporated into the burial could enhance the interment environment.[218] One product tested both in the laboratory and the field was the geotextile Terram. Placed on the Zakynthos wreck site for a 12-month period of evaluation the material exhibited the ability to build up and hold sediments ensuring an anaerobic environment.

Investigations may have been underway to better understand microbial decay and the prospects for utilizing the marine environment for long-term storage; however, the number of artifacts requiring stabilization continued to increase and PEG remained the

[216] Gregory 1999.
[217] Pomey 1999.
[218] Pournou, Jones and Moss 1999.

primary internal consolidant, prompting additional investigations to improve the stabilization method.[219] One the most important advancements for the treatment of multi-degraded oak occurred in 1986 when Per Hoffmann introduced the "two-step PEG treatment." By utilizing percentages of low and high molecular weight PEG in separate aqueous solutions, Hoffmann determined that both the core of the timber and more degraded surface region could be successfully stabilized.[220] The method quickly gained prominence and continues in use to this day. Along with gaining greater consistency with the stabilization of multi-degraded oak artifacts, the procedure was also proved successful with charred wood.[221]

Besides working to improve the application of PEG treatments there was considerable effort placed on understanding specifically how the chemical penetrates the micro and macro structure of waterlogged wood, and then what percentage would be the most suitable for maintaining dimensional stabilization for treatments saturating the wood with PEG or as a pretreatment for vacuum freeze-drying.[222] The Canadian Conservation Institute removed some of the guesswork concerning correct percentages in regards to pretreatment before vacuum freeze-drying with the introduction of the computer program PEGcon.[223] The program calculates the appropriate concentration of PEG based on wood species, actual density of the wood, normal density of the species and the moisture content at the fiber saturation point of an undeteriorated sample of the same species. With some modification over time, the program proved to be successful

[219] Ishimaru and Yukio 1986; Håfors 1994.
[220] Hoffmann 1986.
[221] Caple and Murray 1994.
[222] Schaudry and Knoll 1988.
[223] Cook and Grattan 1991.

and remains in use to the present day. Along with attempting to achieve better results with some form of the PEG treatment method work was also undertaken to assess the level of penetration[224] and the rate of PEG diffusion throughout the cellular structure.[225]

Of increasing concern throughout the conservation community during the 1980s and 1990s was the durability and chemical stability of PEG. Interdisciplinary research and adaptation of pertinent studies from other fields incorporated new perspectives including the bacterial degradation of polymers, in particular PEG.[226] These investigations illustrated that there were three primary paths of polymer degradation, oxidative, thermal and microbial. Geymayer, Glass and Liedl confirmed that the oxidative degradation of PEG affected higher molecular weights more than low molecular weight PEG and that longevity of the chemical could be increased with the addition of antioxidants in the treatment solution.[227] The group of researchers working with Malcolm Blitz[228] confirmed the findings of Geymayer Glass and Liedl concerning the need to reduce the mechanisms of oxidation in order to slow PEG degradation, and that to some extent, this occurred less with deeply penetrated PEG-3350 in oak versus in a Petri dish. They also observed that when in the presence of iron salts the higher molecular weight PEG, such as PEG 3350, exhibited more degradation then low molecular weights and that thermal aging increased PEG degradation. Other researchers[229] observed that the thermal degradation of PEG could occur by hot air,

[224] Finney and Jones. 1993; Jensen 1997; Kawagoe and Ishigaki 1991.
[225] Fukuama and Urakami 1986.
[226] Grattan 1993, Glastrup 1997
[227] Geymayer, Glass and Liedl 1991.
[228] Blitz et al. 1994.
[229] Padfield et al. 1990.

which they noted separated the PEG into three distinct phases: solid, soft paste and liquid. One interesting observation associated with these findings was that the presence of water appeared to protect the polymer against this form of degradation. Throughout the later portion of the third developmental phase, research into the factors leading to PEG degradation continued, including bacterial and fungal attack,[230] and many questions arose concerning how to predict the long-term behavior of synthetic polymers.[231] In the event PEG durability would ultimately be in question, trials commenced to demonstrate that the PEG could be extracted from the artifact and that the object could be retreated.[232]

Another concern regarding PEG treatments that arose toward the very end of the second phase and rigorously investigated during the third was how to offset the corrosive characteristics of PEG on iron. Since any attempt to remove a piece of embedded iron from a fragile composite artifact frequently caused irreparable damage, investigations were undertaken to find additives such as resins or corrosion inhibitors that could be effective at abating the electrochemical activity created by the mildly acidic electrolyte.[233] One particular corrosion inhibitor Hostacor KS1 (Hostacor IT) was investigated, and it was found that when added to PEG solutions acted as an anodic inhibitor, reacting with dissolved oxygen in the solution to spontaneously passivate the iron.[234]

When wood damaging iron salts were observed emanating from timber on display and in storage environments during periods when the relative humidity was over

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[230] Kigawa 1994.
[231] Lemaire 1993
[232] Cooke, Cooke, and Grattan 1994.
[233] Cook 1986.
[234] Argyropoulos et. al 1999.

60%[235] a number of investigations were undertaking to study the interaction between the oxidation of iron and sulfur in the formation of pyrite[236] and the acid hydrolysis of wood.[237] General studies undertaken to assess a number of different parameters of degraded waterlogged wood, including dissolved oxygen, pH and Eh (redox potential), measurements and capillary gas chromatographic analysis of wood extractives from iron impregnated archaeological timbers demonstrated a link between the level of degradation of a sample and the surface pH.[238] Further research using Fourier transform infra-red (FT-IR) and 13C-NMR indicated that there was also a direct link between the incorporation of iron corrosion products and the degradation of wood.

A clear picture was beginning to form that iron found in shipwrecks, in particular the structural remains recovered from inundated sites, had the potential to combine with other elements to form compounds that at periods of relative humidity over 60% could become very active, and that the product of the reactions could seriously damage stabilized archaeological wood. The next logical route of inquiry was to determine methods that could safely extract the deleterious material or convert it to a more stable state.[239] With the issues of PEG and iron corrosion in archaeological timber, during the 1980s and 1990s there was a renewed effort to find the magic bullet substance or process to replace polyethylene glycol, and many conservators felt sugar or one of the many derivatives of sucrose offered the best possible alternative.

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[235] Jespersen 1989.
[236] MacLeod, and Kenna 1991.
[237] Richards 1990.
[238] MacLeod, Brooke, and Richards 1991.
[239] MacLeod, Mardikian and Richards 1994.

The published work of Stamm[240] and Grosso[241] on the use of sugars in conservation of waterlogged archaeological wood was followed by a master's thesis undertaken by James Parrent in the early 1980s and published as a peer-reviewed article in 1985.[242] Many in the conservation community endorsed the prospect of a "new," reversible material for dimensional stabilization of waterlogged wood.[243] Both unadulterated sucrose solutions and sugar alcohols found use as both saturated solutions and pretreatments for freeze-drying,[244] and were determined to be effective, as an inexpensive alternative to polyethylene glycol treatments.

By the late 1980s, wide-scale research on the process was underway to determine its effectiveness and refine methodologies. Through the 1990s, sucrose was the "hot-topic" within the conservation community. Hoffmann[245] employed waterlogged alder (Alnus sp.), to test sucrose on a sample that represented little degraded material, and European oak (Quercus sp.), pine (Pinus silvestris L.) and beech (Fagus silvatica L.) to represent a heavily degraded sample,, and assessed each by anti-shrink efficiency, which verified to Hoffmann the excellent potential of sucrose to act as a stabilizing agent. Within 10 years of Parrent's thesis the results of numerous sugar experiments were in print covering required sugar concentrations,[246] effectiveness for dimensional stabilization versus the degree of degradation determined in the wood,[247] and offering

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240 Stamm 1973.
241 Grosso 1982.
242 Parrent 1985.
243 De la Baume 1987; Also, Morgôs et al. 1987.
244 Murry 1985; Morgòs and Imazu 1993.
245 Hoffmann 1991.
246 Arhelger and Hilbrich 1992.
247 Hoffmann 1994

plenty of recommendations for different additives in order to obtain a successful treatment.[248] Nevertheless, one of the greatest drawbacks in using sugar, and one that ultimately caused many conservators to disfavor its use, was the absolute requirement to control bacterial growth in the conservation solution.[249] In order to find a viable product for controlling microbial growth many different chemicals were tested and the results disseminated in recipe form.[250]

Along with the use of sugar, sugar alcohols (mannitol and lactitol) received considerable attention, especially when combined with PEG as a pretreatment for freeze-drying.[251] In 1985, Murray reported positive results after soaking degraded archaeological wood in the sugar acid mannitol as a pretreatment for freeze-drying.[252] Compared against similar wood samples treated with PEG, the mannitol-treated wood produced a consistently better result. Sugar alcohols are organic compounds prepared from sugars that are water-soluble solids and generally far more resistant to bacterial degradation than sucrose. The combination of sucrose and mannitol exhibited excellent stabilization qualities with anti-shrink efficiency over 90% for wood with moisture contents from 226-668%. In addition, the PEG mannitol mixture could be added to the solution in one step.[253] Another sugar alcohol that gained some acceptance was lactitol, and like mannitol excellent initial results were reported.[254]

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[248] Koesling 1994; Strigazzi and Koberstein 1997; Strigazzi 1998
[249] Morgôs 1992.
[250] Morgôs, A., G. Strigazzi, and H. Preuss 1994.
[251] Imazu and Tadateru 1990.
[252] Murray 1985.
[253] Morgôs and Imazu. 1993
[254] Imazu and Morgos 1997; Imazu and Morgòs 1999.

The use of both vacuum freeze-drying and freeze-drying at ambient pressures began to be more widespread. Comprehensive reports detailing the best techniques, requirements for larger objects and methods to optimize treatments were added to the growing body of knowledge on the subject.[255] The increased use of freeze-drying and altering PEG molecular weights and concentrations during pretreatment led to detailed studies concerning the characteristics of freeze-dried the PEG/wood/water system created by the combination of the three substances. They also lead to a new round of publications that proposed designs for lyophilizes employing both vacuum and the use of atmospheric pressure.[256]

Experiments investigating the appropriateness of different concentrations and molecular weights of pure aqueous PEG solutions demonstrated that both PEG 2000 and PEG 4000 could be successfully freeze-dried in concentrations from 10% to 50% (by weight). The addition of lower molecular weight PEGs such as PEG 200 however, altered the eutectic properties of the pure solution and reduced the compression strength of such freeze-dried solutions.[257] Due to the altered eutectic properties, the authors concluded that the combination of high and low molecular weight PEGs (i.e., following the two-step saturation protocol) decreased the compression strength of the pure PEG significantly enough that it created the possibility of cellular collapse during the freeze-drying process. PEG in a Petri dish, however does not react in the same manner as when

[255] Watson 1987; Bernard-Maugiron, Ginier-Gillet and Tran 1991; Hoffmann, Riens, and Eckstein 1991; and Watson 1997.
[256] Lorin and Lemetayer 1999.
[257] Bojesen et al. 1999.

involved with the PEG/water/wood system. Therefore, Hiron and Tran[258] differentiated PEG in wood from pure PEG when they reported on their results utilizing microanalysis infrared microscopy and Fourier transform spectrometry to establish performance parameters of freeze-dried wood after the impregnation of PEG. Their results demonstrated that the wood/water/PEG system reacted very differently when compared to pure PEG samples. The combined PEG/wood system appeared to be very stable over time, while pure PEG tended to oxidize and destabilize as formate, one of the critical by-products of PEG deterioration, was observed at very low levels. The authors proposed that the stabilization of the PEG was the result of natural antioxidants that remained even in waterlogged wood.

Following earlier investigations in Canada that employed ambient pressure and subzero temperatures, Walter Ambrose hypothesized that the Antarctic environment could adequately dry large timbers and developed a series of experiments to test the theory.[259] The experiments called for the placement of test timbers in underground chambers to protect the samples from windblown erosion created by ice particles while maintaining a consistent freezing temperature. An above-ground, wind-tracking Venturi system introduced airflow over the timbers to sublimate the water from the wood.[260] Data collected from the experiments demonstrated that with consistent freezing, large timbers could be successfully freeze-dried using ambient wind conditions as a catalyst for the sublimation process.

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[258] Hiron and Tran 1999.
[259] Ambrose 1990.
[260] Ambrose, Neale and Godfrey 1994.

Along with sucrose, throughout the period, many conservators dissatisfied with PEG strived to introduce new chemicals and treatments processes, while others worked to refine those already in use. The application of many of these alternative processes, while reported as satisfactory, remained mainly localized in use and did not gain wide acceptance or displace the previously established materials or processes. Irrespective of its inherent inability to be reversible research continued into the use of radiation chemistry for conservation.[261] Likewise, the need to stabilize the waterlogged remains of several Roman period river craft found in Germany initiated the redevelopment and use of formaldehyde melamine resins.[262] Tests conducted with the modern formula revealed that regardless of its inability to be reversed and the observation of deep cross-grain cracks, melamine-formaldehyde resin exhibited excellent dimensional stabilization.[263] Finally, a method developed in Minsk involving phenol alcohol and maleic anhyyride continued to be refined and provide the developers satisfactory results.[264]

A little-known or utilized treatment method beyond its creators, the notion behind the development and use of Cellosolve (1-ethoxy-2-propanol) and petroleum was to provide a supplementary approach to the more traditional methods of waterlogged wood conservation. Appearing in the early 1990s, the treatment method was effective for the treatment of "(1) small, delicate, heavily deteriorated objects, (2) composites made of metal and wood, (3) objects which must not be filled with the bulking agents, (4) objects which need a very light and natural appearance, [and], (5) objects which need fast

[261] Gäumann, Kosalski and Menger 1988.
[262] Lukowsky, Peek and Rapp 1998.
[263] Hoffmann and Wittköpper 1999
[264] Kazanskaya and Nikitina 1991.

treatment."[265] The process involved boiling the object in Cellosolve and petroleum (mixtures of alcanes), then impregnating the microstructure with wax and petroleum followed by vacuum drying. If desired, PEG was found to be a suitable substitute for the petroleum. Although reportedly effective, the treatment has been seldom used.

Evaluating different methods to deliver PEG into wet archaeological wood conservation scientists undertook experiments with polyethylene glycol in supercritical carbon dioxide fluid.[266] By employing the supercritical CO_2 fluid, the PEG penetration into the wood was rapid, completely penetrating multi-degraded wood in a period of days compared to over the year generally experienced by traditional soaking methods. The results were reported to be satisfactory and very promising especially when the supercritical CO_2 fluid demonstrated under specific conditions that the mechanical swelling, which occurred during the process, in fact could reverse part or all of previous collapse and damage.

Attempting to use a similar product as PEG, researchers substituted the copolymers of Ethylene Oxide and Propylene Oxide (Polyalkylene glycol or PAG) into waterlogged archaeological wood and reported excellent results.[267] Continued research during the 1990s by Pournou, Moss and Jones[268] demonstrated that the copolymers of Ethylene Oxide and Propylene Oxide provide a unique structure to PAG that produces low molecular weight, low hygroscopicity and resistance to microbial attack. All of

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[265] Jensen et al. 1994, 523.
[266] Coeuré, Chaumat, Tran, and Perre 1998.
[267] Dean, Jones and Jones 1994.
[268] Pournou, Moss and Jones 1999.

which made them likely candidates for treating waterlogged wood prior to freeze-drying highly degraded hardwoods.

In the mid-1990s, new research began to emerge in publications regarding the use of cross-linked organic polymers and the polymerization of PEG with silanes.[269] Mentioned previously, the polymerization by cross-linking materials after impregnation into wood was not a new concept by this decade and methods including radiation polymerization, condensation polymerization (melamine formaldehyde resins), silanes cross-linking organic polymers[270] had all been attempted or were in use but the cross-linking of PEG for waterlogged wood conservation was a new concept.[271] Experimentation and practical application proved effective for stabilizing most waterlogged archaeological artifacts, especially highly degraded items, however due to issues of irreversibility created by cross-linking it failed to receive wide scale acceptance and application for the stabilization of waterlogged archaeological materials.

Cross-linked monomers, CO_2 displacement, PAG's, sugar and sugar acids were all in an attempt to seek out a more cost-effective internal consolidant that could offer better reliability and greater long-term durability than polyethylene glycol. As the third period of development ended, the search for a PEG replacement continued. The analytical work conducted to understand better the deterioration of waterlogged archaeological wood, and the degradation of consolidants over time, coupled with advances in freeze-drying methodology, would lead to a shift in practice, when possible,

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[269] Smith 1999.
[270] Yahivili 1978.
[271] Klosowski and Smith 1998; Klosowski, Smith and Hamilton 2000.

away from a saturated PEG method in favor of PEG as a pretreatment to freeze-drying. Perhaps the current focus placed on PEG plus freeze-drying will not be the ultimate long-term process; however, the demonstrated efficiency may prove adequate while research continues on potential substitutes.

2001-Present–The Elusive Search, Adapting Methods and Crisis Management

A rainy summer in 1999 ushered in the fourth period of development when regions of highly acidic discoloration caused by iron salt precipitates appeared on the timber surfaces of *Vasa*.[272] This condition posed a serious threat to the material integrity of what some consider the most significant archaeological ship recovered to date, and that status as an icon radically altered the direction of research into the conservation of waterlogged wooden structures. For 40 years prior to that wet Stockholm summer, researchers had been publishing articles regarding the deterioration of wood in contact with iron and the damage that could result from the interaction with sulfur compounds.[273] ICOM-WOAM members dedicated almost an entire triennial conference (1987) to the subject of composite artifacts, and the number of publications reporting on the subject rose dramatically during the 1990s. Yet, within two years of noticing the array of different salt compounds emanating from the *Vasa* timbers, iron oxidation, sulfur and acidification of timber became "hot topics," and many researchers turned their attention to improving industry understanding of the mechanisms occurring with iron-sulfur interaction, including the precipitation of iron salts and acidification of the wood that

[272] Sandström, Hall-Roth and Karlsson 2002, 55.
[273] Birker and Kaylor 1986.

occurred during the process. The fervor generated by "Save the *Vasa*" broadened the scope of research addressing the effects of PEG deterioration on wood and resulted in an intensive reevaluation of the effects of PEG on the mechanical properties of impregnated wood. At the same time, previously established research directions including enhanced analysis and characterization of waterlogged wood, preservative effectiveness, microbial decay, *in situ* preservation, freeze-drying and a host of alternative approaches continued to be explored.

Perhaps one of the greatest paradigms of the period, punctuated by crisis issues of the *Vasa* and other artifacts was a general shift in emphasis to include the evaluation of post-stabilization impacts. These issues included the appropriateness of museum environments in relation to materials of stabilization, degradation of stabilizing mediums and the impact degradation on the surrounding wooden matrix.

During the fourth period, the formation of interdisciplinary teams interjected alternative perspectives and an increasing knowledge base, now available to all over the internet, to analytical work, which has generated a number of different research designs that employ new analytical techniques. By subjecting objects from Nydam Bog (Denmark) conserved with both PEG and Cellosolve/Petroleum to Raman Spectrometry[274] confirmed that holocellulose degrades more rapidly than lignin.

Other methods focused on confirming continued degradation of conservative waterlogged archaeological wood, in particular a reduction in mechanical strength. Mortensen and Mattiesen inserted oxygen sensors into the wood of the *Vasa*, Skuldelev

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[274] Christensen et al. 2006.

and Roskilde Viking Ships and the Hjortsping Boat. The goal was to assess oxygen consumption by the artifact to demonstrate ongoing chemical reactions[275] signifying any changes to the chemical composition of the object. In each case, the oxygen content inside the wood was found to be less than the surrounding ambient atmosphere, indicating oxygen consumption occurring inside the wood and the presence of a degrading environment. Finally, instead of using microscopy to evaluate the level of waterlogged wood deterioration, Sincich demonstrated the effectiveness of Environmental Scanning Electron Microscopy (ESEM) as a visual means of assessing the success of wood consolidation.[276]

The work that began decades before to characterize the minutia of degraded wood continued as researchers sought to find new methods and techniques for assessment. Conductivity and compression strength were noted as one possible method for characterization, [277] and time- and wavelength-resolved diffuse optical spectroscopy was found to be a non-invasive method for the characterization of wood.[278] Previous research frequently focused on the deterioration of the cell wall due to degradation of the holocellulose.

Lignin also became the focus of intensive research during this period. The characterization of lignin in archaeological woods from ships discovered at San Rosse, Pisa, Italy by phosphorous nuclear magnetic resonance spectroscopy, two-dimensional nuclear magnetic resonance and gel permeation chromatography determined that the

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[275] Mortensen and Matthiesen 2011.
[276] Sincich 2012.
[277] Jensen, Gregory and Strætkvern 2005.
[278] Bargigia et al. 2011.

lignin in the archaeological wood from the ships was still very similar to non-degraded reference samples.[279] The use of direct exposure electron ionization along with mass spectrometry and analytical pyrolysis 4/gas chromatography/mass spectrometry investigations, focused particular attention on the alterations concerning the chemistry of lignins. The work highlighted chemical concentrations of carboxylic and phenol at functional groups related to aging lignin creating "enhanced polarity and cation exchange properties to archaeological wood."[280] Finally, UV-microspectrophotometry was employed to characterize lignin distribution on the sub-cellular level in waterlogged wood degraded by erosion bacteria in an effort to better understand the decay patterns created by this form of microbe.[281] One of the most widely applied analytical techniques to be included for archaeological materials testing during the period was the use of DNA analysis to identify and characterize the type of microbes colonizing, and potentially degrading, waterlogged wood.

[279] Tolppa et al. 2011.
[280] Colombini et al. 2011
[281] Pedersen et al. 2011.

CHAPTER V

WATERCRAFT CONSERVATION - DELINEATION AND RECORDING

Introduction

Every ship conservation project possesses a different set of unique criteria and logistical challenges; therefore, no two watercraft conservation projects are ever exactly the same. The depositional environment, the extent of the physical remains, the level of material preservation of those remains, human impacts, original design, construction materials, size, financial constraints, individual ethos and expectations for the final representation all factor into the conservator's and archaeologist's conduct toward the project and ultimately, the finished product. Following the initial discovery and *in situ* investigation of archaeological ship remains there are five specific processes pertinent to the conservation of watercraft:

1) Delineation (both on site and post excavation)
2) Recovery
3) Materials stabilization
4) Reconstruction
5) Exhibition

Each aspect has its own particular requirements, and yet, in order to manage the complete project efficiently, planning requirements necessitate that all five aspects be preplanned as much as possible in order to produce an economically viable and suitable product. Most projects that fail do so because of inexperience, unpreparedness or inability to manage change. Watercraft recoveries may occur frequently, but due to the time required to bring a watercraft project to fruition only a handful of professional conservators and labs have practical experience in all required aspects of a project. Even fewer professionals have experience with multiple watercraft preservation projects.

From the United States, two excellent examples of what not to do are exemplified in the recovery of the schooner *Alvin Clark* (1969) and the USS *Cairo* (1960-1964). Both aforementioned projects failed, due to gross miscalculations concerning at least one of the five previously mentioned divisions of ship conservation (delineation, recovery, material stabilization, reconstruction and exhibition). The salver of the *Alvin Clark* grossly misjudged the costs associated with preservation and the deleterious effects of exposing waterlogged wood to the atmosphere upon recovery of the hull. Without a plan that extended beyond recovery, within a year of the structure breaking the surface of Lake Michigan, the nearly pristine 18^{th}-century schooner was a total loss. Five years earlier the team recovering the USS *Cairo* failed to take into account the engineering factors involved with lifting an inundated, silt-filled structure from the Mississippi River, underestimating the increased weight of the *Cairo*.[282] That fact, coupled with the fragility of the degraded construction material, buckled the hull when tension was taken on the lifting cables. What finally broke through the river surface more closely resembled a massive bundle of barrel staves than a United States Civil War era river gunboat. Both failures are employed regularly as classroom examples of what archaeologists and conservators should avoid in the practice of their profession.

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[282] McGrath 1981.

In 2014, it would be easy to dismiss any inference to these two examples occurring in the present day; after all, both happened in the 1960s when the nascent industry lacked experience, and considerable progress has been made since. Even so, it seems that nearly every year a headline from somewhere around the world reads as the following 2009 online article from Germany. “Archaeology office lets 7,000-year-old boats rot away.”[283]

The act of ship conservation is very complicated and requires the orchestration of many disproportionate parts that must be coordinated. Comparative data assembled from supporting documentation demonstrates that most current-day projects are the result of cultural heritage management and “rescue." Even with the involvement of professional heritage managers, many of these "rescues" have to occur quickly and do not take place with a well-established plan or the resources, mainly financial, to support the action. Most companies, cultural institutions, educational facilities and governments have management plans prepared in advance to react to a crisis, and yet seldom are plans available in the event of finding and rescuing a ship discovered during public works or commercial projects.

The Doel Kogges (2000 and 2002) in Belgium are lucky counterparts in comparison to the previously described German boats. In 2009, seven and nine years after their “rescue” from a public works project, the hulls sat disassembled in a tank farm while vegetation grew from the geo-textile covering the timber (Figure 5.1). Flemish authorities acted on a proposal to complete the project and four years of diligent work by

[283] Anonymous 2009.

staff has limited any further damage by initial inaction and lack of attention. The lesson provided is that the longer the project remains in stasis, the greater the risk for catastrophic failure from accident, loss of staff continuity and changing attitudes. For example, as highlighted in Chapter II (page 60), the stern of the Whaler *Candace* had to be put up for auction when the museum that originally committed to act as the repository had to back to out of the project due to diminished funding.

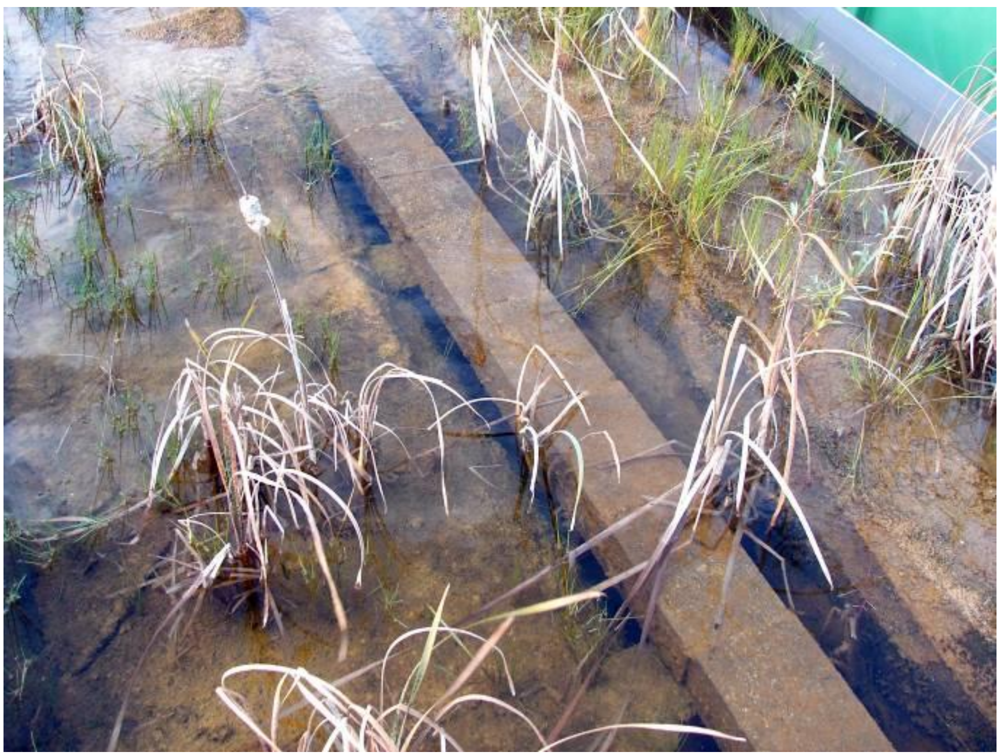

Figure 5.1. Timbers from the Doel Kogges lying in the tank with vegetation growing out of the geo-textile covering the timber. In many instances, the roots of the vegetation penetrated through the textile and firmly adhered to the surface of the timber. Photograph from the author's personal collection.

Watercraft conservation encompasses both large and small artifacts and patrimony with varying levels of significance. Chapters 5, 6, 7 and 8 provide an overview of these five divisions (reconstruction and display are combined in Chapter 8), highlighting the way that certain practices, particular to watercraft, have developed to tackle the different challenges laid at the feet of the archaeologist and archaeological conservator managing a watercraft project. Of the five steps, accurate delineation of both the complete structure and component parts occurs early in the work schedule and is critical to ensure a successful final product.

Artifact Delineation and Site Recording

The documentation of all artifact finds is a typical practice in the fields of archaeology and conservation, regardless of the object's size, shape or composition. Without the laborious and often painstaking process of delineating both the complete hull structure (i.e., the site plan as found), and component parts, analysis of the largest artifact from the site, the hull, would be severely hampered.[284] Structure and timber recording of vessel remains has been an essential part of ship archaeology since the first watercraft excavations in Nydam Bog (1859-1863). From the earliest archaeological excavations, the stock tape measure and transit have been critical accessories in every archaeologist's toolbox. Even today, for archaeologists working underwater in low visibility, the ruler and tape measure frequently remains the only reliable recording method. Before computers became widely accessible, and digital technology blossomed during the 1980s, all work had to be accomplished by the eye through photogrammetry, *in situ* casting, and measurements taken by tape, rule, and transit, or tracings by hand to create direct, full 1:1 drawings. Of the five previously listed divisions of watercraft

[284] Steffy 1994.

conservation, delineation, more than any other, has benefited from technological advances. New methods introduced by technology bolster accuracy, work efficiency and creative applications that in the future promise to provide further important time-saving advancements.

With the advent of computers and electronic recording instruments, those responsible for the documentation of watercraft were quick to adopt new technological methods for the recording of hull lines, complete structures and individual timbers. Apart from a considerable decrease in labor costs, electronic measurement reduces handling of the ship components and the potential for wear or damage. A further benefit of working in a digital environment instead of laying out a drawing on vellum is that with just a few additional steps the representation can be viewed in three dimensions instead of only two. Easily viewed perspective and three-dimensional aspects of the structure not only aid the interpretive or engineering analysis, but enhances insight for the development of elegant and dynamically varied methods of support, that when installed in the museum exhibit, help to inspire the visiting public to further discovery.

Perhaps the first ship recording project to utilize an electronic theodolite for hull delineation was the 1987 recording of the schooner *Wawona*.[285] The survey team did not lift lines from the hull electronically; instead, they utilized an electronic theodolite in combination with quadrangulation and handheld tape measurements to establish the required grid system and position the keel blocks required to support the hull out of water (Figure 5.2). The grid established by the theodolite created stations that ran 90° to

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[285] Anderson 1987.

the keel, which made setting up each recording station extremely efficient. Then, from what can best be described as a gigantic timber square, oriented at any given station, tape measures could be taken to the desired point on the hull from at least four known points. The *Wawona* recording project set in motion ideas on the practical application of recording ship structures electronically and it was not long before others began to adopt and build on the concepts begun with this recording project.

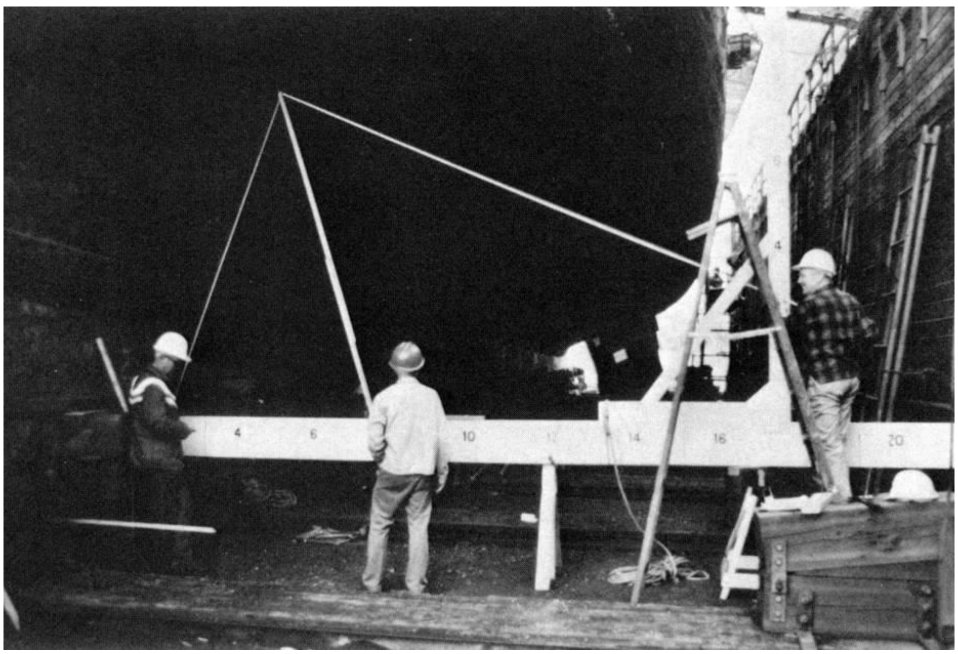

Figure 5.2. Using quadrangulation to delineate the whole shape of the schooner *Wawona* in 1987. From Anderson 1987, 85.

In 1993, Mark Starr, working in the Documentation Office of Mystic Seaport Museum’s, DuPont Preservation Shipyard, refined and further developed a methodology to lift lines from all sizes of watercraft and ship models electronically.[286] For large

[286] Starr 1996.

artifacts, such as a ship, Starr used a Sokia Total Station® to capture three-dimensional points in space (Figure 5.3). Instead of approaching the task in the traditional manner of recording ship lines by measuring to a point on a transverse station, exemplified by the method employed on *Wawona*, Starr captured the waterlines by placing a reflective target every few inches along each plank run. By obtaining the x, y and z coordinates, Starr was able to record both the shape of the entire vessel and automatically the orientation of the plank runs. Once the point cloud had been recorded, the digital data was downloaded into a computer automated drafting (CAD) program and Starr could begin to build a digital model. Since the laser of an electronic theodolite can only record by line of sight a number of set datums were required around the structure to establish a known working field. By orienting the plank run coordinates to these pre-established datums and connecting the points along the plank lines the complete surface of the digital model could be rendered. When formed into a solid object the shape could be uploaded into a naval architecture program (Aerohydro®) where transverse sections could be cut at any desired ordinate station by simply clicking on the computer mouse.

For smaller objects, Starr used an electronic coordinate measurement device (Faro-Arm®). Employing the same methodology as with the larger vessels, the articulating arm of the measurement device easily picked any point on the object, which automatically oriented the point in space along the surface of the artifact; once uploaded to the naval architecture program, sections could be cut at any wanted location.

Figure 5.3. A member of the Texas Historical Commission, La Salle Shipwreck Excavation field crew holds a reflective prism on an artifact to map the site. Similar to Mark Starr's early work the electronic theodolite was also used to record the *in situ* shape of *La Belle*. Photo, The Texas Historical Commission.

While Starr may have helped to pioneer the use of this methodology, his focus was on the preservation of historic floating ship hulls and historic design models. The instrumentation was easily adaptable, however, to the needs of archaeological delineation, and it was not long before ship recording *in situ* employed Total Stations® to pick point the three-dimensional coordinates of out of water shipwreck remains and the monitoring of movement in reconstructed watercraft on museum display. Between September 1996 and April 1997, staff of the Texas Historical Commission recorded artifact locations and the exposed timbers of *La Belle* while still within the confines of the cofferdam before and during disassembly of the hull. The drawings generated by this project were not solid models but hollow outlines effective for illustrating timber orientation and the state of hull deformation (see Figure 10.5). In the field however, the method proved ineffective for delineating specific timber detail, and each longitudinal and transverse timber required a 1:1 tracing to be generated by hand as part of the post-excavation documentation. Those analog drawings were then digitized into a CAD drawing to be presented in orthographic projection. The need for tracings demonstrated that even in the "computer/electronic age" no one instrument or method serves a universal purpose.

In 2000, with metal salts precipitating from the surface of the *Vasa* timbers the preservation division of the Vasa Ship Museum established a geodetic survey system to monitor the potential movement of the *Vasa*'s hull by affixing semi-permanent nodes to the hull and recording the distance with a Total Station from fixed points around the perimeter of the exhibit.[287] Ten years of collected data demonstrated that one of Sweden's most important cultural heritage objects was exhibiting signs of continued deformation. From the accumulated evidence, project managers concluded that a new cradling system would be needed to support the ship.[288]

The use of large-format three-dimensional scanners to record *in situ* watercraft remains continues to develop and has the potential to expedite recording in situations where aboveground exposure of the structure provides a clear line of sight (Figure 5.4).

[287] Malmberg 2002
[288] Kristofer et al. 2011.

Two problems that remain to work out with this method before there can be more widespread implementation involves the high capital expense associated with the purchase of powerful computers to manipulate massive amounts of data that laser scanners and coordinate measuring devices generate, all of which currently remains prohibitive to many. However, as with many forms of technology, more power and enhanced ability should be available at a reduced cost soon, which should increase use. A second issue that will only be corrected with time is that the specialized training required to operate the equipment also frequently limits its use.

If time is not a crucial factor in selecting the method of on-site recording, the requisite points could be obtained with a much less expensive Total station ® in order to gauge the orientation of the timbers and the structure. This process renders a smaller number of data collection points and allows the required drawings to be quickly generated. Capturing millions if not billions of 3-dimensional points in space requires considerable manipulation at a computer console when attempting to separate features that are similar, or directly next to one another.

Two disadvantages concerning dependence on dimensionally scanned data are that while the amount of detail captured by the three-dimensional scanned is impressive, the optics only allow for line of sight acquisition. Enclosed spaces and faying surfaces do not appear in the point cloud. Second, although the product is a virtual picture composed of x, y, z coordinates in space like photography it places a level of separation between the researcher and object. That is to say, all technology is simply a tool; although the digital image may be picture-perfect, close human inspection of the actual item is imperative for accurate interpretation. To obtain the greatest level of detail, and understanding, requires individual timber recording by 1:1 tracings or individually scanned components that can be used to reconstruct the remains part by part digitally on a computer.

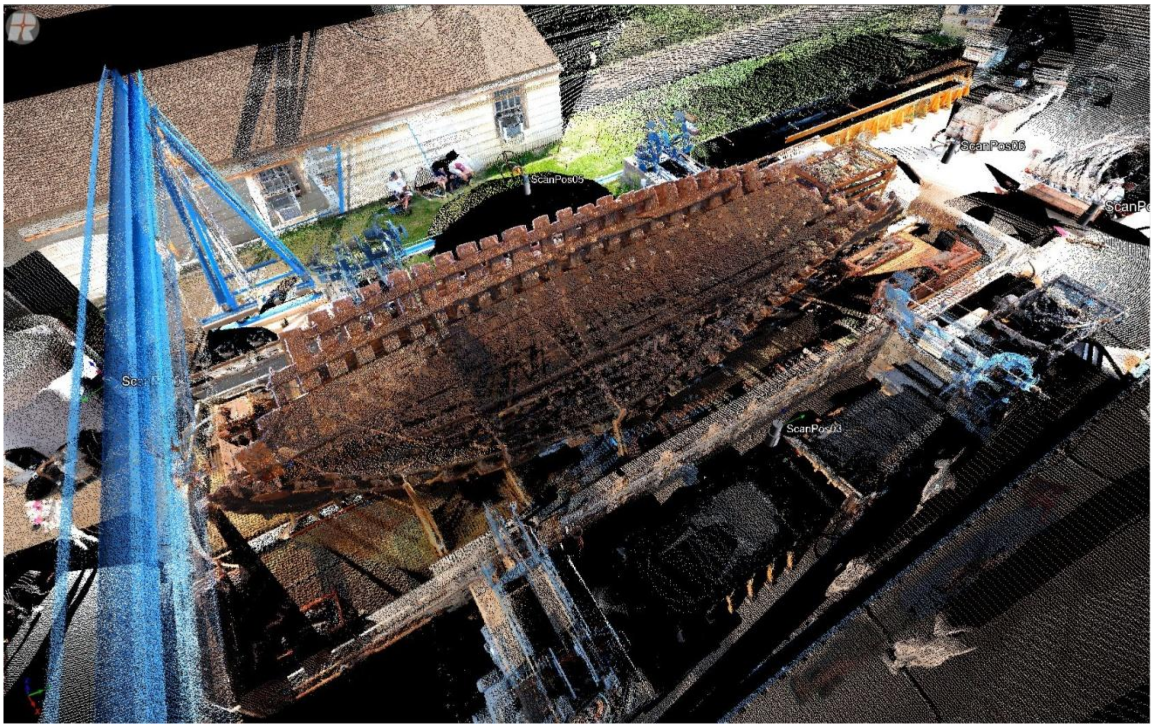

Figure 5.4. A post reconstruction three-dimensional scanned image of *La Belle* undertaken to compare different meaths of digital recording. *3D* image courtesy Center for Heritage Preservation, Texas A&M University.

Tracings and Component Coordinate Measurement

The data generated by mapping the structure in context is invaluable for orienting the components within the assemblage and essential for the overall analysis of both the site and structure. Reconstruction of the vessel relies on detailed recording of individual timbers in order to reestablish the correct geometry and ensure that the fastening holes and fasteners (spikes, bolts, treenails) will align each plank to a frame. Traditionally, the most common method to accomplish this task was a full 1:1 tracing (Figure 5.5). Creating 1:1 representations of timber involves placing sheets of clear Mylar® (preferable for dimensional stability) or clear polythene sheeting over each surface and tracing the outline of the timber and pertinent details, including fastening locations, angles, bevels, tool marks, physical damage, corrosion byproduct and staining.[289] The direct tracing method works well enough for flat, smooth surfaces, but not for surface elevations with curvature or that are irregular due to fracture or erosion. However, placing clear Plexiglas on a frame elevated slightly above the timber produces a more

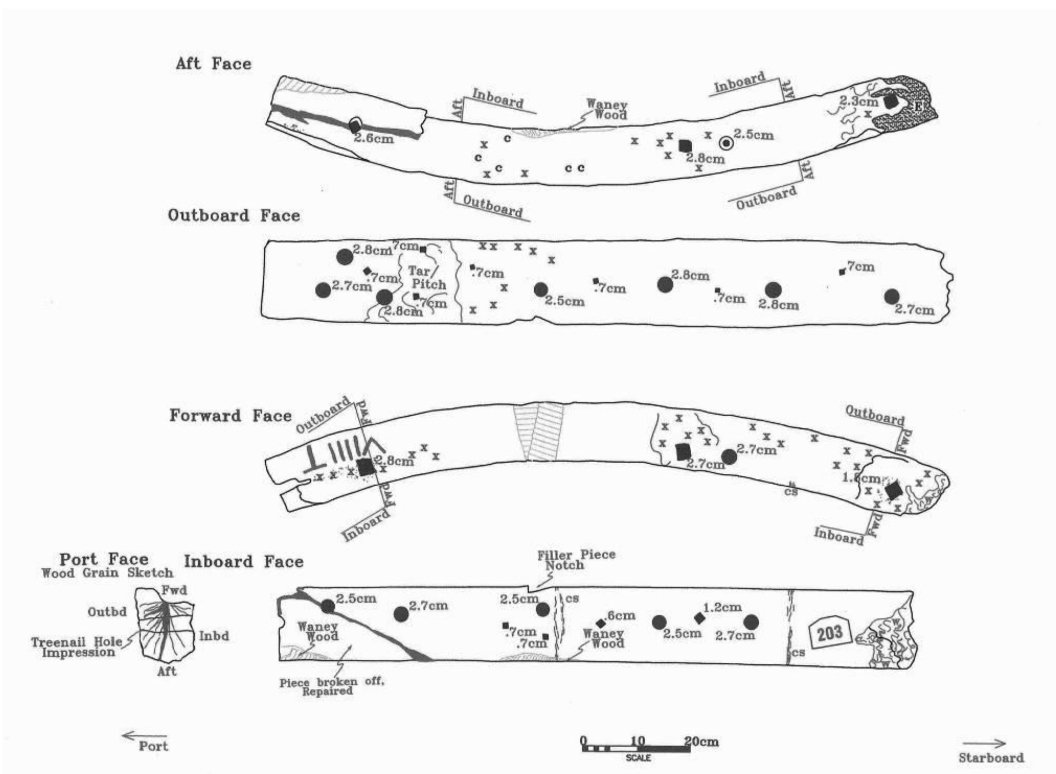

Figure 5.5. Timber drawings from *La Belle* digitized from 1 to 1 tracings by staff of the Texas Historical Commission and later digitized. Timber tracing courtesy Texas Historical Commission.

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[289] Crumlin-Pedersen 1977; Green 2004.

efficient and accurate method to make the tracing. Utilizing a block clamp to hold both the tracing marker and a laser guide in close alignment, all relevant edges, angles and curves can be recorded, even if the focal point is several feet away from the tracing surface.

Frequently, the selection of different colored markers designated certain details such as fasting location, original edges, marks, fractures and erosion.[290] Once completed, orthographic projections of the tracings can be scaled to the appropriate ratio. Before widespread access to computer drafting software to digitize an object, a grid had to be laid out on clear plastic sheets and measurements transferred by hand, or a large-format camera was positioned so it made a negative of the tracing that could be printed at a scaled ratio.[291] From scaled images or drawings of the transverse timbers, the draftsman could then form the shape of the section and fair the sections into corrected lines drawings.

For the detailed accurate recording of ship timbers, the archaeological community has embraced the instrument originally selected by Mark Starr to lift lines from historic half-hull and design models. In many places, especially in Europe and the United Kingdom, the implementation of a coordinate measuring machine has taken the place of 1:1 scale drawings (Figure 5.6). Introduced for archaeological practice in Denmark shortly after 2000,[292] this form of documentation holds considerable promise for not only the analysis of ships, but for the post stabilization reassembly of the watercraft. To date,

[290] Jensen, Petersen and Sraetkvern 2011, 16.
[291] Crumlin-Pedersen 1977, 170.
[292] Ravn et al. 2011, 235.

three-dimensional recording and digital modeling has been employed to document the Doel Kogges, the Newport Medieval Ship and a number of other watercraft around the world.[293] A proficient technician can accomplish a re-creation of the watercraft in three dimensions based on data derived from a coordinate measuring machine. Systematically, and very efficiently in a digital field, all fastening holes, bevels and angles can be manipulated to ensure alignment of floors, futtocks and planks, and that hull plank curves are fair. To further check accuracy, each of the timbers can be printed with a 3-dimensional printer, and components erected into a working model of the preserved structure at any desired scale, as long as they remain within the physical limits of the printer. Perhaps the greatest future prospect for having the 3-dimensional model is that, once corrected for shape and with confidence that all components accurately align, it will assist in stabilizing archaeological timber while undergoing treatment. Duplicate reverse timber shapes can be used to fashion molds from Styrofoam on a C&C router that can hold the shape of timbers during the process of dehydration after saturation with a particular chemical such as PEG or sugar, or during the sublimation process in a freeze dryer.

[293] Jones 2009.

Figure 5.6. Using a Faro Arm® to record a plank from the Doel Kogge.
Photograph from the author's personal collection.

Photogrammetry, Photo Mosaics and Computer Triangulation

The use of cameras for documentation occurs daily in archaeology and conservation and is one of the most important available tools for maintaining an accurate record of "before," "in process" and "after" documentation. In the past, some projects employed photogrammetry or stereo photogrammetry to record individual ship timbers or a site plan.[294] In the future, inexpensive photogrammetry software could possibly

[294] Green 2004.

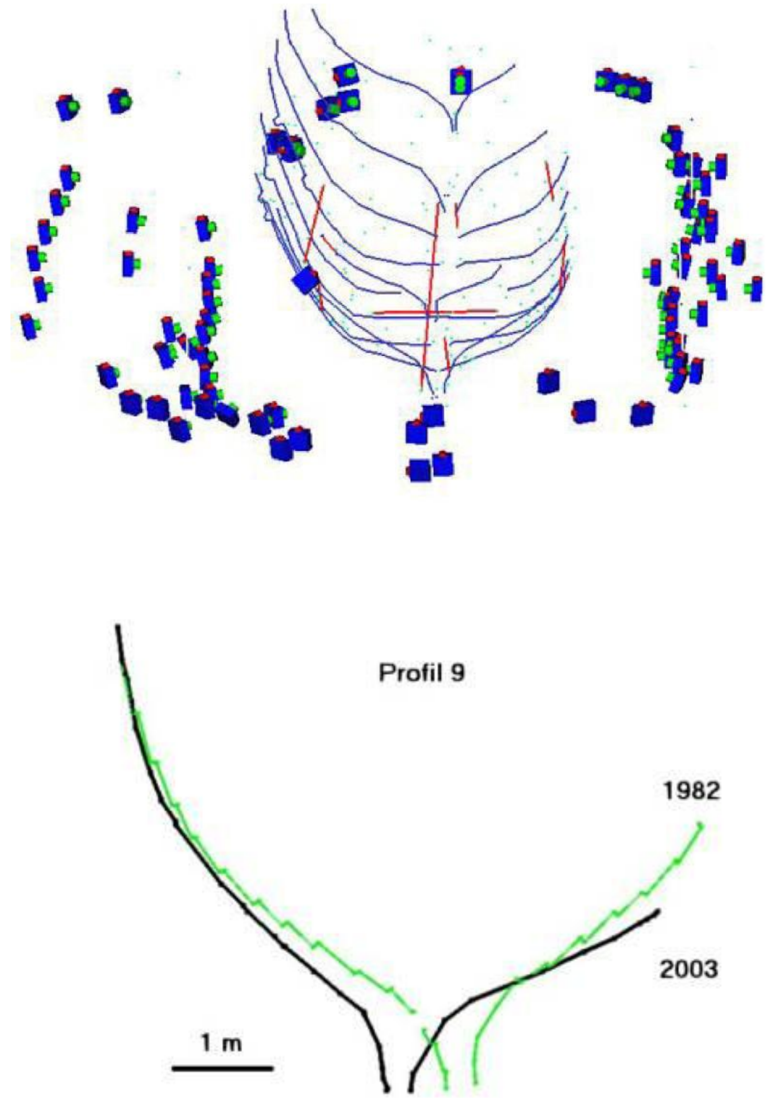

Figure 5.7. Above, the small graphic cameras represent the location where the images used for the photogrammetry model of the Bremen Cog's deformation were taken. Below, sections of the Cog combined for comparison to illustrate the change in shape of the structure at that particular location.Two images combined from Wiggenhagen 2004.

assume the primary role of three-dimensional recording or at least offer a low-cost alternative to the high cost of capital expenditures of electric recording devices. One example where this type of photogrammetry software has been used was to provide a rapid study of the hull deformation occurring to the Bremen Cog (Figure 5.7). When serious buckling of the structure was noted only a decade after installation of the project, staff at the Deutsches Schiffartsmuseum needed to quickly understand the current shape in order to propose solutions to manage the rapidly deforming display. By establishing a wire frame model on the computer through relatively inexpensive photogrammetry software, sections of the hull could be compared with sections taken from line drawings delineated in the early 1980s before immersion of the structure in PEG.

Similarly to three-dimensional scanned clouds, one problem with this method is that details that frequently do not appear in the focal plane of the image could go unnoticed, or mild surface features may not be discernible due to light and shading. There is a disconnect between the technician recording diagnostic features and the object itself. The best relational computer software remains the human brain and there is no replacement for a well-formed analyst. Such was the case with *La Belle*, when Teras Pevny associated several inscribed marks running perpendicular to the tangent of the compass timber above and below the turn of the bilge, which turned out to be "sur marks."[295] Pevny was one of the Texas A&M University Conservation Research Lab staff tracing timbers from the *La Belle*. While surface cleaning the different timbers, he could identify the marks and place them within the larger notion of the hull form. That

[295] Pevny (In Press)

association unlocked the design concepts of the hull and, ultimately the probable construction sequence of the ship.

Molds and Casting

Between 1960 and the early 1990s, several projects applied some form of molding compound to timber surfaces in order to obtain detail or shape. Today, except for underwater projects, and or in cases where the required equipment and technical ability are absent, the relevance of casting for delineation purposes has significantly diminished. Capturing impressions of tool marks and carvings still has a place for underwater application or as an inexpensive or expedient method; however, laser scanning followed by replication with a three-dimensional printer holds considerably greater promise for future application. Before the advent of electronic methods, as long as the molded surface was above water, casting with plaster of Paris and resins proved a very effective method for preserving a representation of the *in situ* structural shape or surface details (Figure 5.8). In the case of Boat Burial Mound #1 at Sutton Hoo (United Kingdom), where archaeologists encountered no actual structure, only the impression of hull shape, some construction details and disintegrated iron rivets. Plaster of Paris was applied in square sections to capture the missing form.[296] When the location of the site eliminated the option of lifting the hull as a complete block unit, archaeologists and conservators applied similar methods to record the shape of the inboard elevation of the

[296] Van Greersdaele 1969.

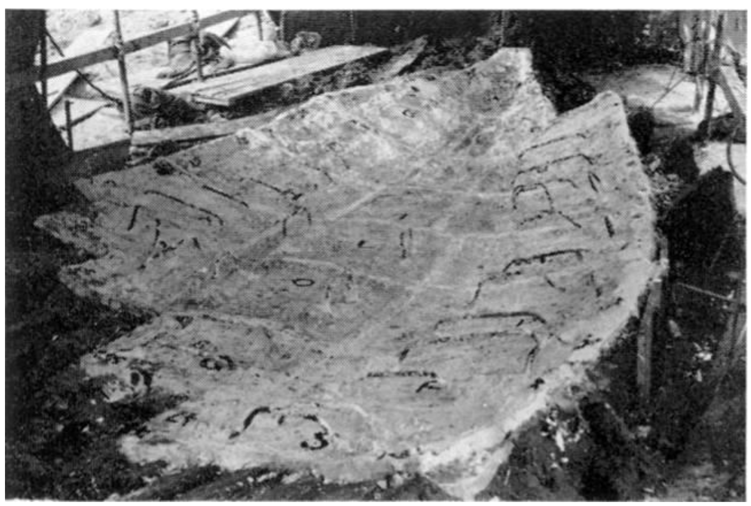

Figure 5.8. Left, the plaster of Paris molding of the impression created by the ship buried in Sutton Hoo Burial Mound #1. Right, a similar molding technique is employed on the planks on the medieval boat found in the Graveny Marshes. From Van Greersdaele 1969, 181, and Oddy and Van Greersdaele 1972, 33.

Graveny Boat's hull planks before removal of the assemblage,[297] in order to augment field measurements of the hull shape. In both cases, the reassembled plaster of Paris square casts acted as the positive mold for fiberglass resin casting of the full-scale object. Possibly the largest and most complex watercraft molding project was the complete molding of the 20 meter Gallo-Roman boat from Bevaix with the resin Uréol in order to retain significant diagnostic surface marks.[298]

In future excavations, it's doubtful that casting on the scale of the cited examples would be reintroduced since there are currently several laser and photogrammetric rendering software programs available, which can create much more accurate 3-dimensional digital images that can print the object with greater precision. However, in some instances underwater environments remain a suitable application for casting, whether to record surface detail or construction techniques that could be possibly lost during excavation and recovery. In the early 1980s, archaeologists and conservators from Parks Canada experimented with the application of two-part poly-sulfide compounds to mold features of the Basque whaling ship *San Juan* (1565) with considerable success.[299] Through the methods that they devised, they found they could cast the iron fasteners *in situ* regardless of its axis.

Conclusion

Recording the structure, component parts, whether by hand or digital methods, has and will continue to be an essential part of archaeology and conservation.

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[297] Oddy and Van Greersdaele 1972.
[298] Renaud 1999.
[299] Murdock and Daley 1981, 1982.

Technology provides an avenue to bolster productivity and offers considerable promise for the accurate three-dimensional rendering of component parts and the complete object. Over time these techniques will become more common, save a substantial amount of time, and reduce overall costs of watercraft conservation projects.

CHAPTER VI

WATERCRAFT CONSERVATION - RECOVERY

Introduction

Although discussions concerning the final disposition of the structure may occur as early as the initial discovery, by completion of the initial excavation and site recording plans concerning the final disposition of the structure must become a priority. If determined to be significant due to age or emotional connection, and if a storage facility or exhibit space is, or can be made available, the structural remains of the watercraft will most likely be saved. If saving the structure ism however, not a desire and reburial at an alternative location is planned due to some form of risk (i.e., the structure is impeding progress of a civil or commercial undertaking, potential looting, etc.), recovery of the object will also be the next step in the project. Generally, the most pressing question regarding recovery always focuses around the safest and most economically efficient manner of extrication from the site. Should the remains of the hull be lifted as a single unit or disassembled and removed by individual pieces or sections? Chapter 6 explores the recovery of watercraft structures by focusing on case studies that illustrate the challenges of safely removing the fragile material and some creative solutions developed to recover the hull as a block unit, sections, or by disarticulated component parts.

Along with materials stabilization, the recovery and transportation of the structure from the excavation site constitutes one of the riskiest aspects of any project. Timbers and fastenings that may appear solid and robust might actually be very fragile and retain little of their original mechanical strength. Improperly lifting the hull in its degraded state can lead to dire consequences as previously exemplified by the short case study of the river gunboat USS *Cairo*.

The selection of a recovery method results from the structure's condition in relation to its location and environmental factors particular to the site, size and level of preservation of the structural components, available time and funding, and finally, the philosophy and creativity of the project staff. All of these factors lead to two general actions, either the complete or the sectional disassembly of the structure in the field, or recovery of the structure as a block unit. Many watercraft have been recovered with only a moderate amount of professional engineering assistance. The exceptions to the statement are of course the largest recovered vessels, exemplified by the *Vasa* and the *Mary Rose*, where teams of engineers labored for years to successfully lift the hulls off the bottom and transfer the structure to awaiting conservators and archaeologists.

The Block Unit

Unless the process of deposition has already disarticulated the structure into many pieces, the first thought of many on the recovery team is if the possibility exists to raise the complete, or nearly complete, structure as a block unit. The theory behind this preference is the result of several factors. First, for some it is an ethical choice holding to the notion that modern hands should not disassemble what past artisans created. Second, it is often a logistical issue concerning the size of the structure and component timbers. Third, once the fastenings are cut, even on small craft, if the timber has any residual memory, it frequently "springs" from its current shape into the orientation in which it grew and was sawn, making realignment of the planks and frames during the reconstruction very difficult if not impossible. Similarly, the sandwich construction comprised of floors between planking may hold the shape of the frames and futtocks in the correct orientation, but each could potentially twist when released from the tight assemblage. Finally, the logistics of managing a complete disassembly of the structure in the lab, or more secure environment, may be more efficient and cost-effective than attempting to undertake the procedure in the field. That is, of course, assuming that the conservation lab has suitable space to store the complete structure and disassemble it into its component parts in the same vicinity where work is ongoing or conveniently transported to off-site storage.

With continued injection of ideas from inter-disciplinary teams, over the past 50 years many creative solutions have been developed to safely raise and recover the block unit. With exception of the previously mentioned large examples (*Vasa*, Nanhai 1 and *Mary Rose*), which required thousands of hours of professional engineering work and construction of massive cradles to support the archaeological remains during the lift, most recoveries have been undertaken solely by archaeologists and conservators with the assistance of engineers on only some of the more complicated projects.

The main methods employed to support a structure during recovery include altering its buoyancy and floating it to the location of the crane, strapping the structure to a lifting frame for a direct hoist out of the site, or securing it to a sled where winches or machinery can tow the structure. If even slightly fragile, a frame is usually built under and around the hull remains in order to take the strain of the lift by a crane. On occasion, the frame has to be designed to act as a sled for hauling over land or marsh surfaces to a point stable enough for crane operation. Perhaps the one constant in all recoveries is that a crane is usually involved to make the final lift onto the bed of the truck for transport to the storage for conservation facility.

The following examples illustrate the challenges of recovering integrated, waterlogged wooden structures, each highlighting a particular feature of the recovery process.

Gondola *Philadelphia*

Thirty years before the catastrophe attempt to lift the USS *Cairo*, similar techniques were employed on an older but much smaller gunboat with drastically different results. On August 9, 1935, the truck of the *Philadelphia'*s main mast broke through the surface of Lake Champlain, New York, ending the vessel's 159-year submersion in cold, fresh water. Seven days earlier, a hardhat diver working off surface-supplied air had located the American Revolutionary War gunboat lying in about 60 feet of water. The rail of the hull was 57 feet [17.37 m] below the water's surface in an upright orientation, and buried in the sediment created by its impact that rose up the sides of the boat approximately 2 feet above its flat bottom.[300]

Walking around the outside of the hull the diver took some rough measurements and sketched a map of what he observed on the bottom, noting in particular that the rudder had separated from the hull and was lying off the stern partially buried in the mud. The anchor cables, both on port and starboard, that once secured the anchors to the

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[300] Hagglund 1949.

catheads had disintegrated and an anchor was lying on either side of the bow. The twelve-pounder bow gun was in a peaked position and remained on its track, but the waist guns lay in a heap on the starboard side, just forward of midships. All of the running and standing rigging had disintegrated and two yards lay across the hull from rail to rail, but the mast remained firmly seated in its step.

Experienced marine salvers, the leader of the expedition Lorenzo F. Hagglund, and his hardhat diver William Lilja had gained considerable skill in marine salvage recovery work while employed by New York City marine salvage companies. After removing the cannons to lighten the load and roughly assessing the condition of the submerged structure, they devised a plan to cut three passages under the flat bottom of the boat with a water jet: at the bow, near midships and at the stern. Through these tunnels, hoisting cables leading down from a derrick barge would be connected to its opposite pair and then to the main cable from the crane. To protect the hull from crushing as hoisting strain was taken on the lifting cables, a log was secured with lashings between cable pairs to act as a spreader. While the hoist took the strain, the diver used the water jet to remove mud from the cockpit and break the bottom suction created by the mud, allowing the hull to be brought to the surface. Even with the use of wire cables, hoisting the boat in this manner caused very little damage to the hull. The only scarred planking that could be attributed to cable chafe against the fragile timber was located near port frame #30 (counted from the bow) leading down and across the bottom planks.[301]

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[301] Fix 2010.

One of the primary reasons for the successful recovery is that the cables and hoist never lifted the gunboat out of the water. With the rail and sheer plank awash, the hull was lashed to the side of the barge and moved to shallow water off Valcour Island. There, a large piece of canvas was spread around the outside of the hull and secured to the cap rail. Hydrostatic pressure on the canvas enveloped and sealed the hull, which allowed the crew to jettison water from the boat and stabilize the semi-submerged structure. Secured with slings to the derrick, a towboat pulled the derrick and gunboat to a nearby railway where the gunboat was carefully brought ashore with the weight of the structure spread over a considerable portion of its flat bottom.

Kinneret Boat

Following over a year of extreme drought in the Sea of Galilee region, water levels in the Sea of Galilee plummeted, exposing vast tracts of the seabed. It was in one of these newly exposed areas that the outline of a 2000-year-old boat was discovered in the heavy clay bottom. The preservation level of the waterlogged wood was very low and exhibited insufficient integrity to support even its own weight. Only the stability of the encasing clay maintained the hull form.[302] The location proved challenging and had the project team not developed a very creative solution for recovery the only choice for recovering the artifact would have been complete disassembly in the field, which after evaluation was not considered to be feasible.

The discovery was made toward the end of the drought and excavation had to take place under the constant threat of rising waters. To protect the ongoing work, crews

[302] Cohen 1991.

damned off the site and maintained access to the interior of the hull by the installation of pumps. To prevent the potential collapse of the weakened sides, as the excavation team cleared the interior sediments they braced the hull by mounting formfitting fiberglass reinforced polyester resin supports that mimicked the hull shape, at every second frame bay. Excavation of the stern revealed that the sternpost had been removed in antiquity and the after ends of the planks had no support once the sediments were cleared from the interior. To stabilize the stern, the application of polyurethane foam to the interior encased the section, providing it with much needed support. Additional bracing by the installation of a thick band of fiberglass-reinforced resin provided the needed support to solidify the missing portions of the stern.

When no suitable conventional method for recovery could be determined, and with the rising waters threatening to again inundate the site, the team decided to apply the same materials and methodology that stabilized the stern to the entire hull. To stiffen the structure, polyethylene foam was sprayed into the interior and over the fiberglass bracing in the frame bays. On the exterior, excavation staff dug channels under the hull to facilitate placement of formfitting fiberglass ribs, similar in construction to those molded to interior, but fashioned to the outboard shape of the hull. When the resin cured, the channel underneath the hull was filled with polyurethane foam. Once cured, excavation began on the adjacent tunnel, and the process repeated. When a sufficient number of external foam and fiberglass braces were in place to support the hull, newly formed trenches exposed the remaining outboard planks and the complete structure encased in polyurethane foam. With a density of around 2 pounds per cubic foot and a buoyancy factor of +60 pounds per cubic foot, the excavation staff determined they could flood the site and float the foam-encased boat several hundred meters to a cradle and then hoist it from the Sea of Galilee by crane.

Hasholme Logboat

An enormous oak logboat measuring 12.78 meters long, 1.4 meters wide and 1.25 meters high was discovered in clay and peat subsoil close to the River Foulness in East Yorkshire during commercial site excavations in July 1984. The subsequent excavation was conducted in August and September by a team consisting of staff and students of Durham University and the Archaeological Research Centre of the National Maritime Museum. To provide support for the cradle design and assistance in recovery, technical section staff members of the Area Museum and Art Gallery Service for Yorkshire and Humberside were included in the project team when the decision was made to preserve the logboat in its entirety.[303]

Following analysis of the hull condition and accounting for the surrounding environment several parameters became clear.

1) "The fragility of the boat meant that it needed support throughout its length.
2) Although its mass was unknown, the density of the wood and its estimated volume suggested a weight of c 6 tonnes.

[303] Morris 1992.

3) The ground at c -1.5 m OD was subject to flooding even in the drought, so speed was essential. Further, the stratigraphy with clay above a peat bog produced a land surface with almost no load-bearing capacity."[304]

Original plans to lift the hull from its excavation trench by closely positioning straps between the artifact and the lifting frame were thwarted due to costs associated with positioning a crane on site. Instead, the team opted for a truss-box frame that would protect the fragile object as it was towed from the trench and across approximately 100 meters of open ground to an area that could safely support a crane. Individual elements of the cradle were designed to a size that could be managed by a mechanical excavator and assembled alongside, over and around the log boat in the trench.

Polyethylene sheeting placed around the exterior of the exposed hull protected the wood from uncontrolled drying and the boat was securely chocked against any chance of movement inside the frame. At the base, crews installed plywood on the cross beams to create a floor that would protect the hull as the cradle slid along the ground. Cables connecting the frame to a winch planted on solid ground slowly pulled the cradle and logboat up a ramp constructed by sloping the earth such that one of the trenches led to a location where it could be safely maneuvered by crane.

Brown's Ferry Vessel

Five years after its discovery in 1971, a team of archaeologists from the South Carolina Institute of Archaeology and Anthropology (SCIAA) recovered the hull remains of a double-ended, flat-bottomed early 18th-century boat from the Black River, South

[304] Gregson and Millett 1985, 13.

Carolina. Measuring roughly 48 feet [14.6 m] long, 12 feet [3.66 eight m] the hull had disintegrated on the exposed side around the turn of the bilge, and was twisted and heavily deformed on the other side due to the compression of over 12,000 building bricks, which was the vessel's cargo when it sank.[305] Regardless of how little remained of the structure, authorities deemed the vessel significant and plans were undertaken to raise and conserve the watercraft artifact for eventual display.

With limited financial resources, and exceptionally poor water visibility, hence the name Black River, planners set about to devise a plan to raise the hull as a block unit. Because of the lack of funding and need for a large structure that had to be transported more than 100 miles to the designated conservation facility, authorities had to devise an inexpensive, yet very elegant and durable lifting frame to safely recover the boat. Their solution was to create a rectangular lifting frame with railroad rails for the longitudinal sides connected by five H-beams oriented squarely from side to side. From the rails ratchet straps every 2 feet (60 cm) apart were passed under the boat through tunnels cut by water jets. With the bricks removed and the lifting frame suspended from the crane hoist, the extraction of the hull began. The use of a large number of straps spread all load forces over the length and girth of the structure instead of point loading the object in a few places. An additional benefit of using a large number of wide straps was that by adjusting these straps during the lift, the strain on the malleable degraded timber shifted and removed the deforming twist.

[305] Singley 1982.

Caprow Logboat

In 2001, the partially exposed remains of a 9 meter logboat, radiocarbon dated to 2885 +/- 50 BP, were discovered in the intertidal mud flats of the Tay Estuary at Caprow, Perth and Kinross, United Kingdom. With calibrated radiocarbon date ranges between 1130-920 BCE, the find is the second oldest known archaeological boat from Scotland.[306] A thorough assessment of the hull and its surroundings conducted in 2002-2003 indicated that the remaining structure was at risk and therefore plans were placed into action to recover the logboat.

Since tidal movements governed access to the site, scheduling any work had to coincide with low tide and daylight hours. During separate periods in July and August 2006, the excavation crew fully recorded, excavated and recovered the log boat. To recover the hull, excavation staff utilized the incoming tidal range to lift the structure free of the site. Once the excavation removed the sediments inside the log, trenches along the sides provided access to the underside of the structure, where sandbags were placed to underpin and support the timber. Three 200-liter plastic barrels were inserted into the interior of the logboat cushioned by foam padding. Plywood wrapped around the exterior of the hull protected the degraded surface in areas where ratcheting straps held the barrels in place.[307] With the barrels secured, as tidal waters inundated the site the logboat rose free of the sediments and the recovery team managed buoyancy compensation by filling or removing water from the barrels (Figure 6.1). Following the initial extraction, the team anchored the structure on soft mud next to the nearby shore to await the next

[306] Strachan, Skinner and Hall 2012.
[307] Strachan 2010.

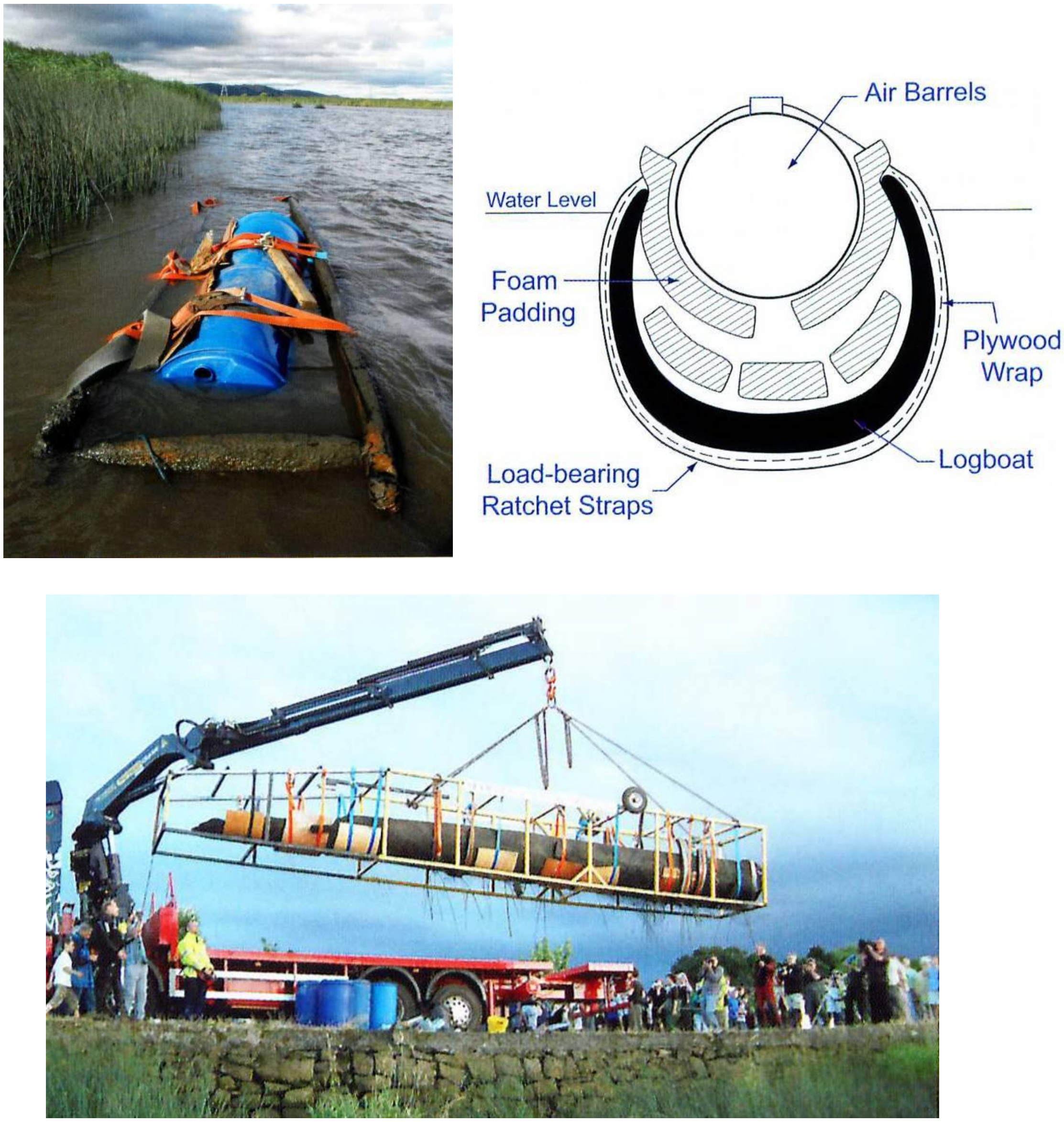

Figure 6.1. Recovery of the Caprow Logboat. Upper left, the barrels inserted in the log that secured in place by ratchet straps. Upper right, a cross-section schematic of the float system. Bottom, the log boat supported within the box frame being lifted onto a truck bed for transport. From Strachan 2012 pages 46, 49 and 52.

outgoing tide. The following day the float system was re-rigged to include a net that would capture any disarticulated material that might fall from the craft during the move at the next high tide. The floating logboat was slowly towed several kilometers to the location where it would be lifted from the water. With a 9.3 meter steel box frame suspended from a crane hoist on land, the logboat was floated inside and secured by closely spaced straps that were placed around the logboat, securing it to be top rails of the lifting frame. With the aid of the crane, the whole unit was placed on a flatbed truck. The straps were gradually released to lower the logboat onto padding positioned in the base of the frame in order to reduce vibration during transport to the conservation facility.

Magor Pill Boat

When one end of a 7.2 meter long by 3.9 meter wide craft, dated by dendrochronology to c. 1194 CE, was discovered at the Gwent Levels of Magor Pill, South Wales, the National Museum of Wales desired to excavate and display the wreck; however, environmental challenges imposed by the site made recovery a considerable challenge.[308] The wreck site lay 450 meter from dry land in the intertidal zone, which limited access to the site for only about four hours per day. A schedule to disassemble the vessel on site was determined to take several months and would extend work into the winter months where winter storms could damage any exposed timbers remaining on-site. In addition, a tidal range of 10 meters and a tidal race of 13 knots ruled out the possibility of effective reburial and *in situ* preservation, or the use of divers.

[308] Dollery 1996.

Lifting the waterlogged wooden remains as a block unit was the most sensible option and engineers proposed two separate designs to extricate the artifact. The first involved forming a rigid box all around the hull. The second was to create a base cradle underneath the structure that would take most of the lifting strain and then attach a lifting frame to the cradle by connecting ratchet straps to the top and bottom sections. Because of the added expense of fabricating and assembling a complete box frame, project planners selected the second option (Figure 6.2). Installation of the aluminum beams began by cutting 2 meter wide by 2 meter deep trenches down each side of the hull. With

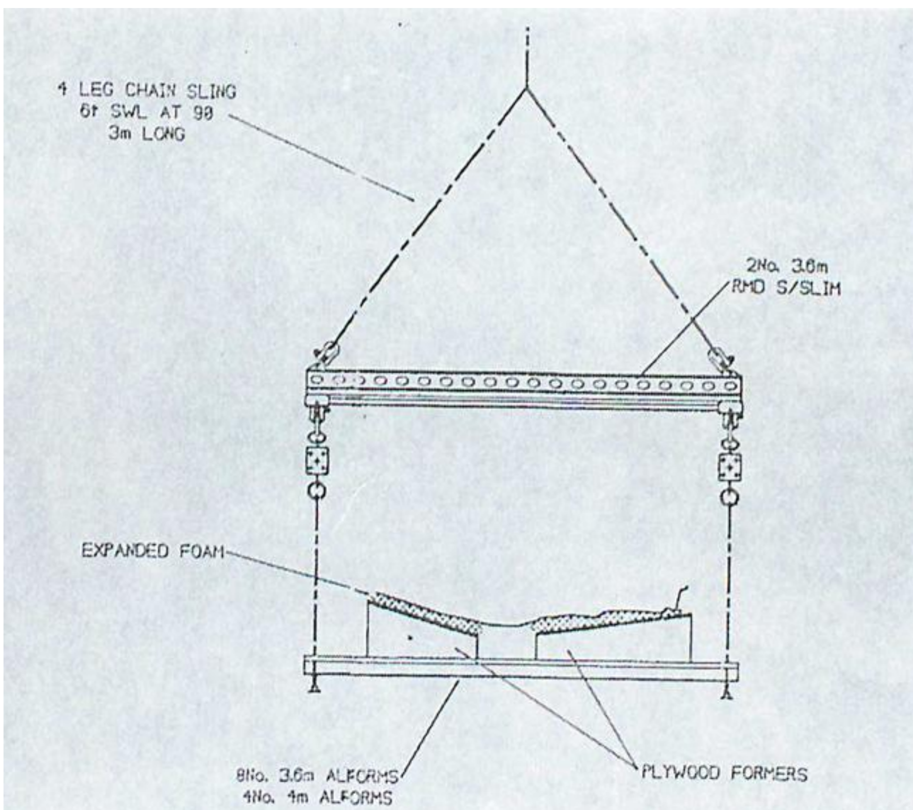

Figure 6.2. A cross-section sketch of the lifting cradle and frame used to recover the Magor Pill boat. From Dollery 1996.

the underside of the wreck exposed, the team cut five transverse tunnels under the hull by hand for beams that would directly support the structure. In each trench running along the hull, a 6 meter beam was laid at the bottom. Four-meter beams were placed through the tunnels and each rested on the longer longitudinal beams. To brace the hull in its depositional orientation plywood boxes filled the space between the beam and underside of the hull with polyurethane foam filling in any remaining voids and further cushioning the surface of the timber. With the base complete, the lifting frame was placed above the site and connected to the cradle with ratchet straps. A slight strain was taken on the frame by the hydraulic arm of the mechanical excavator and the suction created by the remaining mud around the hull was broken by digging out the remaining mud by hand. From the site, the assemblage was lifted onto a waiting barge for the trip ashore.

Recovery by Section

An assortment of factors contributes to a decision to dismantle or cut the hull remains into sections before recovery. Logistical factors relating to the size of the remains may prompt planners to cut the artifact into easily manageable pieces instead of risking catastrophic damage. In addition, the costs associated with sectioning the hull may be considerably less than engineering a cradle and frame to lift everything *in toto*, which may require spending many months in the field disassembling the structure. Finally, retention of diagnostic features or the proposed conservation strategy, which may favor conservation in sections over the block unit, exemplify and, in many cases justify, the alternative approach of removing the structure by section.

Recently there has been considerable debate concerning the recovery of watercraft by cutting them into sections. The frequent reasoning for the action is due to cost, facilities and making an exhibit-opening deadline. At the 2013 triennial WOAM conference in Istanbul Turkey, roundtable discussions on the subject turned into heated debates.[309] However, as highlighted in this review, cutting timbers may in fact be the safest course of action when recovering the structure.

Arles-Rhône 3

Discovered by divers at Arles, France in silt at the bottom of the Rhône River in 2004, the 31 meter long, nearly intact, c. 50 BCE Gallo-Roman River barge posed considerable logistical challenges for archaeologists and conservators.[310] The 50-ton barge possessed very little freeboard and a length to breadth ratio of approximately 20 to 1, which posed a daunting challenge for project planners to deal with lifting the structure as a block unit. The conservation facility selected to stabilize and reconstruct the hull was in Grenoble, 275 kilometers away, which would have imposed considerable risk to the structure during transport. In addition, the length of the vessel extended far beyond the largest storage tank at the conservation facility. The only viable option was to cut and recover the barge in sections.

To recover the hull the crews cut the structure into 10 manageable 3 meter sections. A "U" shaped frame was placed upside down with the side extending into a trench dug along each side of the hull. Once at the appropriate level, tunnels were dug under that particular section and one side of the open frame connected to the opposite

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309 WOAM 2014.
310 Personal communication, P. Fix and H. Bernard-Maugron 2011.

side in order to form a stable base. Once secured in place, and the section free of both the sediments and the rest of the hull, a crane hoisted it to the surface and onto a waiting truck for the trip to the conservation lab.

Dover Boat

In September 1992, during site work for a pedestrian underpass intended to connect the city center of Dover, England and the waterfront of the port, archaeologists discovered the planks of a boat dating to 1340 BCE. The structure was incomplete due to previous salvage attempts in antiquity, and damaged by the installation of sheet piling for a cofferdam surrounding the underpass, which diagonally severed a portion of the boat. What remained viable for future investigation was a 9.5 meter portion of a boat originally believed to be around 13 meters long. Regardless of the past partial dismemberment, authorities considered the find significant and a rapid rescue recovery commenced.[311]

Construction work on the cofferdam was halted for three days to enable *in situ* analysis, survey, photography and extraction.[312] Because of the construction details and available workspace around the excavation pit, recovery involved cutting the boat into longitudinal sections and lifting each from of the pit individually. The team determined the structure could not be lifted as a block nor could it be disassembled, as the integrity and diagnostic attributes of the twisted-withy stitches formed from yew would be lost. Therefore, the portion of this structure to be removed was cut in strategic places where withy and fasteners were not damaged.

[311] Slack 1993; Watson 1993.
[312] Fenwick 2007.

Oberstimm 1 and 2

In 1994, staff from the Museum für Antike Schiffahrt in Mainz, Germany excavated two Trajanic Period Roman warships that had been accidentally discovered near a Roman fort just off the Danube during dredging work in 1989.[313] Plainly two shell-based constructed hulls that employed mortise and tenon joints north of the Alps were a rare occurrence, and thus authorities decided to save the two boats. The type of construction that highlighted the significance of the find also determined the methods of recovery. The excavation staff felt that to disassemble the planks in the field would obliterate the primary evidence they wished to retain, and the complete structures would be difficult to safely recover and transport to Mainz. Therefore, the hulls were sectioned into four parts, two large midship sections and smaller bow and stern pieces.

To brace the sides of the sections against collapse during the lift, museum staff shaped thick polystyrol boards to the interior curvature of the hull that extended from side to side. Each cross-sectional piece was fixed in place to a wooden frame that extended over the section to be removed. Once the supports were in place, the excavation team dug tunnels under the hull and passed straps through each tunnel, making a secure connection to the outside rail of the wooden frame. Between each strap and the wood surface of the boat, staff placed a thick layer of foam to cushion the lifting point and avoid abrasion to the wood surface. Once cut into sections, lifted from the excavation site and placed on a truck bed, each was released from the straps and rested on a form-fitting foam mold that mimicked the complete underbody shape for that section. Once on the

[313] Pferdehirt 2005.

bed mold, the crew wrapped the sections in plastic to abate dehydration during transport and secured each segment against further movement during the trip to the Museum in Mainz.

Recovery by Disarticulated Component Parts

Generally, fragmented or disarticulated timbers, especially when located underwater, are collected and recovered on site. In some cases, the most practical and efficient method and one of the safest for the artifact is to disassemble the surviving structure in the field and ship the components to the conservation lab for cleaning and stabilization, as well as reconstruction if bound for public display.

Barland's Farm Boat

In November 1993, while excavating a 26 hectare site for a supermarket distribution center at Barland's Farm near Magor Gwent, South Wales, a mechanical excavator uncovered the remains of a small flat-bottomed boat, over 9 meters in length, dated to the 3rd century CE by dendrochronology. Because the structural remains were threatened by compression of the site work, disruption of the anaerobic environment and deformation, a team from tbe Glamorgan-Gwent Archaeological Trust, under the direction of Nigel Nayling, excavated the site and dismantled the hull into several sections and component parts for study and eventual display in a Newport (Wales) museum.[314]

When compared to some other projects, the recovery of the Barland's farm boat was relatively straightforward. A temporary shelter was erected over the archaeological

[314] Nayling, Maynard and McGrail 1994.

site before exposing the buried timbers and with cold weather approaching a large thermostat-controlled heater was installed within the enclosure to protect the fragile remains from freeze thaw cycles.[315] Due to the corroded nature of the iron fastenings and robustness of the remaining frame assemblies, the excavation team could lift each of these elements with little strain on the timber by wrapping them with padded straps and hoisting them away from the site. Once the hull planks were exposed, they too were also easily lifted from the depression in the ground. Long planks were cut into manageable 3 meter lengths and placed on purpose-built stretchers for transport to the documentation facility.[316] However, the state of wood degradation on the starboard side and in the bow was such that the fragmented pieces could not be treated in the same manner. Instead, sheets of fiberglass impregnated with polyester resin consolidated the fragmented timbers in those areas and the sectional blocks lifted from the site in 13 individual segments. Packaged for protection during transport, the timbers were transferred to off-site tanks for documentation and later repackaged for shipment from Wales to the east coast of England for conservation.

Doel Kogge 1

During the expansion of dock facilities for the Port of Antwerp in August 2000, along the left bank of the River Scheldt, fragmented timbers emerged from the bucket of a large mechanical excavator, exposing the nearly complete upside-down hull of a medieval cog. The inadvertent disturbance by the bucket tore an approximately 4 meter hole in the 20 meter long, 7 meter wide structure. Fortunately, seeing the timbers and

[315] Hunter and Nayling 1996.
[316] Nayling and McGrail 2004.

realizing their potential significance, the machinery operator halted excavation work after only one-bucket load damaged the hull. Interest in the find grew rapidly (see Figure 2.1) and the decision was made to document the hull and immediately rescue the timbers without a plan for the future disposition of the timbers, and determine whether to keep the find in perpetuity later. With a limited amount of time in which to conduct documentation, a large digital scanner was brought to the site and a complete three-dimensional scan made to record the hull, from which a three-dimensional model was printed (Figure 6.3). This potentially marks the first use of a three-dimensional scanner to record archaeological ship remains.

Figure 6.3. A "printed" solid model of the up-turned Doel Kogge 1 produced by data from the three-dimensional scan of the cog as found. Note the sediments propping up the hull through the 4 m gash created by the bucket of mechanical excavator. Photograph from the author's personal collection.

The size, weight, upside-down orientation and undulating character of the hull deformity diminished the possibility of rescuing the structure as a block unit. Sediments filled the cavity of the overturned hull and acted as the primary means of support for the structure. Its removal would seriously jeopardize hull integrity. Therefore, after consultation with experts in the field, Flemish authorities chose to disassemble the hull in situ and remove individual elements from the site. Fortunately, all of the iron fastenings had completely corroded away, leaving only treenails holding planks to frames. Because of the length of individual surviving planks, each was cut to a distance end to end of no more than 4.5 meters. The keel, transverse beams and mast step were the only longitudinal elements left uncut.

Disassembly progressed rapidly, and within a period of two months from the point of initial discovery, 104 stretchers measuring 4.5 m x 1 m and 12 stretchers measuring 7.5 m by 1 m had been transferred off-site to 29 steel holding tanks awaiting a final decision on the ultimate disposition of the wreck.

La Belle

In 1995, following several years of investigating iron anomalies on the bottom of Matagorda Bay, Texas, staff from the Texas Historical Commission (THC) located the cargo-filled hold of a shipwreck, which included one of the four identifiable bronze cannon that King Louis XIV provided the French explorer René Robert Cavalier, Sieur de la Salle, for his attempt to establish a fortified colony in the New World near the mouth of the Mississippi River. The shipwreck remains were the *barque longue La Belle,* one of four ships that departed France in 1684 and sank during a storm in 1686. The quality and number of related finds within the hold, coupled with the extremely low visibility of Matagorda Bay prompted the THC to construct a double walled, doughnut-shaped cofferdam around the wreck site and conduct an archaeological investigation in a semi-saturated dry environment instead of underwater.

With the bay water pumped out of the cofferdam, tens of thousands of artifacts began to emerge. At the bottom of the pile and acting as a large bowl, holding the contents of the ship's cargo, was approximately 35% of the remaining hull. So significant is La Salle's association with Texas, and with the pre-history of the United States, that there seems to have been little debate whether to recover the ship for eventual display in the Bullock Texas State History Museum being constructed in Austin, Texas. There was however, considerable debate concerning the manner in which to recover the 52-foot by 15-foot artifact–to recover the structure as a block unit, or disassemble it and remove individual elements.[317] Ultimately, due to the poor condition of the degraded, waterlogged wood, the size of the structure and the approximately 160-mile trip to the Conservation Research Laboratory at Texas A&M University, College Station Texas, the decision was made to completely disassemble the remains within the confines of the cofferdam.

The approach taken by the THC was systematic and straightforward; disassemble the hull by reversing the original order of construction (Figure 6.4). With the completion of the excavation of the contents from the hull remains, work focused on disassembling the ship. The archaeologists began by removing the bulkheads, mast step assembly and

[317] Carrel 1998.

Figure 6.4. Disassembly of the hull of *La Belle*. Above, raising the forefoot and keel section. Below, staff disassembling the ceiling plank from the starboard side. Photos, Texas Historical Commission.

the deck under the anchor cable. With the interior of the hull completely empty of all obstructions, work commenced on removing the starboard clamps and ceiling planks. These were fastened together by a combination of 1-inch diameter iron drifts, most of which were completely corroded, and wooden treenails that retained enough integrity to require severing them to dismantle the structure. To break the connection of the treenails, and any fragmented iron bolts, the excavation crew inserted small bottle jacks, modified with a lifting plate the shape of a "Z" in order to navigate the narrow in the frame bays. Seated on a metal pad, enough pressure was placed on the scene between the ceiling plank and the futtock to open a slight gap between the two to accept Teflon wedges that further expanded the gap. Pressure from the bottle jack and wedges continued to apply pressure on the seam until there was sufficient space to insert a long, thin saw blade into the gap and cut the treenail. The process was repeatedly applied until all of the treenails for that particular plank had been cut. Depending on the size of the surviving timber, the planks, futtocks and floors were lifted by hand from the wreck site and taken to temporary wet storage for initial cleaning and documentation. A spreader bar connected to a crane hoist lifted larger elements larger elements from the excavation pit. After initial timber cleaning and documentation, the crane lifted the storage containers onto a service boat for transfer to shore and eventually to the conservation lab.

Batavia

The Dutch East Indiaman *Batavia* wrecked on Morning Reef, which is part of the Wallabi Group of Houtman Abrolhos, in 1629. Discovered in 1963, 35 kilometers off the western coast of Australia, its challenges were significant and heavily influenced decision-making regarding site management and recovery.[318] The first was the isolation of the site. The closest port was Geraldton on the northwest coast of Australia, which was 80 kilometers by water. After that, the next closest city was Perth 500, kilometers to the south. The remoteness required a straightforward and simplistic approach to excavation and recovery of artifacts. The second challenge was that the shallowness of the site, which was open to Indian Ocean swells, caused divers to fight constantly with the surge created by waves breaking over the reef. Once exposed, the timbers of *Batavia* were also subjected to the same high-energy sea state. At any time, a large wave or storm could have uplifted the timbers, crushing them against the reef.

Due to the turbidity and movement of sediments, the entire site could not be excavated all at once before removal of the roughly 20 tons of primarily waterlogged European oak timber that comprised the remains. Once raised to the surface the timbers were shipped to the expedition's field lab and immersed in plastic-lined pits dug in the coral measuring 5 x 9 x 7 meters. Since many of the hull planks were in excess of 10 meters long, following documentation the planks were cut with an air-powered chainsaw into manageable 3 meter sections. Large elements from the transom, critical to understanding the construction such as the fashion pieces, estimated to weigh over 2000 pounds, were not cut but recovered as a single element.

Conclusion

The chapter summarizes some of the more positive case studies of ship recoveries. Each case study highlights the uniqueness of a single event and punctuates

[318] Green 1975.

the notion that no two watercraft projects are the same. Along with the size and structural integrity of construction materials and compaction soil, tidal conditions, currents, weather patterns, project budget, distance to and the capabilities of the conservation facility all play a large role in directing the recovery method. Disassembly or sectioning of the craft is the first step toward narrowing future options, particularly as it pertains to structural integrity, requirements of a supporting structure and aesthetics.

CHAPTER VII

WATERCRAFT CONSERVATION–MATERIALS CONSERVATION

Introduction

Adhering to the conservation community's current ethos, few tasked with stabilizing waterlogged archaeological material would dispute that wet storage, analysis to determine the current state of material preservation, and mechanical cleaning and chelation of unstable ferrous species are all imperative initial steps in the process of conservation of waterlogged wood regardless of individual treatment preferences. The overall importance of each has been noted through the general literature reviews in Chapters 3 and 4. Whether the ship or boat is a complete unit, in sections, or disarticulated timbers, the goals of material conservation remain consistent with the five primary principles listed in Chapter 3 (dimensional stabilization, durability, reversibility/retreatability, minimal intervention and the ability to scale up to meet the project requirements). To that end, many different combinations of treatments have been employed, and many more proposed to displace the water within the wood's macro and microstructures, while consolidating the fibrous material into a bound matrix that enhances mechanical strength and material integrity.

Since the primarily goal is the removal of water and "dry" the wood without inducing cellular collapse (generally followed by volumetric distortion), any ancillary enhancement to the physical properties of the wood, such as regaining "adequate strength"[319] or aesthetic appearances, are secondary and can only be counted as added concerns or benefits. In fact, imparting "adequate strength" on the treated object has been an assumption made by many in the conservation community in respect to waterlogged integrated structures that has led to less than satisfactory results and which is the focus of further analysis in Chapter 9. The goal of this chapter is to discuss the primary materials and processes used for the stabilization of waterlogged archaeological structural objects, providing an overview of the difficulties faced and challenges met by the community.

The stabilization of waterlogged wooden structures may be subdivided into three general categories: consolidative materials (if any), the method of delivery, and techniques to control final drying. Any combination of these divisions accounts for all forms of stabilizing treatments, and in the broadest terms, all focus on two potential outcomes, chemical saturation (as much as is possible), followed by controlled dehydration or chemical pre-treatment before sublimation in a vacuum or through the use of ambient pressures. Many of the concepts introduced in Chapter 3 directly relate to this chapter and therefore some reiteration occurs. After all, much of the previously published work relates to shipwreck finds where excavators discovered and conserved at least some portion of a ship or boat. The third column of the literature review index (Chapter 4, pages 86-87) categorized published documents by specific chemical or the method used for bulking the cell structure of wood and safely removing free water. In the tabulation of the categorized references, 26 different primary materials were found to have been introduced into wood for the purpose of stabilization. The actual number of chemicals

[319] Seborg and Invarity 1962.

used is undoubtedly greater as many experiments have assessed additional chemicals but have received little review in published sources. The number of different chemical applications swells considerably if one takes into account attempts to combine one or more established treatment materials. Not all products, whether used as surface or internal consolidants, have been scalable for application to large timbers or complete structures,[320] and the application of many others have met with varying degrees of success and failure. A list of principal materials used in watercraft conservation projects include (1) potassium aluminum sulfate dodecahydrate [$KAl(SO_4)_2$•12 H_2O], (2) melamine formaldehyde resin [Arigal C, Lyofix, Kauramin), (3) polyethylene glycol, (4) sugar and sugar alcohol, (5) sodium bichromate followed by chromic anhydride and linseed oil, (6) Tetraethyl Orthosilicate (TEOS), and (7) a combination of a solvent and linseed oil, creosote, Carbolium, colophony, paraffin, polyvinyl acetate and soluble liquid nylon. Several of the more recently proposed materials (Chapter 4) such as Ligninphenol, chitosan, cellulose esters, silicone oil and keratin demonstrate promise, but considerably more research and application will be required before considered applicable for scaling up to watercraft. Depending upon the physical size of the structure and the extent of its completeness, delivering the consolidative materials includes hand application, tank immersion, spraying and atomization. The final division involves removal of any remaining free water by controlled dehydration via solvent, management of the ambient humidity around the timber or sublimation. All are in an attempt to reduce stress on the wood by evaporation gradients established between the surface layers and

[320] Hoffman 2009a; Hoffman 2009b; Hocker 2010

the lesser-degraded core while the wood establishes its new equilibrium moisture content, and acclimates to the storage or the display environment.

The impregnation of polyethylene glycol, whether used to saturate the waterlogged wood or as a pretreatment for freeze-drying, has by far accounted for the primary bulking and stabilizing agent used in watercraft conservation projects (Figure 7.1). Of the 277 recovered archaeological watercraft surveyed and entered into a searchable database for this project conservators selected polyethylene glycol for 173 of the projects.[321] The next two highest categories, "undetermined" and "no initial treatment," combined together only add up to 57 watercraft, and 90% of the vessels listed in these categories were excavated before 1950 or before by individuals with little understanding of project requirements. In addition, except for the alum-treated watercraft, the database search parameters did not take into account how many of these artifacts may have received additional or remedial treatments. The next highest category at 21 includes consolidants applied to saturate surface layers to aid in retention of highly friable material while slowing the rate of dehydration and lessening the effects of extreme evaporation gradients.

[321] MS on file, Conservation Research Laboratory, Texas A&M University. Note: remains of the 38 watercraft located at Yenikapi, Istanbul, Turkey collectively referred to as Yanekapi are in the early stages of conservation and as such are only counted as one ("1") for the entire collection.

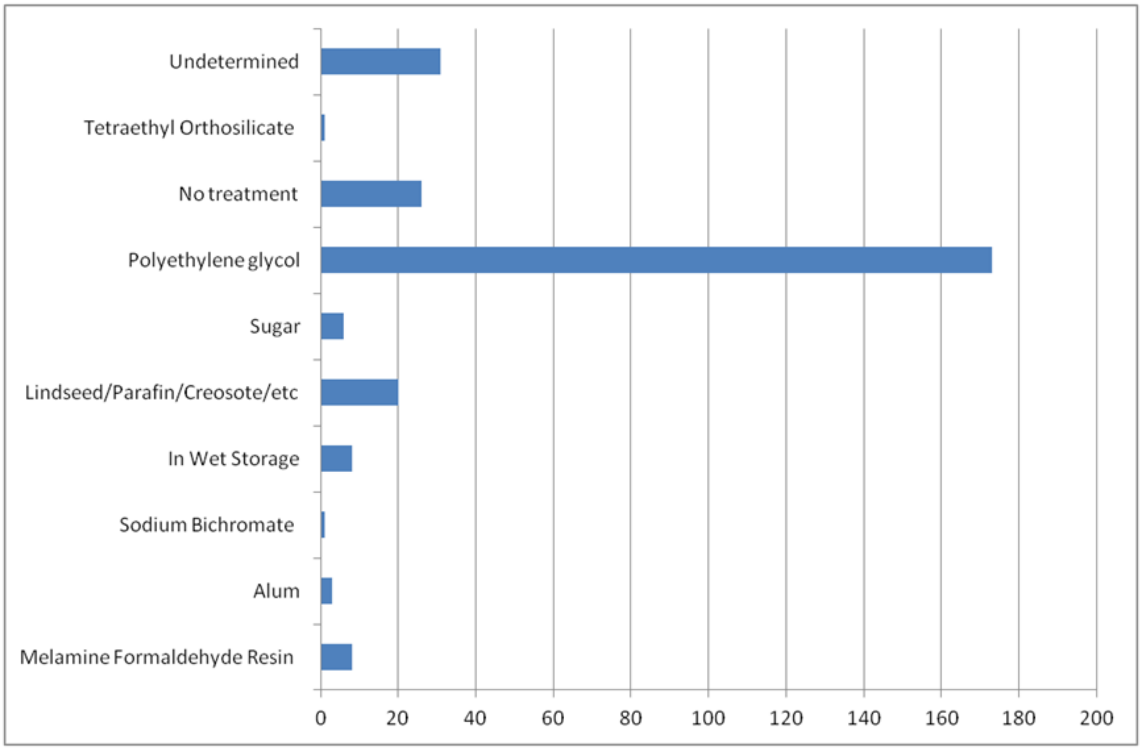

Figure 7.1. The graph illustrates the number of different stabilization mediums employed for archaeological watercraft conservation projects.

Eight recovered vessels, or their portioned remains, currently remain in long-term wet storage, most awaiting financial commitments before stabilization treatments can begin. An additional eight received the melamine formaldehyde resin treatment. Seven watercraft were impregnated with sucrose. At least two watercraft (and component parts of three more) were boiled in potassium aluminum sulfate dodecahydrate, five of which are known to have been re-treated with polyethylene glycol. In an attempt to test alternative materials during the 1970s, conservators in North Carolina saturated a dugout canoe with Tetraethyl Orthosilicate and French conservators impregnated the remains of a larger vessel with sodium bichromate followed by chromic anhydride and linseed oil. All of these treatments are discussed in detail later in this chapter.

Consolidants

In the 120 years before the introduction of polyethylene glycol few reliable treatments were available to conservators confronted with the stabilization of waterlogged archaeological wood. Part of the reason for this is that, before 1860, it would be surprising to find evidence of anyone expending the effort to carry out a regime for long-term preservation. As with the previously mentioned example of the medieval boat discovered in the banks of the River Rother, culturally the item was only a novelty or represented the mundane, an unimportant relic that did not deserve special attention for long-term care. If any substance was utilized it was a surface-applied organic material utilized to partially displace the imbibed water and create a moisture barrier at the wood/atmosphere interface to slow the rate of dehydration. The materials would often provide some consolidation for the friable surface but it was impossible for the consolidant to penetrate deep enough into the wood to prevent cellular collapse and/or distortion. Some of the early surface applied materials included linseed oil, beeswax, paraffin, creosote, carbonlineum, varnishes, shellac, acetates and nitrocelluloses.

The results of the surface treatments were generally less than satisfactory. Often, large cracks appeared, and cellular collapse led to considerable distortion. Describing the status of the few remaining dugout canoes of the estimated 500+ recovered from Swiss lakes during the 19^{th} and early 20^{th} centuries, the observations of Denis Ramseyer echo those of many others.

> They [the artifacts] are often a sorry sight, with wide cracks produced by warping, pieces missing from the bottom or sides, and the wood crumbling away. Early treatment, which consisted of coating the wood with such natural substances as beeswax, oil, spruce resin, wax and benzine a solution of petroleum, benzine and varnish, or treatment with paraffin, did not produce the expected results.[322]

Better, or at least not disastrous, results were achieved by using linseed oil and creosote followed by linseed oil and “white spirits” and lacquer as a sealant. This technique was employed in Norway on the collection of watercraft that includes the Oseberg Ship, Gokstad, Gokstad faering and the Tune Ship. When excavated, the condition of the wood of the Oseberg ship was in good enough condition that reconstruction workers could steam timbers to re-bend them into the original complex curvature.[323] Between the excavation in 1904 and reconstruction in 1907, the Oseberg ship received several surface treatments to slow the rate of drying, but the linseed oil, carbonlineum and creosote mixture only penetrated 2-3 mm into the wood.[324] Over the last 100 years, changes to the chemical composition of the wood and surface consolidant have left the timbers very dry and rigid to a point where considering transport of the vessel is a concern and could lead to significant damage or catastrophic loss.

Methodologies that utilized surface applied materials continued with the introduction of modern engineered products during the 1950s and 1960s. In particular, surface-applied epoxy resins such as those used to consolidate the sodden wood of the Kentmere Boat (discovered 1955), were also not effective at controlling distortion.[325] The viscosity of the epoxy and size of the molecule inhibited significant penetration deep

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322 Ramseyer and Vonlanthen 1987, 19.
323 Rosenqvist 1959, 15.
324 Braovac, S., K. Fackler, T.K. Bader, and T. Ters 2011.
325 Barkman 1965.

enough into the woody fabric, and once cured, the resin created only a hard skin around the degraded surface and collapsed interior. As a result, the wood underwent significant distortion, checking and splitting. Aging of the epoxy darkened the surface of the wood as it oxidized and the artifact became brittle. Controlling the forces of dehydration with surface applied consolidants, whether produced from naturally grown substances or manufactured in a lab, seldom proved satisfactory.

Alum (Potassium Aluminum Sulfate Dodecahydrate [$KAl(SO_4)_2 \bullet 12\ H_2O$])

The only internal consolidant used during the first hundred years of waterlogged wood conservation was the alum method, both alone and with the addition of glycerin. The introduction of potassium aluminum sulfate dodecahydrate [$KAl(SO_4)_2 \bullet 12\ H_2O$] by staff at the Danish National Museum provided conservators with the first method for the internal impregnation of the cell structure to both displace water within the cell while providing a crystalline material for stabilization against the loss of carbohydrates and lignin. In 1911, George Rosenberg, a conservator working at the National Museum in Copenhagen, modified the initial alum treatment protocols by adding one part glycerol (by weight) to four parts alum, and one part water. [326] The mixture appeared to be acceptable, but problems arose due to hydrophilic nature of the material, a characteristic exacerbated by the addition of glycerin to the formula and use of the treatment was discontinued in most countries by the early 1960s.

Alum-treated artifacts were heavy and over time became brittle, developing significant cracks, and many of the objects could barely support their own weight. Other

[326] Christensen 1970, 17.

problems identified with the use of alum is that at elevated relative humidities the alum crystals hydrate, become more fluid and migrate around the cellular structure of the wood. When the relative humidity drops, the potassium aluminum sulfate re-crystallizes, causing considerable damage to the adjacent wood fibers. Christensen remarked on observations he made regarding several broken pieces that had been treated with alum.

> Judging by the surface of the fractures there seems to be, roughly speaking, two types of result. In one type the inside consists of a yellowish mass, so brittle that may be described as a clotted, but decidedly dry powder consisting of a mixture of alum and the completely disintegrated wood substance. This latter shows a strong lignin-reaction to microchemical methods. In the other type the inside is full of cavities bounded by more or less collapsed the comparatively strong wood substance. In these cases the alum seems scarce.[327]

Recent analytical studies corroborate Christensen's findings in that alum-treated archaeological wood exhibits a considerable reduction in carbohydrates and even the lignin chains are often highly degraded.[328] In addition to the physical damage caused by hydration/dehydration and cycles of alum crystallization forms strong acids (pH ~ 1), which further promote the degradation of the natural composite. Researchers surmise that the buildup of sulfuric acid is the result of the decomposition of the alum during the boiling process.[329] Examination of alum treated wood with Fournier Transmission Infared Spectrometry (FTIR) revealed that the high temperatures associated with boiling (90° C) alum degrades the cell wall, breaking down the polymers that result in significant reduction in mechanical strength.[330] When possible, most institutions with the responsibility of caring for collections containing previously alum treated artifacts carry

[327] Christensen 1970, 16.
[328] Braovac et al. 2011.
[329] Kutzke, Braovac and Euler 2011.
[330] Braovac and Kutzke 2012.

on a regime to re-conserve the thousands of objects by replacing the aluminum potassium sulfate with another bulking material.

Beginning in the 1920s and lasting into the 1960s the remains of several watercraft were treated with the alum process. Timbers from the Hjortspring boat (Denmark, excavated 1921), Äskekärr (Sweden, excavated 1933), Lake Lednica Boat (Poland, undetermined date), and approximately 87 pieces from the Skuldelev ships, including the keel from Skuldelev 3, were all boiled in the substance following the previously established standards of the time. Fortunately, by the 1960s the glycerol additive had been removed from the formula and therefore was not part of the Skuldelev ships' timber treatment. Generally, the removal of alum from damaged wood requires successive water baths at elevated temperatures. Ongoing trial experimentation to develop alternative methods of removing the alum include placing the artifact in an electrolyte with an anode screen ($^-$) on one side and a cathode screen ($^+$) and applying a direct current have demonstrated some initial success. Through this method, the potassium ($^+$) (attracted to the [$^-$] cathode) sulfate ($^-$) (attracted by the [$^+$] anode) has in part been extracted from the wood. Extraction of the aluminum however, while it possesses the same charge ($^+$) as the potassium, has not met with the same success.[331]

Exemplifying the course of treatment for the Hjortspring boat, which was part of a large sacrificial find in Jutland (Denmark), alum with an additive of 15% glycerol was impregnated into the timber in the 1920s and then the reconstituted hull was exhibited in a moist environment. By 1960, the natural polymers of the wood were so damaged that

[331] Christensen et al. 2012.

before any possible immersion in heated water baths the pulverized regions of wood had to be consolidated first with liquid nylon. Only after the matrix was stable could the fragmented timbers remain in 90° C water for several months without further damage.[332] Not until sufficient amounts of alum had migrated out of the wood could conservators re-introduce high molecular weight PEG into the wood as a bulking and stabilizing agent. In a similar manner, the alum from Äskekärr and 22 timbers from the Skuldelev ships was removed and replaced with PEG. No information could be obtained on the final disposition of the Lake Lednica Boat, but the remains of the other retreated watercraft continue to be stable enough for display.

Melamine-formaldehyde

The conservation of waterlogged wood using melamine-formaldehyde prepolymers was first introduced as a waterlogged archaeological wood consolidant in the late 1950s under the trade name Arigal C,[333] and similar formulations have been employed to stabilize waterlogged archaeological wood over the last 50 years. After halting production of the resin during the 1970s, a comparable product reappeared under the name Lyofix. Again, when production halted in the 1990s, a new formulation of melamine formaldehyde resin was released under the trade name Kauramin and it assumed the role as substitute consolidant. A product originally developed to protect against rot in cotton fibers, as a polycondensate, the cross-linking that occurs upon polymerization renders the treatment irreversible in wood. Tests and practical applications indicate however, that with careful drying only a 25% preservative solution

[332] Jensen 1989.
[333] Müller-Beck and Hass 1960.

is required to be effective at controlling dimensional stability[334] while protecting surface detail. Apart from aspects of the irreversibility, however, the treatment has some additional shortcomings:

- Deep cracks tended to develop across the grain. Often they are very fine, but they nevertheless reach far into the wood.
- There is a tendency for timbers to warp, and to develop ‘hollow’ patches in surfaces.
- The color of the wood is often unnaturally light, grayish to beige and cream. [335]

The benefits of melamine resins are water miscibility and a small molecular chain with low viscosity (further thinned with a 5% addition of urea) that leads to thorough and rapid penetration of the wood. The hard and durable matrix formed within the wood structure adds rigidity and strength with a much lower strength to weight ratio versus the use of other internal consolidants. Because melamines resins cure in the presence of acids, care must be taken to ensure that all organic and inorganic acids are mechanically cleaned from the surface or neutralized before impregnation of the resin commences. Generally, a .5% addition of triethanol amine to the active part of the system ensures neutralization of any remaining organic acids in the wood. Following impregnation of the melamine formaldehyde resin, the artifact must be rinsed to remove any residual solution, covered with wet absorbent layers to soak up any resin that might flow from cavities, and then covered with plastic film to ensure the integrated material does not dry out. If an accelerated cure is required, impregnated pieces are heated to a temperature of

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[334] Pferdehirt 2005.
[335] Hoffmann and Wittköpper 1999, 163.

50°C but the resin will cure at room temperature over a longer period. Once cured the water remaining in the wood is removed by controlled dehydration.

Use of the melamine resin process is scalable to larger projects, and with significantly less time required for impregnation, one might anticipate widespread use; but primarily due to the aspects of irreversibility, application has generally been localized to a few locations and has not received worldwide acceptance. All part of the collection of the Museum fuer Antike Schiffahrt in Mainz, Germany, the remains of eight watercraft (Mainz 1–Mainz 6 and Obertimm 1 and 2) have been stabilized by this method. Noted in the previous chapter, two of the boats, Oberstimm 1 and 2 were both recovered in large block sections to avoid dismantling of planks that were set and fastened together by mortise and tenon joints. Since following the planned treatment the resin-cured wood would be hard, rigid, mostly inflexible and irreversible, the planking that had formed as a result of the depositional environment had to be reshaped in the block unit by molds cut to the theoretical corrected hull shape.[336] Slowly, over the course of several months, the hull planks were drawn in towards the longitudinal centerline against the molds and secured for the remainder of the treatment process. The treatment solution consisted of 25% melamine resin in deionized water, .5% of triethanolamine to neutralize any remaining acids, 5% urea to lower the viscosity of the solution and 10% butandiol to lessen the cross grain checking and impart some flexibility in the finished product. Impregnation of the timbers required a soaking period of approximately six

[336] Pferdehirt 2005, 35.

months and upon completion each section was wrapped in absorbent cellulose and plastic sheeting before being placed in a large box at a temperature of 50°C for two weeks.

To accelerate drying the heating box was converted to a microwave chamber and the timber pre-dried at a temperature of 30° to 40° C until the moisture content decreased to just above the fiber saturation point of 40-50%.[337] Had the microwave heating not been employed, an object the size of a ship or large timber may have taken considerably longer than the one month required in this case study. Following the microwave drying the boat sections underwent controlled dehydration for six months in order to decrease the remaining moisture in the wood down to approximately 15%, a point considered safe to equalize with the ambient environment. The results of the treated sectional remains were successful enough for reassembly of the hulls for display and aesthetics enhanced by filling any surface crosschecking with wax and darkening the surface with a natural oil.

Throughout the last fifty-five years, several different treatment methods, other than PEG, have been proposed that could be used to stabilize watercraft. Presented by Erwin, Henry and Wesser at the *Pacific Northwest Wet Site Wood Conservation Conference* in 1976,[338] treatments with Tetraethyl Orthosilicate (TEOS) were intended to replace polyethylene glycol and touted as an inexpensive alternative that could rapidly produce a finished product. The principle behind the treatment was that acetone dehydration drove off the free water within the wood, leaving only the bound water with which the precursor tetraethyl orthosilicate could react to form silicon dioxide. However,

[337] Pferdehirt 2005, 37.
[338] Irwin, Henry and Wesser 1976.

trials and experimentation with TEOS by Semczak,[339] Jespersen[340] and Gratten[341] found the material to be difficult to work with or that the treated material became brittle to such an extent that it was extremely fragile; thus, many abandoned the process by the early 1980s. Only Bright[342] provides a positive impression of TEOS.

In 1978, conservators in North Carolina impregnated a 20-foot long dugout canoe found in the Neuse River with Tetraethyl Orthosilicate. To avoid the expense of vat construction for such a short treatment cycle conservators dug a trench and lined it with polyethylene sheeting to conduct the stabilizing treatment. Once the canoe was in place the team added acetone and soaked the wood for one week to chemically dehydrate the timber.[343] At the end of the week, the acetone was replaced with TEOS. After only five days conservation staff observed that a "uniform silicate formation in all parts of the structure [had] occurred." The only drawback noted was that after treatment the wood required three coats of linseed oil to darken the appearance to an acceptable color.

In what can only be described as a onetime treatment, scaled up for a watercraft stabilization project, was a treatment that employed sodium dichromate followed by chromic anhydride and linseed oil.[344] Initially located during harbor dredging in 1929, subsequent dredging operations in 1973 relocated the partially disarticulated remains of a Roman cargo vessel, and the decision was made to recover the 17 tons of timber of the Port Verduns 1 ship for conservation and display. For one week, the timbers remained in

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[339] Semczak 1977.
[340] Jespersen 1982.
[341] Gratten 1982, 132.
[342] Bright 1979, 263.
[343] It is doubtful that soaking the canoe for only one week could drive off all of the free water, but the results were still as satisfactory.
[344] Bouis 1985.

an aqueous solution of 15% HCL to remove any remaining concreted material. A second bath containing an aqueous solution of sodium dichromate plus chromium trioxide ($Na_2Cr_2O7 + CrO_3 + H_2O$) introduced a stabilizing agent into the wood. A third solution neutralized the chromate, and the fourth bath, lasting anywhere between two and five weeks depending on the size of the timbers, impregnated the wood with linoleic acid. Finally, linseed oil was applied to all surfaces to help control final dehydration of the timbers. At the time the treatment was stated as being a success and considerably cheaper than polyethylene glycol.

Sugars

The notion that sugar could adequately supplant PEG, or at least serve as a less expensive, yet acceptable alternative to PEG reached its strongest period of acceptance during the 1990s. Preliminary trials demonstrated promise, and a shorter impregnation period coupled with lower product cost prompted some to scale up previously tested procedures in order to conserve several medium and small watercraft. One of the earliest attempts was the bow section of what came to be referred to as “Da Zuckerschiff” (The Candy Ship).[345] Later, a second much larger craft received the similar name, differentiated only by its discovery location (Friesland).[346] Following its discovery in 1964, the 10 meter long Poole Logboat remained in wet storage, or in the midst of an uncompleted PEG treatment that lasted for 30 years until treated with sugar during the

[345] Hoffmann 1995.
[346] Hoffmann and Kühn 1999.

1990s and early 2000s.[347] Finally, four of the 30 dugout canoes discovered at the Lake Phelps archaeological site in North Carolina received a stabilizing sugar treatment in 1986 before installation in a local museum.[348] Finally, although not technically a boat and treated with synthetic sugar alcohol (lactitol), the successful treatment of a 6 meter wooden coffin with similar characteristics to a dugout canoe illustrates the effectiveness of scaling up sugar alcohols to stabilize larger waterlogged objects.[349]

Two different treatment methods using sucrose appear to have been successful and satisfactory for stabilizing waterlogged wood. One, highlighted by the conservation of the Friesland Ship, slowly increased the percentage of sucrose in solution. The other, illustrated by the conservation of the Poole Logboat, placed nearly all of the treatment solution into the vat with the timber at one time. With the Friesland Ship, conservation staff disinfected the timbers of any potential microbes for 10 days in a solution of .1% KATHON WTE. That solution was drained and a 20% sucrose solution, which again included .1% KATHON WTE, was pumped into the treatment vat. A cover placed over the top of the vat sealed off the treatment solution in order to lessen the effects of oxygen uptake and sunlight while keeping airborne contaminants and insects away from the solution. After three months, the aqueous solution of sugar was increased to 40% and five months later, the final increment brought the sucrose to the saturation point of 67%. To ensure the integrity of the biocide each additional increment included the biocide .1% KATHON WTE. Analysis of core samples taken from different parts of the ship timber

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[347] Hutchins 1997. (After rinsing out the unbound PEG from the timber there appeared to have been no negative interaction between the PEG and sugar.

[348] O'Cain, Watkins-Kenny, Kennedy, and Kenny 2012.

[349] Imazu and Margos 1999.

indicated that by 20 months the core of the wood was only slightly behind percentage in the exterior layers. After 25 months, a foul smell began to emanate from the solution, as turbidity increased and the color changed, indicating that microbial activity had accelerated.[350] Since most of the timber was close to the saturation point, conservation staff made the decision to halt the treatment, dispose of the solution and steam clean the timber surfaces. Apart from the sugar and biocide the only other additive for the treatment was calcium hydroxide [Ca(OH)2], lime water, to raise the pH after nine months when the pH of the solution dropped from a pH of 6.8 to 4.8. Had the acidity of the solution not been raised the acids would have degraded the sucrose and promoted microbial activity that in turn would have reduced the disaccharide into its monosaccharide fractions. Following surface cleaning, the structure dried in a semi-controlled environment until the wood reached its new equilibrium moisture level. Over time, even though the gaps between the plank seams increased, the timber shrinkage was within established ranges. The ship remains continue to be exhibited with no cited problems concerning the treatment program.

Although sucrose was also used on the two large recovered halves that comprise the Poole Logboat, the treatment regime used for stabilization was quite different from the two German “Candy Ships.” British Sugar offered the project, as an in-kind donation, 20,000 liters of a 63% (wt/wt) aqueous solution of sucrose used in the formulation of soft drinks.[351] Following experimentation and consultation with experts concerning whether

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[350] Hoffmann 1999, 198.
[351] Hutchings 1997. Also personal communication with Donny L. Hamilton 2014. During experiments conducted while teaching conservation techniques and principles of conservation to graduate level students in archaeology, Dr. Hamilton achieved very satisfactory results using sugar syrup used in the

or not the viscosity of a 63% aqueous solution would cause osmotic shock and effectively dehydrate the wood in solution, the decision was made to proceed with the full percentage, not build up the percentage in an aqueous solution over time. The two halves of the dugout were placed in solution along with a .1% (wt/wt) increment of KATHON CG. After 44 months in solution, the interior sucrose percentages were very close to the saturation point and the solution left in place to allow for greater equalization. Although the initial plan allocated 5-6 years for impregnation phase, in actuality the treatment process lasted eight. Insufficient monitoring and maintenance during the final months missed an opening in the cover where rainwater intrusion and insect contamination accelerated microbial activity and spoiled the final solution. The original had to be removed, and the logboat sections disinfected before new 67% (wt/wt) solution added to complete impregnation of the outer surfaces where the sucrose had inverted to fractional parts due to microbial hydrolysis. The monosaccharides glucose and fructose are far more hygroscopic and unstable than the disaccharide, and without assurance by creating a new solution, the surface could discolor, and become sticky during periods of elevated humidity.

Experiments conducted during the course of conserving the Friesland ship generated pertinent data concerning sucrose solutions and their use for conservation of waterlogged archaeological materials.[352] Foremost amongst the findings was that even at high concentrations of sucrose, which included a biocide, several species of mold and

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production of the soft drink Dr. Pepper. Hamilton observed that the dimensional stability of the degraded wood was satisfactory while the coloring additives in the syrup produced a very pleasing appearance on the wood surface.

[352] Mietke and Martin 1999.

yeast were able to survive the elevated osmotic pressures. The authors concluded that the utmost amount of sterilization was required from start to finish in order to ensure that the treatment protocol would be a success. These critical steps included using deionized water, maintaining a low dust and contaminant free environment that had little air movement, and proper maintenance of screen covers to abate any chance for insect contamination. Finally, consistent monitoring of the solution for any rapid drop in pH levels, which is one of the precursors for disaccharide reduction.

The problem with using sucrose, highlighted by the case study of the Poole Logboat, is that although seemingly simple there is little tolerance for error and the tipping point for a disastrous outcome can occur very quickly. This fact is not only in evidence during the treatment program but throughout the curated life of the artifact. Installed in a substandard display environment following stabilization with sucrose in 1986, where moisture levels in particular were elevated beyond acceptable limits, the four dugout canoes from Lake Phelps, NC began to exhibit blooms of white crystalline precipitates over large sections of the timber.[353] Samples of the evolving substance were assessed by UV absorbance and tests indicated that the sugar had been reduced from the disaccharide to its monosaccharide fractions, glucose and fructose. Due to a lack of reporting during the 1980s, what is unclear is whether the degradation of the sucrose occurred during tank treatment or solely in the moist display environment, but the exhibit climate seems to have been a factor. For the stewards of these four dugouts retreatment was the only solution to the instability of the sucrose.

[353] O'Cain et al. 2012.

Sugar Alcohols

Similar to sucrose, interest in the sugar alcohol lactitol grew during the 1990s and demonstrated potential for conserving watercraft. In 1995, excavations at Simoikeyama Tomb, Tenri City, Japan uncovered a moderately degraded 6 meter long waterlogged coffin dugout made from a single log of umbrella pine and dated to the end of the third century CE.[354] An assessment of the timber revealed that the moisture content (Umax) on the exterior was 300-400% and 200-250% on the interior of the timber. The total treatment time with synthetic sugar was 16 months with an anti-shrink efficiency of 95-98%. The treatment commenced with a one-week pretreatment soak in 1% EDTA–2Na followed by several weeks of rinsing. The initial aqueous solution of lactitol was 40% and over 13 months four additional 5% increments raised the overall percentage of lactitol in solution to 60%. When the impregnation was complete, pulverized lactitol crystals were applied to the surface to initiate crystallization and the coffin air-dried at 50° C for two months. Upon completion all remaining residue of the sugar alcohol was rinsed from the surface with warm tap water.

The staff of the project were satisfied with the results from the treatment procedure, especially as it even preserved traces of the vermillion paint on the interior and exterior surfaces of the coffin. Apart from the saturation treatment lactitol also showed considerable promise as a pretreatment for freeze-drying. Since it is hydrophobic it is not dramatically influenced by fluctuations in relative humidity below 90% and as a synthetic is not susceptible to reduction by microbial activity. Yet, few individuals have

[354] Imazu and Margos 1999.

utilized this course of treatment for the stabilization of either waterlogged archaeological wood or watercraft and its use primarily remains localized with those who developed the process.

Polyethylene Glycol

Regardless of the noted dissatisfaction over the decades, where watercraft conservation is concerned, no stabilizing medium compares to the wide scale use of polyethylene glycol. After the initial publication by Morén and Centerwall in 1960, it became the standard by which all other treatments have been measured. From the start, different percentages and molecular weights of PEG were impregnated into ship and boat timbers in an attempt to find the right formula. All met with varying degrees of success, especially in the first few decades. Highlighted by the historiography in chapter 4, no material has been tested and evaluated more than PEG, which alone illustrates the polyols' importance to the field of waterlogged archaeological wood stabilization. Grasping for some chemical to replace alum, conservators managing the conservation of the earliest recovered vessels in the late 1950s and early 1960s, including portions of the Skuldelev Ships (excavated 1957 to 1962), the Flumicino 1-5 ships and the *Vasa* longboat, selected PEG. The 1970s were highlighted by conservation of the *Batavia* and Zwammerdam boats, and during the 1980s by the *Mary Rose* and the Musee de Civilization boats, which were all conserved with PEG.

The standard course of action for all of these projects was to saturate the wood with as much PEG as possible. Today the preferred course of treatment reduces the quantity of PEG impregnated into the wood followed by vacuum freeze-drying to sublimate the water from the sodden material. While this shift in preference may have occurred, if the object is a block unit, the timbers are too thick for freeze-drying, or the freeze dryer of the required size is cost prohibitive, PEG saturation method remains the alternative choice of most conservators.

Many of the early issues noted with PEG treatments for both small finds and watercraft were mainly the result of too high a percentage of low molecular weight PEG, which often left surfaces of the wood sticky or greasy feeling due to the hydrophilic nature of the low molecular weight PEG. Many watercraft conserved in the 1970s and 1980s remain on display after 30 or 40 years later with little related issue caused by the consolidant. Two problems with PEG that will never be solved, especially when the treatment process must be taken to the saturation point, is the considerable weight added by the wax and increase of the integrated material's physio-elastic characteristics.[355] Active research regarding both of these issues and the impact on integrated structures is discussed in Chapter 9.

Delivery Systems

The type of consolidant, size, availability of facilities, condition of the structure, philosophy of the staff and programmatic requirements all govern the manner in which the stabilization materials are applied to the structure or timber. By hand, with a brush, is certainly the oldest method but one seldom used at present, because thorough impregnation of the consolidant requires continuous contact with the wood, and numerous exterior applications cannot build up enough pressure to force the chemical

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[355] Hoffman 2010.

molecules deep enough into the lesser-degraded core of the wood. The four delivery systems used most often include open tank immersion, rigid shell immersion, spraying and atomization

Immersion in an open tank (with separate lid), whether the watercraft be in sections, disarticulated timbers, or a medium-sized block structure, has been the most effective and common way over the last 150 years to impregnate waterlogged wood with a stabilizing medium (Figure 7.2). Complete immersion is one of the fastest methods of impregnation due to hydrostatic pressure continually forcing greater quantities of the chemical into the wood. It is also one of the easiest to manage, as all that is needed is a tank, circulatory system, biocide, and, depending on the eutectic temperature of the consolidant and the climate of the load treatment location, a small heating system. Although tank immersion may be the most straightforward delivery system, it may not always be the cheapest method, especially if irregular timber shapes leave sizable spaces between timbers, or around the shape of the block unit, which will require PEG solution to fill the void. Often it is possible to fill the space with some form of displacement. Before conservation, the interior of the Bremen Cog was filled with bags containing brine to displace as much PEG solution as possible. If displacement is not an option, the cost of having to fill void spaces with treatment solution may make the procedure prohibitive.

Figure 7.2 The rows of vats that will be used to saturate the timbers of the Doel Kogge with PEG. Photograph from the author's personal collection.

If the size of the structures renders tank immersion prohibitive, spraying has historically been a viable alternative to tank immersion. The requirements for spraying generally extend the time needed for treatment over that of immersion, but the process is straightforward. All that is required is an adequate containment area, heat pump and a circulation system capable of handling viscous fluids at high pressure. Over time the percentage of aqueous PEG sprayed onto the artifact increases in order to raise the level of PEG inside the timbers. Spraying heated PEG however is not without problems. The 17 m long 1.5 m wide Hasholme logboat was sprayed during the mid-1990s with a two-step (high/low molecular weight) PEG 200 followed by PEG 4000.[356] Although the timber was small enough that it could have been successfully treated by immersion, no specific facilities were available. Confronted with the prospect of building a large vat to conduct the treatment or spraying, the conservation team decided that spraying within a containment booth would allow for a dynamic approach to visitor access. The timbers would not be obscured by a cloudy treatment solution, and visitors could pass by the booth and watch conservation through large glass windows.

Although the treatment process for the logboat was successful, soon after spraying began staff discovered that heat generated by re-circulating the solution, coupled with the dense mist within the containment area, created significant physiological barriers. Workers had to manage wearing cumbersome containment suits and respirators at elevated temperatures. Not every member of the staff could simply don a suit and assume responsibility for work inside the chamber. Two additional problems noted with spraying, especially large structures like the *Vasa* and the *Mary Rose* is that frequently the overhead of beams and decking or semi-enclosed spaces do not receive enough contact with the sprayed consolidant, resulting in insufficient impregnation.[357]

Another issue directly related to spraying is damage to the timber surfaces resulting from runoff of the solution from the upper structure. The *Mary Rose* has suffered damage from run-off of the sprayed solution hitting the upper works and migrating down the side of the hull. On the way to the bottom, the fluid finds the path of least resistance. Month after month and year after year of run-off traveling over the same

[356] Foxon 1997.
[357] Hocker, Almkvist and Sahlstedt 2012.

timber has significantly eroded the wood and created vertical channels down the side of the starboard side.

Conservators in Italy developed a treatment process in the mid-1980s that involved immersion of the structure within a form fitting rigid shell (Figure 7.3). Intended to provide stability during recovery and stabilization for the carbonized remains of the Herculaneum 1 boat,[358] the rigid shell method has been utilized for a number of watercraft stabilization projects in Italy, including the Comacchio ship, the small Ravenna ship and the Roman ships of Pisa S. Rossore.[359] The rigid shell is comprised of silicone rubber and layers of fiberglass in a matrix of polyester resin. The shell and artifact are affixed to a metal frame, which allows the shell to uniformly cradle the structure and absorb the added load created by the treatment solution. The circulatory system is a self-contained unit where the aqueous PEG solution is pumped into the shell at the top and is exposed to the artifact as it passes through to the bottom where it collects and again enters the circulatory piping and filters. The use of the rigid shell greatly reduces the amount of consolidant (PEG) required to stabilize the block unit.

[358] Steffy 1985.
[359] Meucci 2005.

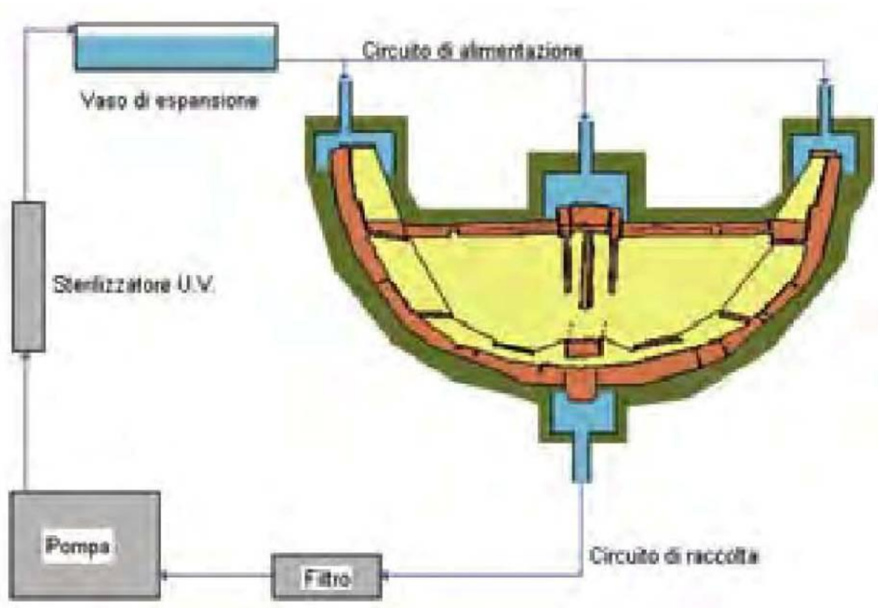

Figure 7.3. Schematic of the rigid shell impregnation system. From Meucci 2005, 52.

When confronted with the challenge of conserving a 12 meter long Greek shipwreck dated to the sixth century B.C.E that was too fragile for spraying and two large for the lab's freeze dryer the staff at ARC-Nucléart, Grenoble France developed the concept of atomization for saturation of the structure with PEG.[360] The atomization nozzles spray a very concentrated solution of PEG and can efficiently saturate timber up to 80% weight in the solution without the damaging effects of the spray itself or runoff (Figure 7.4). Following initial testing the remains of the Greek ship were saturated between May 2000 and March 2003, actually reaching saturations up to 90% of PEG in the solution, which was determined by analyzing the PEG concentration in samples

[360] Chaumat, Bernard-Maugiron, Gelas and Barthez 2002.

undergoing the same misting treatment. Following completion of the treatment, the ship remains were subjected to controlled air-drying to remove any remaining water.

Drying

Impregnation of chemicals into the wood serves to bulk the cell wall and displace enough of the water to lessen moisture gradients between the surface and the core sufficiently enough to hopefully avert significant distortion or cellular collapse during drying. Many methods have been devised to dry archaeological waterlogged wood, including controlled and uncontrolled dehydration, chemical dehydration primarily by controlling the atmosphere, kiln drying, and sublimation by freeze-drying under a vacuum or by ambient pressures.

One of the oldest methods left over from the 19th century is the burial of the waterlogged wood in sand in an attempt to regulate and slow dehydration of the wood while obtaining uniform compression. This method however, has never really provided a satisfactory stable product as it is very difficult to regulate the moisture of the sand. Yet, in the last 60 years it was attempted at least twice, each time with poor results.

Stabilization of the Bloomington Dugout Canoe, located in 1967 protruding from a Minnesota riverbank, was conducted by a combination of the sand burial and polyethylene glycol impregnation. After digging a trench and burying the timber in sand, polyethylene glycol was poured into the sand for several weeks upon advice from sources at the University of Minnesota in what turned out to be a futile attempt to further control the rate of drying. The timber emerged from the sand in a “spongy” condition.[361]

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[361] Bloomington, MN Historical Society.

No documentation is available concerning the shape and condition of the canoe at the time of excavation; however, images taken 40 years later depict a structure that has undergone significant distortions. Coupled with the observation of the spongy condition, one can only conclude the process was not very effective.

The second example of trying to dry timber by partial burial were timbers recovered from the wreck of the 18th-century French supply ship *Machault*, recovered from the North Channel of the Restigouche River, Canada in 1972. When the costs of burial for slow drying were estimated at 10% of the cost associated with a PEG tank immersion, the decision was made to utilize the less expensive option.[362] However, throughout a period between 1972 and 1977, the moisture content of the timbers in the sand failed to drop below 65%, and therefore the decision was made to remove the timbers from the sand. The timber was stacked on stickers, and wooden boards were placed between the tires of timber and sprayed with a 15% aqueous solution formulated by blending equal portions of PEG 1540 and PEG 300. For the following two years, the ambient humidity in the building surrounding the wood was reduced; conservators continued spraying the timbers with different aqueous percentages of the PEG blend. The lack of PEG impregnation left the timber vulnerable to human error, and confusion over maintenance of the proper dehydration environment caused PEG-treated wood to dry too rapidly. The outcome of treatment was not favorable. Splitting and distortion of the timber caused considerable movement, and ultimately any attempted reconstruction was impractical.

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[362] Jenssen and Murdock, 1982.

Controlled air-drying following impregnation with a consolidating agent is generally the accepted standard for current treatment. Unlike the example of the Bloomington dugout canoe and the timbers from the *Machault* is that consolidation in combination with a slow, controlled draw down of humidity (in the case of PEG and sugar) has been demonstrated to produce the most predictable results. Only freeze-drying or a cross-linked polymer allows for the use of less than the saturation level of a consolidant.

After the initial work conducted during the 1960s and 1970s, small objects or boat fragments were pre-treated with polyethylene glycol, freeze-dried, most employing a vacuum, and then the pieces glued and/or pinned into the original timber shape for reassembly into the integrated structure. During the early 1980s, the application of freeze-drying larger pre-treated objects seems to have been a natural progression. In the 1990s capital investment in larger lyophilizers allowed for the first large dugout canoes and sections of smaller skeletal based watercraft to be vacuum freeze-dried. Over the last decade, a preference for pretreating waterlogged wood with PEG followed by vacuum freeze-drying has become one of the standard conservation regimes. With the design and installation of larger vacuum freeze-dryers at conservation labs around the world larger watercraft continue to be pretreated with polyethylene glycol and vacuum freeze-dried.

During the late 1970s and early 1980s, Canadian conservators determined that the cold, dry Canadian winter, with consistent temperatures around -10^{o} C and lasting approximately four months, could be used to freeze-dry watercraft at ambient pressures.[363] A dugout canoe and several small boats located during the construction of the Musee de Civilization in Quebec were pretreated with PEG-400 followed by outdoor freeze drying. After approximately two and a half months, after about 50% of the water had been removed, the watercraft were brought into a controlled facility where the structures were air-dried until the wood reached the fiber saturation point. Overall, the conservators determined that the average anti-shrink efficiency for the canoe was 75%, which is understandable considering that less than a 25% aqueous solution of PEG-400 was used as a pretreatment.

The fabrication and purchase of larger freeze-drying units during the 1980s and 1990s allowed for larger objects to be vacuumed freeze-dried. What is most likely the first large complete structure to be successfully vacuum freeze-dried after pretreatment with PEG was the 3550-year-old (1994 CE), 7.9 meter logboat from Bielersee, Bern, Switzerland. The consolidant protocol followed a blend of 400/600 PEG as this material was in stock following an earlier project and PEG-2000.[364] Following sublimation of the water, no significant dimensional change including shrinkage or movement (twisting) could be observed.

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[363] Grattan, McCawley and Cook 1981.

[364] Meyer 1997.

CHAPTER VIII

WATERCRAFT CONSERVATION–RECONSTRUCTION AND DISPLAY

Introduction

The combination of the final two steps of archaeological watercraft conservation, reassembly of sections or disarticulated timbers and the display (or storage) of the structure are logical pairings for review. The artifact's final disposition, whether in storage or on display, directs the extent of effort placed on reconstruction. These final steps in archaeological watercraft conservation projects have yielded some of the most creative expressions of cultural identity. Unfortunately, several factors including ineffective design systems, the lack of insight into how best to re-present the cultural item, and not maintaining the proper climate around the object have often combined to produce unsatisfactory circumstances and even catastrophic results.

In many instances, especially in past decades, it would seem as if display and the appropriate climate surrounding the object were project afterthoughts and not a priority of the planning process. Thousands of hours and potentially tens of thousands if not hundreds of thousands or millions (in a particular country's currency) were spent recovering and stabilizing the craft, only to have insufficient funding for display led to watercraft installed adjacent to open windows or spaces so tightly enclosed there was little possibility to enhance visual aesthetics, dynamic presentation or interpretation.

Watercraft, even when removed from their designed environment, create a dynamic sense of place. To ignore this characteristic inhibits the value of the artifact and its use as a communicative tool. Without sufficient display dynamics, after the initial euphoria is over the structure frequently becomes a burden to both staff and institutional finances and often goes neglected only to be reassessed when problems occur. All too frequently in the past, in particular during the period before 1960, many archaeological structures met fates similar to a majority of recovered Swiss lake craft.

> Taking up too much room, many of them were chopped up for firewood when the buildings that housed them were renovated or demolished by new museum curators who were not very interested in prehistoric times. Others were so badly damaged by being moved or stored under appalling conditions, sometimes being alternately baked in the summer and frozen in the winter, that it was decided to get rid of them. [365]

There is an extreme difference in visitor reactions relating to the *Vasa*, the Viking ships in Norway and Denmark, the Bremen Cog or *Batavia,* in contrast to ships when crammed into a narrow passage, small room, or left so incomplete that a considerable amount of imagination is required to visualize how the object might have once looked. For many people ships and boats are alien objects in modern society and therefore, not part of one's cognitive structure. With preconceived notions of euphoric recall and a mental picture of what a ship or boat should look like, a poorly executed exhibit can distort the interpretive message and easily squash any motivation for further discovery.

Executing a dynamic ship exhibit is neither simple nor inexpensive. To reconstruct the ship without interfering with or establishing a sense of place can be very challenging and requires a special understanding of museology.[366] Complicating matters of re-presentation are often the climactic limitations of many facilities, especially older

[365] Ramseyer and Vonlanthen 1987, 19.
[366] Sancho Querol 2009.

museum buildings or small regional museums that are frequently converted municipal buildings, which were never intended to house artifacts. While not totally ignored, for much of the four periods of conservation development, the overwhelming bulk of the research concerning archaeological waterlogged wood focused on the practical, physical and chemical stabilization of the artifact. Seldom did the environmental characteristics of where the structure was to be installed, or the best manner to physically or theoretically re-present the structure, received much attention. Nevertheless, stabilized materials and the structures they form continue to react with their surroundings, and this action often leads to significant damage and considerable expense over long curation periods. Fortunately, over the last decade the conservation community has steadily began to address this oversight.

Exhibit Display and Reconstruction

Due to the complicated geometry created by the shape of most watercraft, elaborate internal or external structures are a requirement to support the hull in the foreign museum environment and many often hinder the display presentation, affecting not only the visual aesthetics, but also the visitor perception and the re-presentation of meaning. As Hoffman eloquently stated when referring to the display design of the Bremen Cog, "a ship is most beautiful when you can see and appreciate the lines of her hull unimpeded. To avoid any outside supporting structures, the cog was rebuilt, hanging from the ceiling, suspended by a system of steel rods."[367] When objects are seemingly incomplete with no attempt to outline the missing structure, or the remains end up in a

[367] Hoffman 2001, 131.

cramped and less than desirable location within the museum the result is frequently a perceived loss of value to the visiting public and museum staff. If the public cannot discern three important aspects of the vessel, the lines or shape of the hull, the construction details, furniture, or propulsion system, and the projection that creates its "sense of place," the object often loses its magnetism and the ability to captivate the visitor. Of these three categories, the shape of the vessel and manner of its construction are both obvious attributes required to interpret the development of naval architecture, the object's intended use, and to contrast construction methodologies employed by different cultures. Visual aesthetics and completeness of the artifact are equally important considerations, as they set the tone of the experience through the establishment of "place."

Notions regarding "sense of place" and the politics of re-presentation are not commonly associated with discussions related to historic or archaeological vessels and an aspect of the field desperately requiring more research and interdisciplinary study. Nevertheless, the audience's relationship with the object in a manner that provides the visitor the greatest understanding of heritage, culture, and the significance of their environment[368] is only recently beginning to receive more consideration in exhibit preparation and in consequence the stabilization of the substrate material to meet that goal.

All of these conditions impose requirements on the design methodology from the first moment the title of "significance" is associated with the object whatever that

[368] Gallagher 1993; Jackson 1994.

significance may be. In order to achieve a balance between the long-term protection of what will generally be a wood-polymer integrated material/integrated structure and the artifact’s ability to perform its recycled role as a meaningful symbol of historic and cultural patrimony, the lines of compartmentalization between archaeologists, conservators, curators and exhibit design need to continue to soften and more holistic approaches adapted. No longer do rows of artifact cases with rigidly ordered object

Figure 8.1. The imposing beakhead of *Vasa* looms out over the visitor creating a sense of place so intense and iconic that visitors to the museum have made the statement, "you have not been to Stockholm unless you have seen the *Vasa*.” Photograph from the author's personal collection.

dichotomies appeal to the contemporary interests of the museum audience that possess a long list of entertainment options and no museum wants to be considered a *kunstkammer*, or “cabinet of curiosities.” The modern museum endeavors to educate and inspire its audience toward further discovery, all the while competing with alternative suppliers of entertainment for a limited amount of leisure revenue.[369] Cast against the backdrop of modern museum theory, the display of archaeological ship remains represents somewhat of a paradox: a large, static, often seemingly lifeless object, but one possessing a certain vitality and characteristics sufficient to pique visitor curiosity through size or “otherness” (Figure 8.1).

For many people, one of the first memorable museum experiences as a child is gazing upward at massive skeletal reconstructions of dinosaurs. Ships of both antiquity and the historic period, recovered, reconstructed and preserved by museums, like the dinosaur become tactile avenues for audiences to experience, explore, and discover facets of heritage or culture, and a way to interact with their environment seldom achieved through books, images or scale models. The authors of the *Belmont Report* relating changes in the American museum profession during the 1960s recounted the story of the mother of a deaf mute who wrote an impassioned letter to the director of a major American natural history museum following a visit to the museum that stresses this point. “The child was so impressed by the dinosaurs that he went home and drew a surprisingly accurate depiction of the *brontosaurus*. Wrote the mother… ‘How could we have explained [in words] the density of the bones, the height, the very existence of the

[369] Casey 2005, 80.

pre-historic animals …[or] the environmental difference the dinosaur enjoyed?"[370] Watercraft displays provide this same inspiration and opportunity for discovery. On a survey trip of shipwreck conservation and re-presentation in North America, one museum educator described to me the use of the small skeletal remains of a 40-foot (12 meter), 17th-century ship in their museum's care that is little more than some assembled floors and futtocks extending from the keel to just beyond the turn of the bilge.[371] "There is no better learning tool in this museum! School groups appreciate the transatlantic crossing experience so much more when I tell them that this boat carried their entire class, teachers included, across the Atlantic Ocean."[372]

This stated attraction is not exclusive to modern society. In 1802, when Charles Willson Peale placed a mastodon excavated from Newburgh, New York on display in his *Philadelphia Museum*, it rapidly became one of the most popular natural history displays of its era attracting thousands each year.[373] Following Peale's death in 1829, P.T. Barnum purchased most of the *Philadelphia Museum's* collection for Barnum's *American Museum*; however, he could not procure the mastodon. So impressive was the artifact that the French National Museum desired the item, and when the acquisition was aborted due to the Revolution of 1848, the remains were transferred to another well established museum, the Geologisch–Palaontologische und Mineralogische Abteilung

[370] American Association of Museums 1968.
[371] Holly 1969.
[372] Personal communication with Young 2002.
[373] Bigham 1995.

des Hessischen Landesmuseums at Darmstadt, Germany, where the Mastodon skeleton remains on display to this day.[374]

Watercraft reconstruction must blend material integrity and structural stability with the exhibit needs. Almost at first glance, the visitor has to be able to understand and appreciate what they are viewing. If the exhibit is not dynamic, the visitor will not be impressed, caring a little less about their view and the uttering the following statement,"that's just some old row boat they dug up someplace."[375] This statement and several similar were overheard during a two-week observation period around the boat in question. The "row boat" in question is actually 53 feet length overall and arguably the most significant archaeological watercraft monument constructed in North America.[376] Apart from the verbal expression of disassociation, many were observed to pass the American Revolutionary War Gondola *Philadelphia*, paying it only the obligatory glance or brief stop for a quick scan of the structure's interior before moving on to other attractions.

With the proper investment in the creation of "space" for the boat, it could be the perfect launching point for a discourse on context of not only one of the most important battles of the American Revolutionary War, but also the entire conflict, colonial shipbuilding, the social history of individuals and general transportation of the period. It could even lend itself to a discussion on topics of math and physics regarding why watercraft float or how one might determine the length of one of the geometric shapes

[374] Sellers 1980, 310.
[375] Personal observation made at the National Museum of American History, Washington DC, July 2005.
[376] Brattan 2002.

when all that is known is one distance and one angle. But this was not the case as day after day the seemingly endless line of lemmings mechanically droned on past the structure. This statement is not intended to insult visitor intelligence; some people were actually engaged by the exhibit, its labeling and artifacts. Most of the people observed however, projected classic signs of "visitor fatigue" and as the out-of-place boat in the back corner, on the third floor of the National Museum of American History (Washington DC), incomplete, and tightly constrained within three walls, the *Philadelphia* could not project enough allure to capture the interest of most everyday visitor.

A similar case can be said for the display location of the Ultrcht ship, but instead of being relegated to the back corner of the attic, as is the case with the Philadelphia, the remains of this Roman Period watercraft are in the museum's basement.[377] Glassed off and under a low vaulted brick ceiling where the visiting public at the Central Museum in Utrecht, visitors can never really gain a proper perspective of the hull; even when viewed from the profile, the location distracts visitor focus from the artifact's "place" (Figure 8.2).

Too frequently, museums install watercraft simply where they fit. Of course, the first defense is always the lack of funding and therefore an inability to move the artifact to a better location–but is that really a viable argument in modern societies? In coordination with archaeologists, conservators, architects, landscapers and museum administration and staff, the French Ministry of Culture was able to recently recover,

[377] Thomasen 2000.

conserve and install the 30 meter long Roman Period river barge Arles-Rhone 3 in a purpose-built wing of the museum in Arles, France. The display space is open from every angle and the visitor is able to explore and receive a strong visual message from

Figure 8.2. Museum visitors viewing the Ultrcht ship from behind the glass partition in the basement of the Central Museum in Utrecht, Belgium. Internet download from http://centraalmuseum.nl/en/visit/exhibitions/lights-wood/

the exhibit. In displays such as this, visitors respond well to the designed space. Due to the capital investment in its surroundings, and place, the structure is able to better aid the programmatic mission of the institution and create a better experience for the visitor.

"Visitor fatigue" is a concept first described 1935[378] and is the result of a combination of factors including: (1) uniformity in design, (2) static presentation, (3) typical museum design, (4) different levels of abstraction, (5) presentation dominated by the scientific viewpoint, and (6) insufficient connection with the visitor's frame of reference.[379] In this case, "frame of reference" is aligned closely with cognitive structure of the visitor and projection of "place." The most attractive and successful watercraft displays are those that like the dinosaur are awe-inspiring, relay a unique perspective, spark memory and able to instantaneously form a communicative relationship with the visitor.

Denice Blair Leach has contended that museums are composed of at least four different domains that make up "place," "origin domain," "creation domain," "display domain," and the "experiencer-object domain."[380] "Origin domain" or where the object was built, instills the artifact with particular meaning. A museum watercraft display is inherently out of sync with this domain and therefore some attributes of the origin must be incorporated into the exhibit.

> The museums relationship to the origin domain affects how people perceive it as place. If the relationship between people, objects, and memory is dissolved, then much of the museum place ceases to exist. This means museums are missing some of the aspects of dimensionality that often impart a sense of authenticity and permanence to origin places, possibly accounting for much of the supposed artificiality in museums.[381]

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[378] Melton 1935.
[379] Schouten 1987, 160-161.
[380] Leach 2007, 199.
[381] Ibid., 201.

The cognitive image in almost everyone's mind when you ask them to recall memory of a ship or boat is an object surrounded by the vastness of a blue ocean. The term vastness and the physical limitations of cramped exhibit space are polar opposites and impact perception. Perception, as absorbed the senses, becomes translated into thoughts, mixed with memories, and creates meaning. Memory of what watercraft look like in the mind's eye should not conflict with the physical remains of the artifact, requiring each to support the other, yet curators and conservators continue to be leery of adding features back onto watercraft remains in order to aid delivery of the message. Instead, they seem to assume that the assemblage of timbers will tell its own story simply by cultivating and depending on age value.

In part, this was the case in designing the original exhibit space for the reconstructed remains of *La Belle* to be permanently on display at the Bullock Texas State History Museum (Figure 8.4). The exhibit was designed to display the ship in an upright, plumb and level position. This was later changed to project a more dramatic and meaningful image. Initially reconstructed for conservation in an orientation that was plumb and level, the exhibit design team incorporated that orientation of those physical remains and proposed to use the bowl shape interior as a *de facto* exhibit case (Figure 8.3). No attempt was made to fill in missing portions of the hull or even provide some sort of framing that would project an outline or convey transverse connectivity of the frame sets. The interior of the remains would be filled with artifacts in glass cases, essentially turning the archaeological remains into a 300-year-old recycled shelving unit. Fortunately, alternative designs were proposed that dynamically alter the perceived value

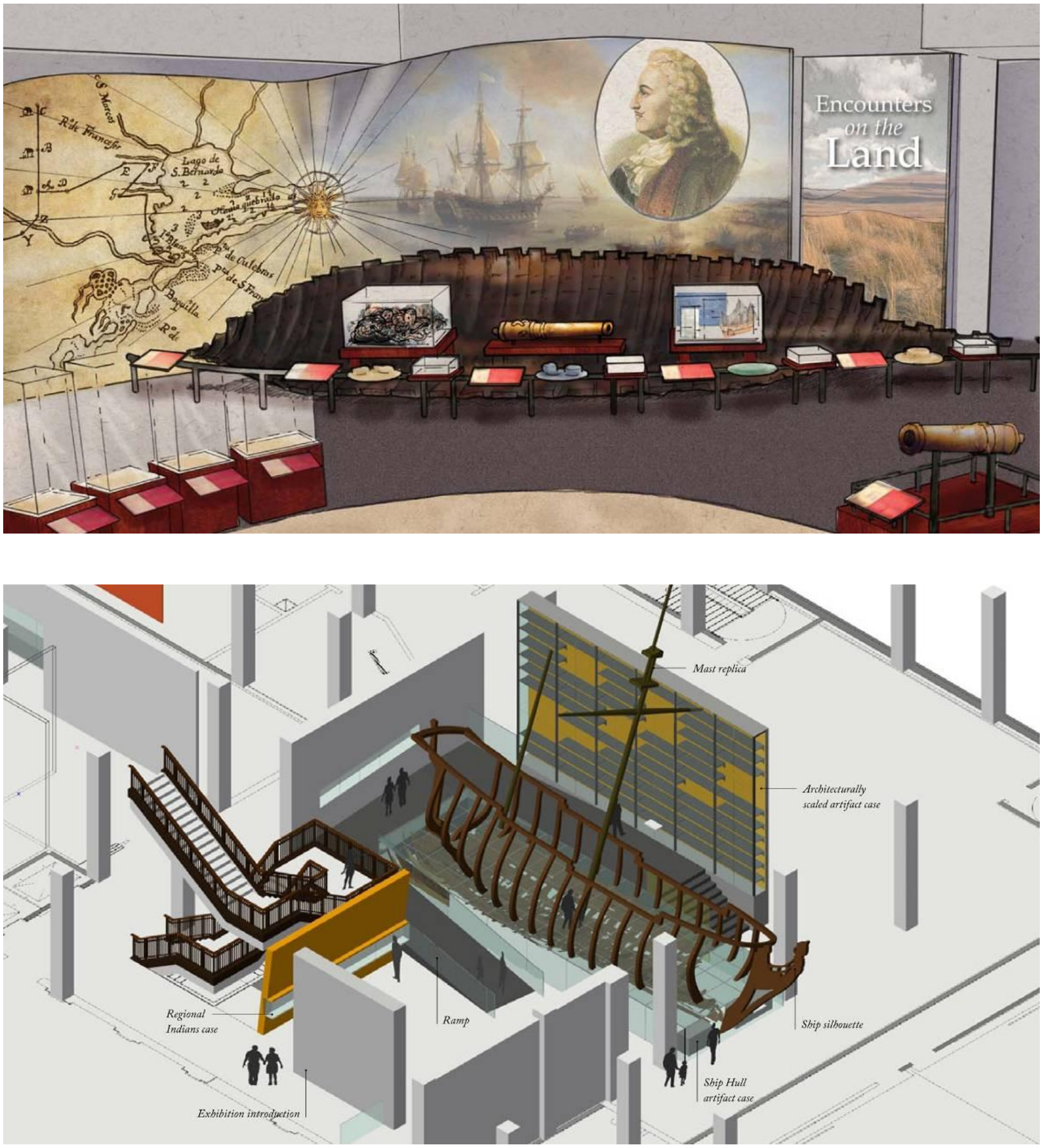

Figure 8.3. Top, the initial conceptual exhibit design for *La Belle* in the Bob Bullock, Texas State History Museum, Austin TX. With no attempt to fill in missing sections, the structure just sits in a static position accepting a role as a 300-year-old recycled shelving unit. Bottom, the dynamic, interactive alternative conceptual design speaks for itself. Courtesy Bullock Texas State History Museum.

of the ship. The artifact itself will be returned to its depositional position (listing to starboard at 68.5°) and a glass table constructed over the top to allow the visitor to walk above and look down into the hullx filled with artifacts. More importantly, several of the frame sets will be carried above the glass floor and connect to the rail at the top to form the interpretive shape of the vessel. In this dynamic approach, the visitor will interact and become part of the remains of the ship allowing him or her a virtual form of perception to spark memory and hopefully engage the individual and inspire them to further discovery of their cultural and heritage landscapes.

Abstractness, previously listed as one of the factors creating “visitor fatigue,” cannot displace one’s cognitive structure. The display must quickly communicate form and function if it is to aid in the making of meaning. Simply attempting to exhibit the structure with no additional form and relying solely on authenticity and age value is static and boring to the modern visitor.

The collection of ancient ships housed at the Musée d'Histoire de Marseille is a prime example of failing to create a strong visual image by engaging only the actual remains. In the museum’s online description they employ the phrase “pride of place” and tout the fact that they have the “largest collection of ancient ships in the world,” but to view the watercraft themselves one can barely discern the difference between these ancient ships and Huck Finn’s Mississippi raft or modern sculpture that might be viewed in a museum of modern art.

Virtually the first thing you see is a flotilla of six enormous Greek and Roman ships, which were discovered in the ancient port in 1974 but were too large to be displayed in the former museum (Figure 8.4). Their remains, reconstructed on beds of white pebbles, now hold pride of place in the opening rooms of the new museum (as you can see, the boats–one of which is pictured–have understandably disintegrated somewhat over the centuries, but models enable you to visualize what they once looked like). It's the largest collection of ancient ships in the world.[382]

Figure 8.4. One of the ancient Mediterranean boats reconstructed at the Musée d'Histoire de Marseille. While a scale model may be able to depict what the vessel look like the static nature of the structure and the fact that it is so incomplete is too abstract for the viewer to make much meaning of the object. Marvellous-Provence.com. Internet download August 2014.

A sense of place created around the artifact dictates the way in which it will be perceived by the audience and how the visitor will create memories and meaning.

[382] Marvellous-Provence.com

Dynamic exhibits cost considerably more money than simply executed installations, but the results toward achieving the museum's programmatic mission is much more likely served.

Painted flat and bar stock steel are the most frequently utilized materials for structural support systems of both clinker- and carvel-constructed watercraft. The materials are relatively inexpensive, easily worked, durable and strong enough to provide sufficient support for most reconstructions. Often, it is possible to outline the watercraft's interpreted shape and provide context for the loss of solidity and a stable platform from which to hang fragmented timbers.

The Roskilde and Skuldelev reconstructions have drawn heavily on inspiration created by Harald Åkerlund's presentation of the Falsterbo ship[383] (Figure 8.5). During the reconstruction of Falsterbro (1947-1948), Åkerlund tucked narrow strips of flat plate steel under the bottom of each plank, which provided direct support for the fragile timbers while following the plank run re-created the actual shape of the vessel. When integrated archaeological watercraft of clinker construction the steel assemblage has proven both elegance in design and the aesthetics of the installation are visually appealing. The use of steel has proven far less successful with carvel-constructed watercraft. With no place to hide the bands of steel as in clinker constructions the basket that forms around the hull planks is often obtrusive and the heftier timbers of carvel constructed watercraft require more steel to be incorporated into the unit for support. The greater amount of steel increases the load on the basket that then requires even more steel

[383] Crumlin-Pedersen 2002, 88.

to support the weight of the cradling materials. To transfer the load of both artifact and support structure to the floor necessitates the need to add many vertical supports that often looks like a forest of steel growing under the artifact and sometimes, as in the two reconstructed Punic ships in Marsala, Sicily, force the visitor to look through the steel just to view the archaeological remains.

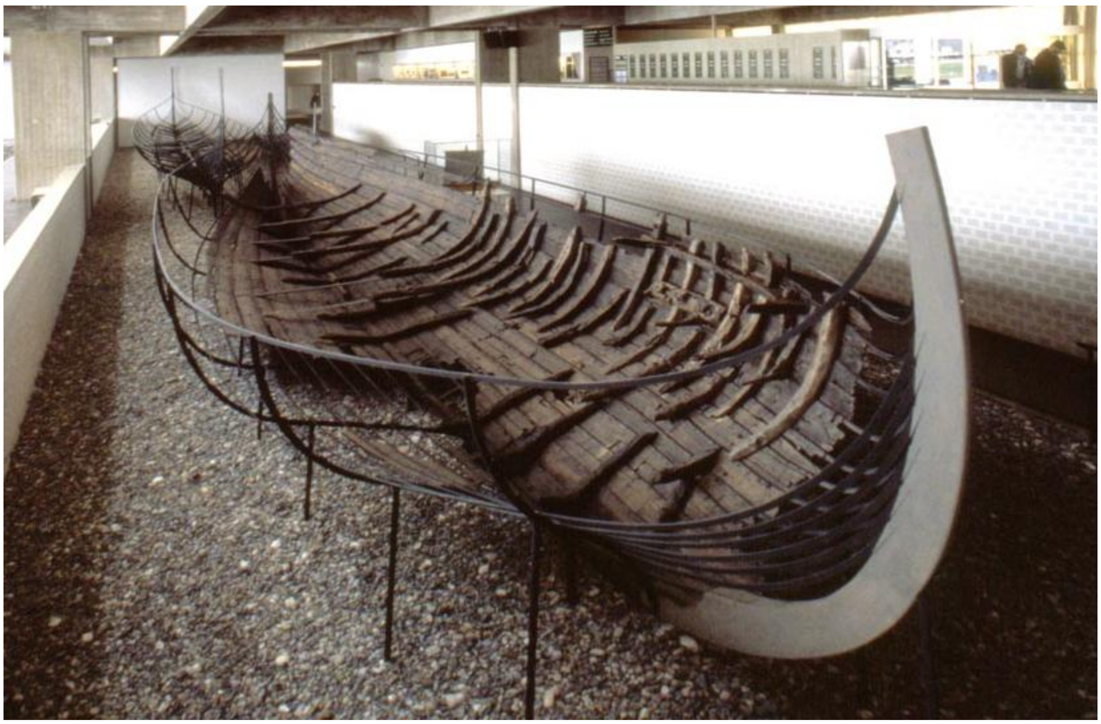

Figure 8.5. Steel incorporated into the hull remains of the Skuldelev vessels is elegant, interpretive and effective for supporting the structure. Photograph from the author's personal collection.

Museum Climate

Throughout the last 50 years, numerous articles and published books have been written on the subject of the museum environments and maintaining the proper general climate for storage and display.[384] It was however not until the last decade, that the conservation community specializing in the stabilization of wet archaeological organic materials, and in particular watercraft, began to address issues pertaining the environment surrounding ships and boats. This “new” direction is yet another corollary to the acid salt precipitants evolving from the *Vasa*, continued problems caused by alum and the hydrolysis of sugar that has degraded as these issues cast a light on several previously overlooked topics pertaining to the state of artifacts in the years after stabilization and the environment in which they were displayed.

Historically many museums exhibit and storage environments have not been suitable for the continued stability of large integrated structures. This coupled with perhaps a lack of understanding concerning the maintenance of proper temperature and humidity controls by small museums unable to employ a conservation staff, or in larger museums where a lackadaisical attitude or belief that the modern building is perfectly suitable, created an unfounded reliance on facilities that frequently proved to be as unstable as a house of cards.[385] Over the last century and a half watercraft have frequently been installed in undesirable environments. Apart from the issues of alum and glycerin imbibed into the Hjortspring boat, the remains were installed on display in a moist basement for over 30 years that allowed for continuous sorption of moisture from the ambient atmosphere. Even in the modern era there continues to be numerous examples of watercraft exhibited in uncontrolled environments. Since 1926, the Oseberg, Gogkstad and Tune Vessels have been installed in an environment that opens directly to

[384] Applebaum 1991; Thomsen 1986.
[385] Malberg 2003.

the outside. The two boats of Nin (Croatia), while installed in a quasi-climate controlled building, are exposed to a range of year round temperatures and relative humidity fluctuations in an effort to the reduce yearly budget, it’s is the museum policy to open large windows that line a grass filled courtyard approximately eight feet away from one of the major artifacts (Figure 8.7). This example was also observed at the Pilgrims Museum, Plymouth MA and the remains of *Sparrow Hawk*. Fortunately the timbers from

Figure 8.6. Left, the display hall for the Boats of Nin (Nin, Croatia) along the right side of the image open windows allow a considerable summer moisture to be drawn in from the adjoining courtyard. Right, Sparrow Hawk erected in extremely close proximity to open windows at The Pilgrims Museum (Plymouth, MA, USA). Photographs from the author's personal collection.

Sparrow Hawk were recently reinstalled while on loan to another local museum that has a more suitable and stable indoor climate, but decades passed within a poor environment that further destabilized the wood.

Within the structure of the museum, microenvironments can form because of the building's physical dimensions and layout causing temperature and humidity gradients. The precipitation of acid salts that emerged from the timbers of *Vasa* around 2000 prompted a study by the Vasamuseet to evaluate climatic factors surrounding the ship display.[386] The result of this investigation concluded that while the museum was only 10 years old the engineering of the HVAC system was not sufficient to manage seasonal moisture fluctuations or undetermined variables such as a mass of visitors wearing wet clothes after entering museum building during inclement weather. A new system installed by the museum maintains the desired environmental controls and has virtually eliminated the dominant factor (moisture) required to drive the electrochemical activity to taking place inside the wood. The potential for problems remain, but at least while nearly dormant it allows for interdisciplinary teams to formulate better or more permanent treatment solutions.

Similar to the general study conducted by the Vasamuseet, ongoing research looks to determine how both restrained and unrestrained planks react and move with changes in humidity.[387] Also, how humidity influences artifacts stabilized with different substances by determining ion mobility by measuring electrical conductance of both

[386] Hocker, 2010 and 2011.
[387] Jensen et al. 2011; Jensen et al. 2012.

conserved objects and aqueous solutions of stabilization substances.[388] Even general museum cleaning practices of watercraft have drawn recent scrutiny and evaluation.[389] Since the Oseberg ship is located close to the museum entrance, doors that open directly to the exterior, dust and other contaminants frequently settle on the friable surface of the ship's hull. For the last 30 years, a general cleaning schedule removed the contaminants on a yearly basis. When the observation was made that a considerable amount of the surface was being removed, the vacuum spoils were closely monitored. The result was that fragments of the ship collected by the vacuum weighed 17.3 g, which equaled 18.5 cm^3. The insight opened a dialogue amongst the conservation staff involved with the artifacts' stewardship to reassess preventative measures and determine better ways that could be instituted to reduce the amount of debris landing on the timbers and its removal without erasing portions of the friable surface detail.

Conclusion

Apart from logistics of size and weight, watercraft, while a seemingly easy artifact to display, are very difficult to project a sense of place when the "domain spaces" are not taken into account or the artifact does not retain enough wholeness to relate to the cognitive nature of the visitor perceptions. Archaeologists, conservators and museum exhibit staff must continue to push the envelope in order to create appealing and dynamic watercraft reconstruction displays that continually draw the visitor to the artifact and instill in their audience the desire for further discovery. Equally as difficult is making the

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[388] Jensen, P., A. Helms, and M. Christensen. 2012.
[389] Storbekk, E., and G. Hjulstad. 2008.

historic material function within the integrated structure that seeks to balance both the need for safe and ethical stewardship and dynamic re-presentation.

CHAPTER IX

MERELY THE ACT OF CONSOLIDATION?

Introduction

Reviewed in Chapter 8, the final step for most archaeological ship conservation projects is the installation of the structure in a museum or gallery exhibit space. Here, the object, frequently an incomplete integrated structure comprised of a weakened construction material, modified by the impregnation of a foreign material, and set in an environment contrary to its designed shape, must pass the ultimate test of durability. It must remain in the designed position without experiencing deformation of shape or collapse. At the same time, the structure must project a unobstructed dynamic form to draw the interest of the visitor and inspire future discovery. All of these criteria must be met, if the hull remains are to perform as anticipated for many years if not decades.

In 1975, Jean Bouis, the conservator tasked with the responsibility to stabilize the Port-Vendres 1 ship remains introduced the expression “paleoxyle” in referencing his experience with waterlogged wood. He reasoned that deterioration of the material had so completely altered the physio-chemical attributes of the wood that it warranted a new term to discern it from the treatment of commercially available wood.[390] Similarly, in 2009, while characterizing waterlogged degraded wood Giachi, Macchioni and Santoni made a similar observation. “Wood becomes sort of a ‘new material’ with chemical,

[390] Bouis 1975.

physical and mechanical properties very different from the original material."[391] When wood scientists impregnate chemicals into wood the term used to describe the result is "modified wood." When conservators apply similar chemistry to waterlogged wood under the same pretense, the term traditionally employed is "consolidation." Is there a difference? Does the use of the word consolidation reflect more the aspiration of reversibility and a fear that the use of the word "modify" somehow changes the ethical approach? In addition, has that desire impeded the long-term successful stabilization of many watercraft artifacts?

As early as 1960, Alfred Stamm, the Forest Products Laboratory wood scientist frequently cited in supporting articles on waterlogged archaeological wood conservation along with R.A. Baechler, published an article on the "modification" of wood in which polyethylene glycol impregnation was one of the five highlighted processes. Chapter 8 evaluated those critical aspects of the watercraft conservation and display as it relates to its stabilization and environment in order to propose certain adaptations that may be useful for future reconstruction projects. Above all, what must be remembered is that design is a compromise. If one's intention is to retain wood in the swollen state and dimensional stability is the number one priority, automatically some other characteristic of the design must be demoted below the primary criterion. In the case of waterlogged archaeological wood, traditionally strength has been sacrificed for dimensional stability in the swollen state, and the prospect of reversibility or retreatability.

[391] Giachi, Macchioni and Santoni 2009, 21.

Structure

To the Scottish Captain of the *Dimbula,* the small steamer in Rudyard Kipling's short story, *The Ship That Found Herself*, his vessel was '…in no sense a reegid body closed at both ends. She [was] a highly complex structure o'various an' conflictin' strains, wit' tissues that must give an' tak' accordin' to her personal modulus of elasteecity.'[392] Kipling animated the *Dimbula*'s individual components to accentuate the interconnectedness of a floating structure. Since catastrophe may occur if any element fails under a working load, all parts, including the shape they form, must function in coordination to meet the rigors of ocean navigation. When removed from an archaeological context for museum display, curation of the remains no longer requires the structure to meet the rigorous standards of ocean service. Yet, Kipling's notion of interconnectedness suitably applies to the reconstruction and conservation of archaeological watercraft. Factors concerning propulsion, stability, dynamic loads, or the anticipated strain and stress of massive environmental forces are no longer relevant; however, new challenging criteria arise that require the orchestration of many detailed functions. Principally, this is the need to compensate for the solidity lost through the possible absence of hull symmetry, but the greatest challenge to overcome in managing the eventual watercraft display is that, at sea level, air is 784 times less dense than water, which creates considerable stress and strain on individual elements in a manner for which they were not intended. No ship was ever designed to support its own weight–the water around the ship served that function. Removed from the aqueous, supporting

[392] Kipling 1987, 60.

environment, and once conserved comprised of "modified," weakened, swollen wood, gravity is the enemy and deformation is the devil that has to be beaten.

A phrase, never overused in discussions pertaining to once floating and waterlogged marine structures, is that design is always a compromise that revolves around the most important criteria for the project. The selection of one stabilizing material, in order to make the process "reversible" or "re-treatable," may require a significant support system that detracts from the overall aesthetic of the museum display. Any attempt to enhance the aesthetics may take from other vital criteria. The need for balance leads to two courses of action: excepting that, the foreign environment requires added structural support to offset the change in fluid dynamics, or a combination between re-engineering a better construction material and relying on fewer external/internal supports.

Regardless of weight or size certain principles of physics apply to the manner in which watercraft obtain their characteristic form. The first is Archimedes Principle, which states that when a body is immersed in a fluid partially or fully submerged, an upward buoyant force will be generated equal to the amount of fluid displaced. In other words, forces acting through the center of buoyancy will counteract the downward pull of gravity acting through the geometric center of mass (Figure 9.1). Second, although the integration of hydrostatic pressure around the hull changes with depth and the density of fluid, the aqueous solution consistently cradles the entirety of the underwater form. Granted, this assumes a bilateral structure in perfect symmetry and resting in a static fluid, which is an almost impossible scenario, but the amount of support in water is substantially greater than on land.

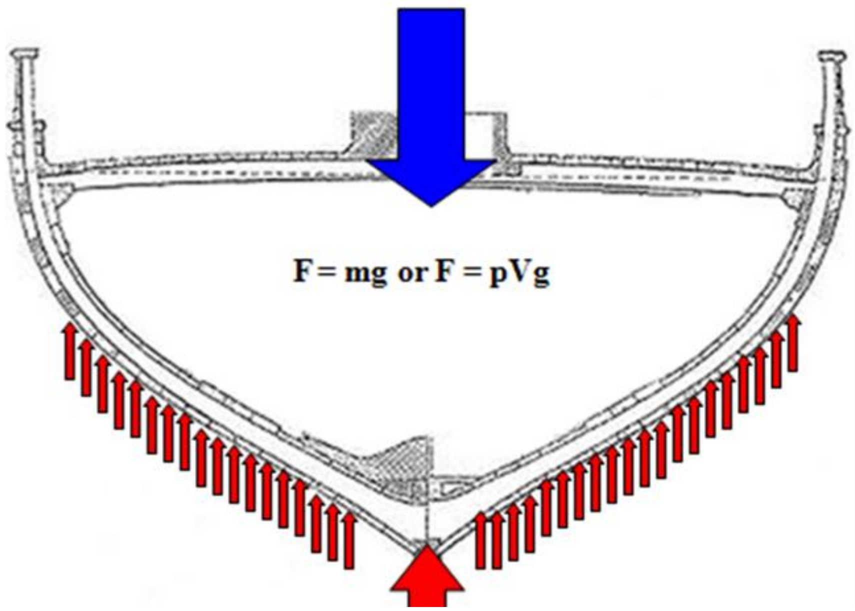

Figure 9 .1. The illustration depicts the forces of gravity (down pointing arrow) and buoyancy acting through its longitudinal center (up pointing arrow) and the uniform cradling of the hull in an aqueous solution (small arrows) Illustration by P. Fix.

When working in the design environment the watercraft structure is always in motion and its shape continually changes due to environmental influences, loading, and the underbody shape. Even over tensioning of rigging on a sailing ship can seriously affect its permanent hull shape. During a ship or boat's working career structural deformation, principally hogging or sagging, frequently occurs due to any one of the aforementioned reasons. Perhaps the most widely known form of the deformation, hogging, generally occurs due to increased buoyancy in the midships section than at the ends, and over time, greater consistent pressure under that portion of the hull forces the keel to rise and a bend forms. This bending of the keel forces deformation throughout the entire integrated structure as some components parts will be in tension and others in compression. The example of hogging highlights what should be an expectation of watercraft structural performance in a museum installation. With no buoyancy the constant exertion of gravity on portions of the structure will cause shifting and movement unless universally supported. Since watercraft are integrated structures, created through different component parts, strain taken by one element and exerted through the joining fastenings on another could create a domino effect that ends in major distortion. The only way to counteract the movement is to ensure that all areas have ample, and if possible, uniform support.

The exertion of gravity results in compression on any structure. For watercraft, the backbone of the structure is the keel, which acts as the primary beam from which all other construction radiates. Under normal service conditions, except in those unfortunate periods of grounding, hydrostatic pressure alleviates much of the force exerted upon the beam. In the atmosphere provided by the museum environment, with no benefit of hydrostatic support, serious damage to the keel can result from compressive forces if the mass of the upper works (in this case everything above the keel) are not managed by the addition and integration of additional supporting elements. With small craft, the mass above the keel may not be sufficient to compress the keel, but the greater the mass of the structure, the greater the concern. During the reconstruction of Bremen Cog (1970-1979) the hull was rebuilt upon keel blocks, a standard practice in any shipyard. Even with a significant portion of the hull weight relieved by the hanging system, there was sufficient compression to create undulations in the weakened timber created by compression and the space between the blocks (Figure 9.2). The amount of compression on any medium to large craft alters the physical properties of that component. Recent studies of the Oseberg ship in advance of its potential transfer to another site indicates that the mass of timber on top of the keel compresses the material in such a way as to alter its normal reaction to the atmospheric environment.[393] Unlike the Bremen Cog, the keel of Oseberg lies not on intermittent blocks, but on a continuous line of blocks. The structure receives little additional support to alleviate the forces of gravity. Only two lines of metal posts placed under the turn of the bilge provides supplementary support, but primarily in the form of transverse stability to hold the structure in place upright and level. All of the weight is taken directly upon the posts through point loading or spread along the keel. The compression between the flat surface formed by the blocks and the weight of the hull above alters the keel's ability to absorb moisture creating a situation where the material is drier than what would normally be expected for the material and drier than the rest of the timber comprising the upper structure. Even though much of the mass is transferred through the keel, the point load on each of the posts lining port and starboard creates a hollow depression at the pressure point and sagging between some of the posts.

[393] Jensen et al. 2013.

Figure 9.2. The reconstruction of the Bremen cog during the 1970s. Note the keel blocks under the sternpost lower left corner of the image. From Hoffmann 1986, 216.

Curators and exhibit designers who have taken a minimalistic approach to watercraft support structures in the creation of an aesthetically pleasing display and a dynamic sense of place have frequently been confronted with significant deformation of the structure. In the last decade, several well known watercraft have fallen into this category, two in particular include the Bremen Cog and the *Vasa*. The weight of the PEG laden starboard side of the cog generated an imbalance that overwhelmed the point-loaded cables suspended from the ceiling, knuckling the lower structure and nearly shifting the keel off its base of support.[394] The original cradle supporting the *Vasa* underwent modification in the 1980s to bolster its capabilities, but between 2000 and 2010 the data compiled by the yearly 3-dimensional monitoring program determined that creep of the timbers is occurring to such an extent that the deformation requires that a new cradle be designed, engineered and constructed if Vasa is going to remain on display in its current location in perpetuity.[395]

The concept for supporting the Bremen Cog from the ceiling of the Dueche Shiftarts Museum came from ship models hanging from church ceilings throughout Northern Germany. [396] Several cables dropped vertically from the ceiling to capture the large crossbeams while a row of additional cables extended at an angle down to points below the turn of the bilge on the starboard side. The remaining portions of the hull were affixed to one another and received no additional support (Figure 9.3). The cables adequately carried the weight of the structure while in the aqueous PEG solutions between 1981 and 1999, as the weight of the timbers were offset by the buoyant forces of the fluid. Shortly after the conservation tank was removed and the Cog prepared for final display significant stress fractures appeared in the lower timbers and the structure began to noticeably deform. This movement culminated in the keel beginning to slide off the keel blocks, which potentially could have caused the starboard side to collapse. The solution to manage the radically shifting shape of the hull was to abandon the system of cables from the ceiling in favor of a rigid system that integrated steel supports that

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[394] Hoffmann 2011.
[395] Kristofer et al. 2001.
[396] Hoffmann 2002.

replicated the Cog's framing. Once tied together and to the ship timbers the weight of the structure will be taken up by the new framing and transferred to the floor, preventing any movement. Planning, re-documentation of the hull, construction and integration of the new supporting elements and correction of the hull shape took approximately eight years to correct.

Figure 9.3. The Bremen Cog support system. Photograph from the author's personal collection–video capture.

Since its 1961 recovery, the support system for the *Vasa* has consisted of a network of transverse struts shaped to fit the curvature of the hull that end near the bilge. In addition, cables suspended from the ceiling bolster the stability of overhanging stern gallery and post under the stem prop up the bow. Apart from these aids however, retention and maintenance of the hull shape relies solely on the integrity of the wood, fastenings and the joints they form. By 2010, data compiled from the geodetic monitoring system [397] indicated that hull deformation was seriously affecting the icon and a new cradling system was required.

Unlike the Bremen Cog the *Vasa* is complete with no missing major elements that would influence bilateral symmetry and structural integrity. Nevertheless, with tons of PEG and timber continually pressing downward on the reverse arch comprised of wood weakened by water logging and impregnated by a substance that is known to impart viscoelastic characteristics on wood movement should have been anticipated. The displacement tonnage of *Vasa*'s hull is calculated at 1210 tons, and even though the PEG solution could only be taken to 45%, the amount of PEG-1500 and PEG-600 absorbed into the timber potentially increases the total mass by 100 to 200 tons. Therefore, not only is the structure expected to remain unchanged in an adverse environment, the inclusion of the internal consolidant further hampers its ability to perform the re-cycled role as a museum display by increasing the weight of the timber far greater than evolved through nature.

Materials

If waterlogged wood performs differently than what is normally expected of the material, as noted earlier in the chapter, and impregnation of chemical further alters those characteristics. This begs the obvious question, "is conserved waterlogged archaeological

[397] Malmberg 2002.

wood a "modified product?" For the longest time the word, consolidation, has been used to describe the action of impregnating waterlogged wood with a particular material, signifying that the undertaken process unifies and thereby strengthens the degraded element. It may seem a trivial argument to debate but does the use of the word consolidate/consolidant influences action. The case can be made that in respect to waterlogged archaeological wood conservation the preference for the term consolidation over modification leads to measures that frequently result in unfortunate consequences. If the goal is to create a dynamic exhibit with few external supports, the load imposed by the structure either has to be taken by the impregnated substrate material, or by any cradling structure.

According to the USDA Forest Products Laboratory modified wood is "wood processed by chemical treatment, compression, or other means (with or without heat) to impart properties quite different from those of the original wood."[398] A congruent definition of modified wood is:

> Wood modification involves the action of a chemical, biological or physical agent upon the material, resulting in a desired property enhancement during the service life of the modified wood. The modified wood should itself be non-toxic under service conditions and, furthermore, there should be no release of any toxic substances during service, or at end of life following disposal or recycling of the modified wood. If the modification is intended for improved resistance to biological attack, then the mode of action should be nonbiocidal.[399]

Consolidation may strengthen certain properties by merging two but at the same time may alter other properties. In wood, the modifier alters the cell properties by altering the cell wall and chemical modification generally occurs by a cross-linking

[398] Forest Products Laboratory 1999, 463.
[399] Hill 2007, 21.

reaction between the reagent in the hydroxyl and polymer groups of the wood. By using the word modify it accepts that there is a definitive change in the material and that all altered characteristics must be addressed.

In wood that has been impregnated to the saturation level, frequently the product takes on more of the characteristics of the modifying agent than that of the original material. In studying the deformation of the Bremen Cog, Hoffmann confirmed the visco-elastic characteristics PEG impregnated archaeological oak wood. [400] Traditionally, one of the methods of correcting PEG saturated timber that has shifted in an undesirable direction during drying is to warm the material with heating blankets and physically reshape the wood to fit to the desired orientation. Reshaping with minimal surface supplied heat and then locking in the new shape as the material cools is not a normal property of wood. Wood has always been enjoyed for its considerable elongation to break ratio and that attribute can be exaggerated with steam. Decades ago, when I worked in a museum preservation shipyard the rule of thumb for steaming wood in a box was to steam the wood one hour for every inch of thickness. Therefore, to alter the natural shape of the timber requires a considerable amount of energy. Even after drying, the memory of the timber frequently redirects the shape closer to its original form unless restrained by a jig. Again, this is not the case with PEG saturated wood where one can manipulate the shape as the temperature of the integrated material reaches closer to the melting point temperature of the PEG. Other re-treatable options (acetone-rosin) create a new product so brittle that the object risks shattering into numerous pieces if dropped

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[400] Hoffman 2010.

onto a hard surface. These statements are not a general call to abandon the retreatability standard or any one of the chemical products used to impregnate waterlogged wood. The intent is to illustrate that far more alteration is taking place inside the wood than a simple consolidative unification. If the end product is not capable of performing in the required manner (i.e. part of an integrated structure in a hostile environment for which it was never designed) more intervention must be taken in regards to the support system and often for even small to medium sized strucutres. This may include disassembling the structure instead of keeping it as a block unit, or replacing certain elements with stronger more durable materials that replicate the form regardless of authenticity.

Over the last decade, more research has explored the changes in wood properties resulting from the degraded state. [401] Most of the research relates to one of three watercraft that have demonstrated significant deformation due to severely weakened state include the *Vasa*, Bremen Cog and the Oseberg ship. Most have evaluated the mechanical behavior resulting from the effects of degradation. Part of the work by undertaken by Broavac on the Oseberg ship looks to create a model of degraded wood within the integrated structure in order to fabricate the most appropriate and elegant cradle for a particular ship. How effective a model created off one ship (Oseberg) would translate to another degraded structure is the question. The global deterioration, perhaps involving missing elements and different degrees of degradation between wooden components may be too complicated and may not apply to all structures. As a natural polymer, variations occur in wood between different trees of the same species and with

[401] Ljungdahl and Berglund 2007; Bjurhager, Iverson, and Berglund 2011; Almkvist, Johansson, and Bjurhager 2012; and Bader et al. 2013.

in a particular tree. In their analysis, Braovac's team determined there was different degradation between fragments or individual pieces or different degradation within the same piece.[402] The fact of the matter is even with exceptionally strong models there may be no way to predict actual strength of degraded timber, or how the impregnated material alters the element's performance. Couple that with requirements for bearing strength and an object in a non-design environment, really the only way to approach the support of some watercraft is to provide complete framing support, hidden as best as possible to not detract from the dynamic effects of visual presentation.

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[402] Braovac 2011, 156 157.

CHAPTER X

LA BELLE: A CASE STUDY

Introduction

Due to the high concentration of marine organisms in the temperate waters of Matagorda Bay, Texas, few on the Texas Historic Commission's archaeological team in summer of 1995 surmised that the La Salle Shipwreck Project would yield significant levels of preserved organic materials. Yet, as large pumps caused the bay waters within the confines of the double walled cofferdam to recede, thousands of organic artifacts began to appear. The largest artifact, constituting approximately one third of its original volume, was the hull remains of *La Belle;* this was the barque longue that was part of French explorer René Robert Cavalier, Sieur de la Salle's failed expedition to form a the New World colony at the mouth of the Mississippi, in what is today part of the state of Louisiana.

Following extensive debate revolving around the most appropriate manner in which to recover the exposed hull, the Texas Historical Commission's final decision was to disassemble the structure *in situ* and transfer the timbers to the Texas A & M University Conservation Research Laboratory for stabilization.[403] Between 1997 and 2003, the conservation staff from the University's Nautical Archaeology Program cleaned, documented, and reconstructed the remains of the ship in a lift dock enclosed

[403] Carrell 1998. Carrell, in her manuscript detailing the disassembly of the hull discusses many aspects of the debate about recovering the hull as a block unit or be disarticulated timbers. Also, Bruseth and Turner 2004.

within a 14,400-cubic foot concrete vat (60' x 20' x 12') before chemical stabilization of the wood with polyethylene glycol. In the decade that followed, the methods employed to stabilize the hull timbers were adapted to meet current research standards of archaeological waterlogged wood stabilization, and financial prudence. After the initial decision to reassemble the timbers into a block unit and saturate them with a two-step protocol of low and high molecular weight PEGs before controlled drying,[404] the treatment was changed to incorporate lower quantities of PEG as a pre-treatment to freeze-drying the timbers on specially formed molds to hold the correct shape in a 40' x 8' diameter vacuum freeze-dryer. This case study accentuates two of the most important facets in the pre-planning for the conservation of any object as complex as watercraft; the need for flexibility in order to adjust conservation and display methods to meet changing external stimulus, and manage the artifact as an integrated structure not just as component parts with volumetric substance.

In the winter of 1997, following the hull disassembly by the Texas Historical Commission, the charge to the Texas A&M Conservation Research Laboratory (CRL) was to conserve the disarticulated hull remains of *La Belle* (Figure 10.1). Roughly, 23,000 pounds (~10,250 kg) of waterlogged wood for permanent exhibit in a new museum under construction in the Texas state capital, Austin, and dedicated to Texas history. The hull timbers, which represented 384 of 14,000 excavated artifact lots (each principal timber received a unique identification number) arrived at the CRL from February to May 1997 as part of the twice weekly shipments from the field. CRL

[404] Hoffmann 1986.

Figure 10.1. Looking aft at the hull remains of *La Belle* following excavation of the small artifacts from the main hold. Heeling to starboard at an angle of 68.5°, considerably more structure remains of the starboard side. Photo, The Texas Historical Commission.

Director, Dr. Donny Hamilton's mandate to his staff was to develop a conservation plan to stabilize the timbers as a reconstructed block unit instead of the component parts. Hamilton's concern that the uneven condition of the degraded wood, coupled with areas of considerable ferrous corrosion permeation, shipworm worm infestation, significant curvature and twist of some planks, and the sizable scantlings of several timbers would result in differential movement even during a controlled dehydration. If that were to occur, there were obvious concerns that the fastenings holes would never again align plank to frame, thereby preventing a post stabilization reconstruction.

In working toward that final goal, methodologies deviated from that of the original directive to reflect current disciplinary practice, but the undertaking continued to adhere to crucial design mechanisms that allowed the CRL staff to continually reassess the plan and apply or modify certain methods safely and efficiently. Chapter 10 recounts the challenges of planning, reconstruction and stabilization of this valued watercraft artifact by detailing the methodology and the decision-making processes used to assess the artifact, create a support system suitable for both conservation and final display, and stabilization of the degraded waterlogged timbers.

Background

Initial underwater investigations of the site using SCUBA tanks conveyed the potential for an abundance of artifacts, but not until pumps emptied the Matagorda Bay waters from the double-walled cofferdam, could archaeologists from Texas Historical Commission understand the true breadth and overall scope of the wreck site. Beneath a single bronze cannon and small assemblage of artifacts, which had been removed from the wreck site a year earlier (1995) for identification and analysis lay evidence of an immense collection of late 17th-century French material culture–approximately 1.6 million artifacts, the largest such collection discovered to date in North America from a single contextual site.[405] What would prove to be the largest artifact on the site, the eroded tops of the ship's futtocks sticking proud above the ocean floor, were the hull remains of *La Belle* (Figure 10.1). In hindsight, the Commission's decision to invest in the construction of a double-walled cofferdam proved to be correct. With the rapidly shifting sediments in Matagorda Bay and extremely low visibility, it is doubtful that an underwater excavation employing surface supplied air or SCUBA tanks could have successfully recovered a similar quantity of small finds. Certainly, the poor condition of the hull would have made recovery of that artifact as a block unit, large sections, or disarticulated component parts virtually impossible.

The Archaeological Remains

La *Belle,* the *barque-longue* of 50 tons[406] associated with Robert Cavillier's failed New World colony, is not only a significant feature of national and international history, but also an icon of Texas culture and heritage. Out of a fleet of four vessels that departed La Rochelle, France in the summer of 1684, by end of 1685, *La Belle* had become the colonists' only means of water borne conveyance, principal container, secluded fortress, floating dormitory and life raft. Archaeologically, within the boundaries of the site, the artifacts recovered represent a rare opportunity to assess what 17th century French

[405] Personal communication with La Salle Excavation Project Archaeological Director Dr. Jim Bruseth October 2014.
[406] Marine Royale. 1689.

colonists believed requisite to survive and prosper in the New World.[407] The surviving timbers constitute approximately one-third of the original hull, provide definitive data concerning the progression of French naval architecture during the late17th century, the manner of construction practices, denudement of French forest, cargo distribution, a setting for shipboard life during the period and a gateway to explore social hierarchy of French shipyards during the period.

The plan for *La Belle*'s original construction was *en fagot*, which translates into English as "in bundles." In this case, bundles of pre-cut and shaped timbers to construct one particular ship. La Salle initially planned to transport the crucial skeletal components of the shoal-draft *barque longue* to North America in one of the larger ships and raise the structure upon arrival on the banks of the Mississippi River. With insufficient storage space in the hold of the warship, *Le Jolly*, however, the timbers had to be hastily erected in France before departure and sailed to the New World as *La Belle*. Since the hull was supposed to be a kit, all floors and many futtocks retain a number designation relating to the timber's placement in the ship as it corresponds to the midship frame (Figure 10.2). All futtocks and floors forward of the master frame, which is designated by a mark similar to an asterisk, have an inscribed "A" (*avant* or before). Aft of the master frame frame sets are designated with a "D" (*derriere* or after). Including the master frame 29-frame sets survive as part of *La Belle*'s archaeological structure, 12 frame sets forward and 16 aft. The remains of most frame sets include a floor timber that crosses the centerline and sits on the keel, and four futtocks (three on starboard and one on port.

[407] Bruseth and Turner 2004; Bruseth et al. (In Press).

Since the hull listed to starboard considerably more framing timber survives on starboard than on the port side (see Figure 10.10–) weights and moments for distribution of mass analysis).

Figure 10.2. Since the hull was originally to be constructed *en fagot*, the inscribed mark "VII A" designates the correct orientation of the floor at this point on the keel, which is seven frame sets forward of the master frame. Photograph courtesy, The Texas A&M University Conservation Research Lab and The Texas Historical Commission.

Site Formation and Structural Deformation

Apart from the salvage of rigging, readily accessible armament and cargo from the wreckage of *La Belle,* French and Spanish chronicles do not mention dismantling the hull. Nor did the hull rapidly break apart as had occurred with the expedition's 300-ton store-ship *l'Aimable* after grounding on shoals at the entrance to Matagorda Bay[408]. Henri Joutel in recording Monsieur Chefdeville's testimony concerning the grounding of *La Belle* wrote, that a wind "stirred up the waves and made the hull of the ship settle deep into the sand. The water covered her except for the poop deck."[409] A log kept by Juan Enríquez Barroto, pilot of one of the Spanish *piragua,* the *Ňuestra Seňora del Rosario* dispatched Christmas Day, 1686 to locate La Salle's colony supports Chefdeville's portrayal of events. A year later, on April 4th 1687, following the Spanish expedition discovery of the *navio perdido* (lost ship), Barroto recorded *La Belle* "[had] all the starboard side, the deck and prow under water" He included that "[t]he masts [had] fallen into the water (because the shipworms had eaten in two at the holes) with all the rigging."[410]

In Monsieur Chefdeville's account, *La Belle,* undermanned and out of control, was blown South and across Matagorda Bay by a "northern" in late January 1686. The crew attempted to save the ship from grounding on the shoals of what is present day Matagorda Peninsula by casting off the only remaining anchor but with little success. Once the weight and inertia of the ship fetched on the anchor cable, the bow swung head to wind, but the size of the back-winding mainsail produced sufficient effort to cause the anchor to drag and *La Belle* to ground on the shoals of the peninsula.[411] It is a logical assumption that the grounding of *La Belle* on Matagorda Peninsula raised the hull slightly out of the water destabilizing it by lowering the center of buoyancy thereby

408 Foster 1998, 93.
409 Foster 1998, 137.
410 Weddle, [Barroto] 1987, 171; Also, Jones 2014.
411 Foster 1998, 139.

increasing the metacentric height, which shortened the roll period. When the second storm struck the grounded vessel several days later, the short, and most likely violent roll moment, acting similar to a metronome caused the ship to settle deep into the sediment.

When uncovered in 1996, the bow exhibited a nearly northerly heading. In addition to the orientation, the excavated hull maintained a 68.5° list to starboard, further supporting Barroto's observations.[412] Over the ensuing 300 years, one can only surmise that storms off the Gulf of Mexico battered the wreck and shrimping nets scoured the top surfaces contributing to the ship's deterioration. The movement of sediment in that region of Matagorda Bay is set by the tidal range running along the mainland shore and directed by the prevailing wind pattern–south easterly, and by "Northerns," winter storms that blow hard from the north, for short durations during the winter months.[413] The portion of the hull that survived was due to the water column and continuously shifting sediments of Matagorda Bay, which entered the structure through openings in the hull, depositing sediment that over time filled the interior of the ship sealing it in an anaerobic environment. The entombment finally halted the destructive progression of shipworms on the port side at the turn of the bilge around midships, and preserved the starboard side to approximately one foot (25.4 cm) below the estimated deck line (Figure 10.3).[414]

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[412] Carrell 1998, 4.
[413] McGowen and Brewton 1975, 4-5.
[414] Grieco 52.

There are perhaps multiple scenarios of how the deposition of the hull occurred and just enough of the structure survives to deduce some logical estimates. Evidence that early in the wrecking, portions of the hull were buried and exposed, which resulted in

Figure 10.3. Looking across the port bow to the starboard side illustrating the differential presentation due to the starboard list of the immersed hull. Photograph courtesy, The Conservation Research Lab and The Texas Historical Commission.

intervals of localized scouring, reburial and continued settling. Hull and ceiling planks not thoroughly impregnated with ferrous corrosion by-products, coated with concretion, or riddled with shipworm tunnels were found to be highly degraded, very soft and flexible with little shape memory. It is presumed that the ductile nature of many of the hull and ceiling planks, coupled with the lack of integrity of longitudinal fasteners in the futtocks,[415] and the fractured futtocks created undulations in the hull noted by members of the excavation crew.[416] This deformation was not permanent since the physical reconstruction demonstrated the hull planks and futtocks again formed a fair curve. In what remains of the structure, the two principal regions of fracture that caused the undulating interior surface occurred on starboard from the master frame forward to frame set "A-8" (8th frame set forward of the master frame) aft to "D-4". Transverse shearing fractures occurred to 15 starboard futtocks on 13 different frame sets, a majority in proximity of the bilge turn. Fracture of longitudinal members included the forefoot-keel scarf located between frames sets "A-3" and "A-4", and the three starboard clamps near "A-3 to "A-5" (See Figure 10.4).

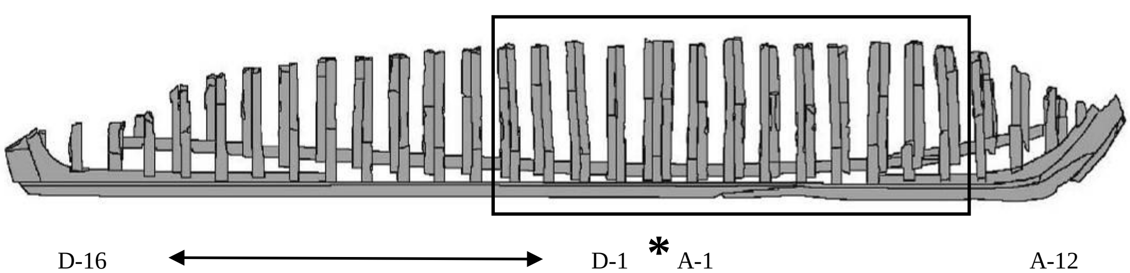

Figure 10.4. The starboard elevation based on electronic survey data. Note the downward deflection of the forefoot. The asterisk delineates the midship frame set. The box denotes the frames where the first futtock fractured. Structural delineation courtesy the Texas Historical Commission. Graphic illustration by P. Fix.

[415] Carrell 1998, 12.
[416] Personal communication with site crewmembers Peter Hitchcock and Taras Pevny May 2001.

At some point very early in the wrecking process I surmise, sediment scouring around the bow exposed that region to the water column and removed the underlying support for the forward portion of the ship. Evidence for this hypothesis derives from observations that the keel, closer to the stem (and stern) had considerably heavier shipworm infestation than the center of the keel. During the grounding, Chefdeville indicated that the vessel generated enough storm driven momentum sailing across the Bay to drag the anchor released to halt the vessel's progress.[417] If this were the case, the stern would have plunged into the bottom on impact creating a furrow on either side of the keel until forward motion ceased. The violent rocking motion of the second storm caused the settling of the hull indicated by both Chefdeville and Barroto, creating a depression in the sediments on starboard. What we cannot know is how much of the port side was buried. Obviously, all of the port side was eventually buried, but we cannot know how long was required to entomb the complete ship. The contents of the hold, the cable and skeleton in the cable locker would have been somewhat protected by the hull and sediments slowly built upon them. Even though La Salle reported in his journal that shipworm activity in the Bay was so extensive that the pumps on *La Belle* were in operation 24 hours a day, had the worm damage occurred before complete burial, one would expect to find a more uniform damage pattern throughout the length of keel timber.[418] This however is not the case, indicating it was quickly buried resulting in long sections around the midpoint of the keel where there is only minor observable shipworm damage. The volume generated by the starboard side in contact with the sediments is

[417] Fowler 136.
[418] La Salle 1877.

significant and since compaction of the sediments could not be considered quick sand, it is hard to fathom how the hull could sink to the depth as found from the initial wrecking and second storm. Most likely the deposition took several years to complete entombment and for the site to reach stasis.

If the sediments propping up the bow were scoured away, approximately 18,000 foot-pounds[419] of force caused the downward rotation of the stem. The heaviest shipworm damage along the forefoot extends aft to a point just forward of where the forefoot and the skeg scarf together. If the point where it lessens is accepted as the fulcrum, the bow hinged at the keel scarf drooping approximately four to five inches (10-13 cm) at the extreme forward end. The resulting strain of the downward rotation at the bow was transferred through the timbers on the starboard side and is possibly the event that caused the rupture in the three upper stringers near the fourth frame set forward of midships. The settling of the bow may have, in part, also contributed to the fracturing of the first futtocks. Since these timbers are set on the forward or aft side of the joint between the floor and second futtock around the turn of the bilge, any force pulling the timbers toward the bow would be taken up on the first futtock (Figure 10.5). The point where each ruptured occurred was either heavily saturated with corrosion products or constituted the interface between the heavy corrosion and weak fibrous wood. Unfortunately, the actual breaks in the timber provide no definitive clues as to the direction of strain since each break was relatively clean and devoid of splinters to indicate the fracture angle. Deterioration and post depositional movement of the structure

[419] This calculation only considers known remains of the timber. Had more of the structure survived, the force generated by the couple would have been considerably greater.

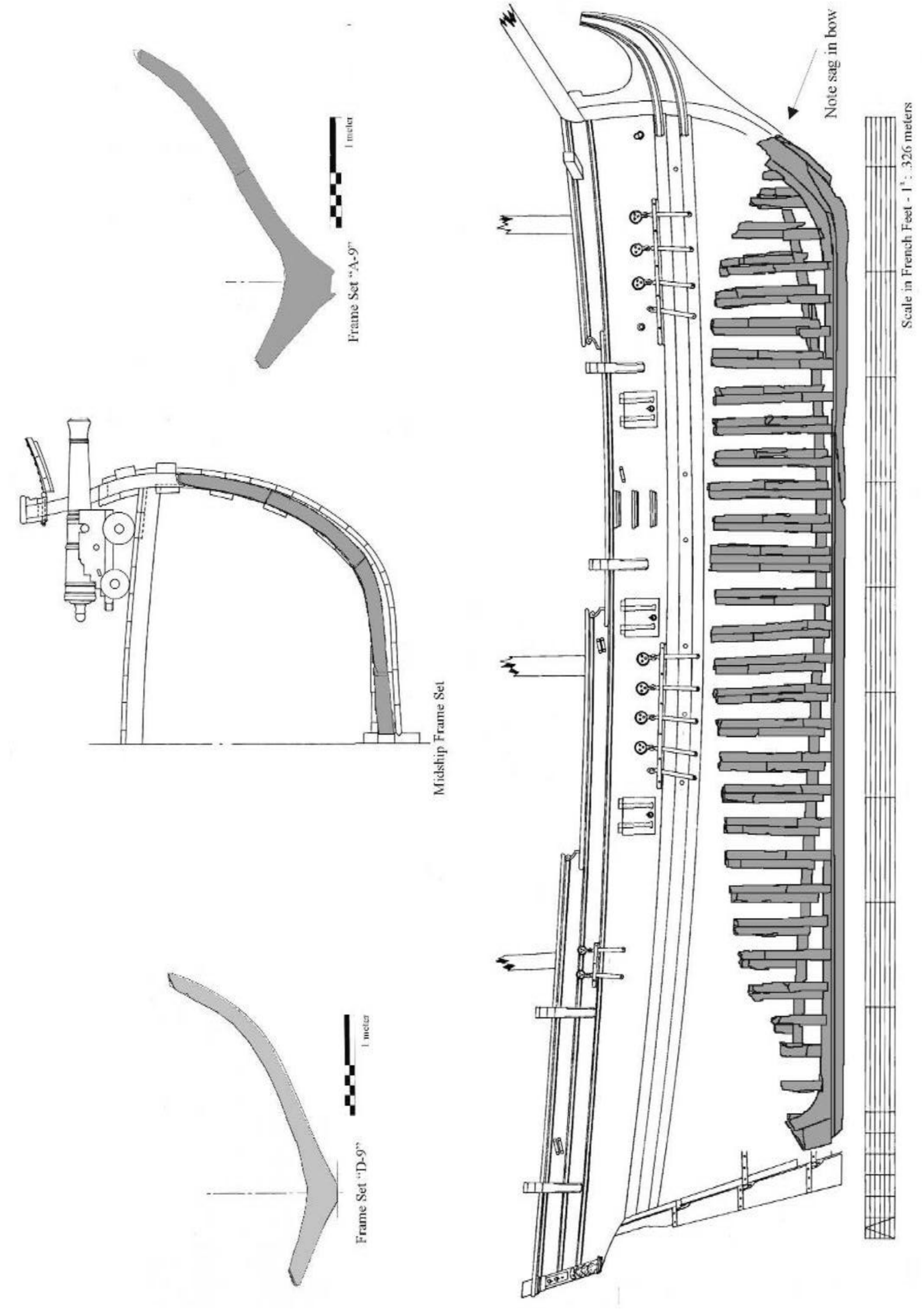

Figure 10.5. Illustration depicting deformation of the hull shape both in sections and in profile. Structural delineation courtesy the Texas historical Commission. Graphic illustration by P. Fix incorporating reconstructed profile by G. Grieco.

Figure 10.6. Clockwise from top left. Frame sets “D-1” through “D-4” starboard, illustrating the formation of the frames by joining overlapping futtocks. Upper right, looking aft at the symmetry formed in the floor length by the narrowing lines and the natural breaking point the lengths create. Lower left, the longitudinal seam created in the hull construction by not staggering the length of the floors and second futtocks. The longitudinal break placed considerable strain on the first futtocks. Lower right, an example of the first futtocks cross-grain fracture. Photograph courtesy Texas A&M University Conservation Research Laboratory and The Texas Historical Commission.

are only a few of the contributing factors however, why so many first futtocks ruptured. Timber selection and general construction techniques also played a prominent role.

The design of the hull created a continuous arc where the second futtock followed the radius established by the floor. The first futtock overlapped these two timbers, which closed the butt joint between the two timbers. If taken independently the location of joint would not generally be considered a defect; however, carpenters followed the natural curve of the ship along the narrowing line when determining the length of each floor. This fair curve created a hard break from “D-5” forward to “A-8” (Figure 10.6) with only the first futtock for support. Had carpenters staggered the floor lengths the long, longitudinal joint would have been eliminated and the strength of the structure greatly increased. This long hinge in combination with the poor selection of timber for the first futtocks placed too much strain on the timbers once hull symmetry was compromised causing the clamps and first futtocks to fracture.

The selection of wood for these particular timbers (“A-8” to “D-4”) does not follow logical shipbuilding practice and provides strong evidence illustrating the shortage of proper shipbuilding timber in France during the latter half of the 17th century. Since the length of each timber closely mimics the shape at the bilge turn, following standard practice, one would expect to find compass timber employed where the wood grain followed of the curve of the timber. This was not the case with *La Belle*. All the fractured first futtocks exhibit relatively clean cross grain breaks, indicating each was fashioned not from compass timber, but from large flat-sawn boards. When the strain was placed upon the joint between the floor and first futtocks, the weaker cross grain could not support the applied load, causing the line of fractures.

Timber Assessment

Wood identification conducted on selected timbers indicates the keel, keelson, riders, buttresses, ceiling, stringers, hull plank, dead wood and rising wood were all fashioned from a species of *Quercus* (oak). Bulkheads, pump well box, and sole of the anchor locker were a species of P*inus* (pine).[420] The timber arrived at the conservation facility from the field, wet, surrounded by carpet foam in long plywood boxes lined with plastic sheeting. A visual assessment of the individual timbers revealed a material that had endured significant non-homogeneous deterioration, and surface a texture ranging from extremely hard and dense to spongy and easily depressed with only moderate touch. The timber surfaces also exhibited a range of colors from grayish tan to dark brown with large regions of dark red to bright orange around the degraded longitudinal iron fastener holes and throughout the ceiling in the main hold (Frame set A-5 to D-5) caused by ferrous corrosion product permeation of the wood. Almost all timber close to the exterior of the hull exhibited signs of heavy shipworm infestation (Figure 10.7).

Zoological Degradation

While deterioration to individual components resulted from a combination of factors, there can be little doubt that the common shipworm (*Teredo Navalis)* was responsible for most of the hull disintegration. The ends of every futtock and some floors, the stem and sternpost were whittled to nubs and the hull and ceiling planks on

[420] Carrell 2003.

both starboard and port contained evidence of considerable worm infestation especially toward the upper works as well as the toward each end. *Teredo Navalis*, or common shipworm, is a genus of bivalve mollusk, with a long wormlike body and a thin shell casing that bores into wood when in its larval stage and grows in size as it tunnels its way

Figure 10.7. Above and left, the heavy damage to the underside of the forefoot. Right, a fragment of one of the starboard upper hall planks. Both timbers were heavily damaged by *teredo navalis*. Photograph courtesy Texas A&M University Conservation Research Laboratory and The Texas historical Commission.

through the material. The walls of the tunnel are lined with a calcareous material that increases in size as the animal grows. X-rays taken of a number of ship timbers clearly depict the progression of the mollusks as they excavated deeper into the timber (see Figure 10.8). Also noted is the increase in the diameter of the animal the longer they inhabited the wood. The size and quantity of animals was quite astounding when first viewed. Estimates of wood loss from tunneling in given timbers is approximately 40% of the overall calculated volume. Over time, each tunnel vacated by a worm filled with silt and due to the spiraling nature of the paths these added contaminates that remain lodged in the timber increasing its mass but not altering the density of the wood or contribute any additional strength.

Figure 10.8. An x-ray of a degraded third futtock from *La Belle* approximately 18 inches long illustrating the depth and extent of shipworm penetration. X-ray courtesy Conservation Research Laboratory.

Moisture Content

Moisture content is one of the most widely used analytical methods to determine the amount of deterioration to the microstructure of the wood.[421] To create a profile of deterioration through the individual timbers a 12 mm incremental woodborer was used to extract core samples. These samples were sliced at 1 cm increments before beginning procedures to determine moisture content. (ASTM-D4442-92 Method A, Primary Oven-Drying Method) Finding timbers that exhibited little infestation or ferrous corrosion contamination made the selection of which wood to core a difficult task. Many of the timbers that on the exterior appeared sound produced core samples that compressed to almost two-thirds the original size as tunnel voids collapsed in the boring tube. Even some samples that appeared to be suitable cores came under scrutiny when quantities of sand and shell appeared in the bottom of the containers after the oven-drying process. The amount of contamination in the wood was more of a factor in effectively conserving the wood than in determining the engineering requirements for the cradling structure during conservation. The results obtained from the cores were treated as very rough estimates. Throughout the ship, the moisture content ranged from 90%, several centimeters inside the keel, to over 500% on a section of starboard hull plank located near the surface top of the futtock ends (Figure 10.9).

Ferrous Corrosion

During the excavation, archaeologists removed over 1,350 metal artifact lots or encrustations from the main hold located between frame set “A-5” and “D-5”. In close

[421] Squirrell and Clark 1987.

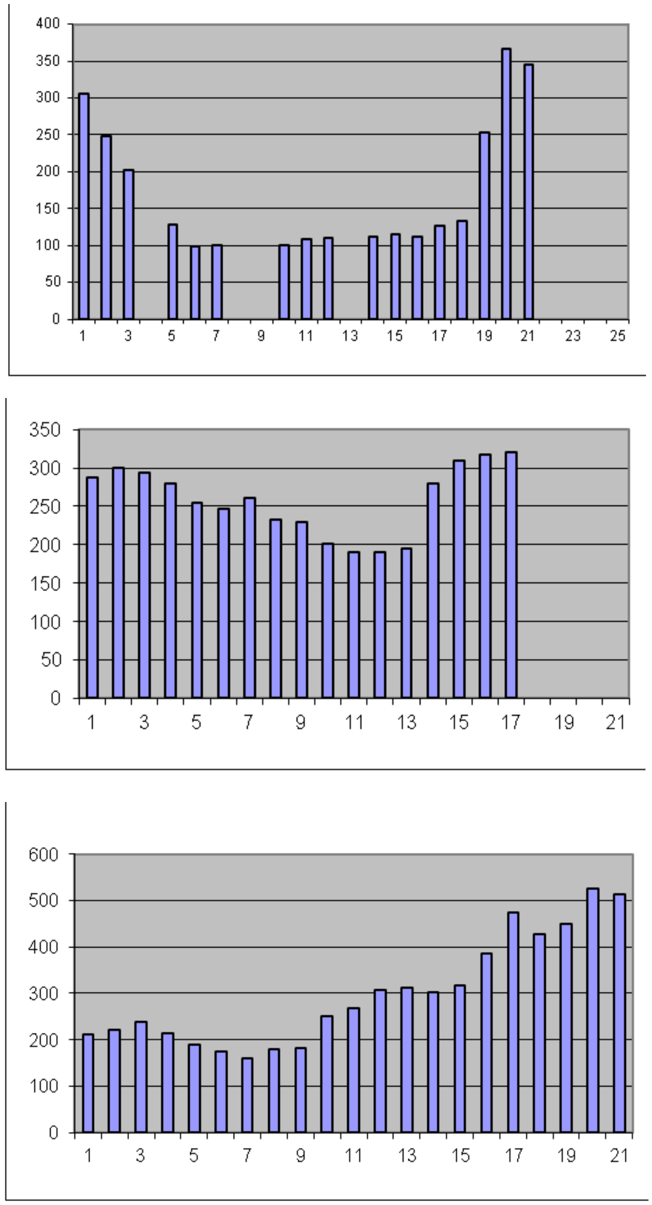

Figure 10.9. Example graphs depicting moisture content profiles from timbers of *La Belle*. On top, the keel where the left side of the graph represents the top of the keel. The middle graph represents hull planking below the turn of the bilge. The bottom graph represents timbers toward the top of starboard. The left side of the graph for both middle and bottom represents the lower edge of the plank of X-ray courtesy Conservation Research Laboratory.

proximity to the ceiling planks, there were 44 pieces of iron bar stock, pewter, brass pins, hawks bells, rings and other domestic items, four complete casks of lead shot and scattered lead balls, iron tools, nails, bolts, two casks of axe heads and three "four-pounder" bronze cannon (two on each side). Once submerged, these different metals created a galvanic cell where electrons flowed from less noble metals such as iron to the more cathodic metals such as copper and bronze.[422] The deterioration of iron fastenings and cargo impregnated the surrounding wood structure with ferrous corrosion products. So extensive was the impregnation that in some areas the timber displayed physical properties closer to fiber-reinforced cement than wood. The accumulation of the corrosion products in the wood altered the physical properties of the timber, especially around each iron fasteners, and created numerous "hard spots" around the hull, each with a greatly reduced elongation to break ratio.

Volume, Density, and Rotation of the Remaining Structure on Land

With an understanding of how the structure and construction materials might perform, a comprehensive assessment of the hull's physical properties was required to discern the loads exerted on any cradle that might be constructed in the future. We first determined the density and placement of each component within the structure and plotted the component centroid. Through summation of the mass for each piece and its corresponding function in regards to the rotation of the longitudinal, vertical and transverse center of gravity was calculated for the global structure and each combined frame set. Most of the information that was required for this procedure was available

[422] Hamilton 1996; also North and Macloud 1987.

through the documentation undertaken in the field and corrected timber tracings undertaken at the conservation lab. Once exposed, the excavation team delineated the hull components in three-dimensional space, with a Sokia Total Data® Station, electronic theodolite.[423] The x, y and z coordinates once downloaded into Auto-CAD® wereconnected to produce a three-dimensional model of the hull *in situ*. As each timber was removed from the hull in the field, the four sides were traced on Mylar and Texas Historical Commission contractors Toni Carroll and Taras Pevny updated the original one-to-one you field drawings once the timbers arrived at the Conservation Lab. When corrected, the timber tracings were digitized into Auto-CAD® files (see Figure 5.5 for an illustration of a representative La Salle Shipwreck Project timber tracing from *La Belle*). To find the density of each timber we used the digitized timber tracings to determine the molded area of each floor, futtock, and longitudinal timber. This figure was then multiplied against an average of several sided dimensions. The density for each piece was achieved by weighing first eight and later twenty-four representative oak timbers. These timbers included floors and futtocks from different areas of the hull. Later a second study increased the number of the sample to twenty-four, where twelve of the timbers were impregnated with ferrous corrosion products and twelve were not, or did not exhibit visible indications of corrosion products on the exterior surfaces. The volume of the hull planking and ceiling was determined by delineating the half-girth measurement at each frame station on the lines drawing and applying the Simpson multiply (2xΣf x 1/3 CI) to deduce the area of the curve over the hull length. Tabulated,

[423] Carrell 1998, 6.

		Above Baseline		About Midship Station				Starboard		Port	
	Weight	Vert. Arm	Vert Mom.	Fwd. Arm	Fwd. Mom	Aft Arm	Aft Mom	Arm	Mom	Arm	Mom
	Lbs.	ft.	ft.lbs.	ft.	ft.lbs.	ft.	ft.lbs.	ft.	ft.lbs.	ft.	ft.lbs.
XIA	138.091261	3.4451	475.7382033	18.6033	2568.953156			0.175	24.16597068		
XA	225.675239	3.5435	799.6802094	16.4378	3709.604444			1.132	255.4643705		
VIIIIA	253.226322	3.3794	855.7530326	15.2238	3855.066881			2.1655	548.3616003		
VIIIA	327.120165	3.0185	987.4122181	13.4521	4400.453172			2.6248	858.6250091		
VIIA	320.443691	2.6904	862.1217063	12.1725	3900.600829			2.8873	925.217069		
VIA	317.797363	2.5591	813.2752317	10.2039	3242.772512			3.0349	964.483217		
VA	267.322889	2.4608	657.8281653	8.2353	2201.484188			3.0513	815.6823312		
IIIIA	325.225821	2.1655	704.2765154	6.7261	2187.501395			3.0677	997.6952511		
IIIA	312.399046	2.018	630.4212748	4.9871	1557.965282			3.0185	942.9765204		
IIA	327.909421	1.821	597.1230556	3.3466	1097.381668			3.0841	1011.305445		
IA	283.211881	1.8538	525.018185	1.6733	473.8984405			3.1333	887.3877867		
*	475.049021	1.8046	857.2734633	0	0	0	0	3.117	1480.727798		
ID	303.436806	1.8048	547.6427475			1.6733	507.7408075	2.756	836.2718373		
IID	323.865672	1.8133	587.265623			3.4122	1105.094446	3.0513	988.211325		
IIID	348.072606	1.8567	646.2664076			5.0527	1758.706456	3.019	1050.831198		
IIIID	312.696727	1.9358	605.3183241			6.5948	2062.172375	2.8545	892.5928072		
VD	314.470262	2.0998	660.3246561			8.3337	2620.700822	3.1826	1000.833056		
VID	345.765966	2.1819	754.4267612			10.1219	3499.808531	2.7724	958.6015641		
VIID	332.899711	2.3295	775.4898768			11.7132	3899.320895	2.6248	873.7951614		
VIIID	297.917816	2.5264	752.6595703			13.4193	3997.848548	2.7232	811.2897965		
VIIIID	283.170523	2.8709	812.9542545			15.0926	4273.779435	2.7396	775.7739648		
X	246.527779	2.9529	727.9718786			16.8315	4149.432312	2.2639	558.1142389		
XID	224.333108	3.117	699.2462976			18.4392	4136.523045	2.0342	456.3384083		
XIID	187.077099	2.8545	534.0115791			20.1125	3762.588154	1.2304	230.1796626		
XIIID	192.815901	2.8217	544.0686279			21.8187	4206.992299	0.8859	170.8156067		
XIIIID	98.5082525	2.0342	200.3854872			23.5248	2317.386938	0.3609	35.55162833		
Planking Starboard	4996.7234	2.9349	14664.88351			2.1819	10902.35079	4.808	24024.24611		
Port	2002.657	1.8034	3611.591634			2.067	4139.492019			2.1266	4258.850376
Keelson	1023.654651	2.0998	2149.470036			3.4122	3492.9144	0	0		
Keel	1219.862975	1.0499	1280.734137			5.0527	6163.601654	0	0		
Stem	89.042884	2.8545	254.1729124	20.4	1816.474834						
Stem Apron	228.1460197	1.77174	404.2154289	16.405	3742.735453						
Stern Post	22.35270735	1.9686	44.00353969			28.97123	647.5854258	0	0		
Stern Knee	268.5709983	1.57488	422.9670938			22.967	6168.270118				
Riders #75	282.0792204	2.69042	758.911576			3.4122	962.5107157	0	0		
#73	288.2630638	2.82166	813.3803567			6.5948	1901.037253	0	0		
Buttress #178 Port	123.520881	2.59199	320.1648883			5.0527	624.1139554			2.2967	283.6904074
#74 Starboard	107.6450201	2.542775	273.7170659			5.0527	543.8979928	3.281	353.1833108		
Celing Port	1459.871511	2.36864	3457.910057			2.0814	3038.576564			2.0995	3065.000238
Statboard	2381.895662	2.41568	5753.897714			2.1498	5120.599295	2.8642	6822.225556		
Stringer Port	213.6232783	1.995687	426.3252848			2.0156	430.5790797			2.9478	629.7186997
Starboard	854.4931131	4.48537	3832.717347			2.2115	1889.71152	3.9167	3346.793176		
			56083.01593		34754.89225		88323.33584		53897.74077		8237.259722
Total all Weight (#)	22947.43273										
		Vertical C.O.G =	2.44397779		Longitudinal C.O.G. =		2.334398109		Transverse C.O.G =		1.989786029

Figure 10.10. Illustration depicting the density and moments for *La Belle*. Compiled and calculated by P. Fix.

the density of all timber equaled approximately 23,000 pounds (10,443 Kg); 16,000 pounds (7265 Kg) of that total was on the starboard side (Figure 10.10). A study of the sum of density and moments for the entire structure placed the longitudinal center of gravity approximately 2.3344 feet (.7115 m) aft of the midship frame section, 1.9898 feet (.6065 m) to starboard and 2.4439 feet (.7449 m) above the base of the keel.

Design and Development of the Support System

The amount and degradation of the hull remains, coupled with the physical parameters of the exhibition space, dictated the support design. Planning research led us to four examples of creative and elegantly designed support systems that had been integrated into museum displays for four models. In designing the support for *La Belle,* three particular systems were contrasted against the needs of this project; the *Batavia*, the Cog of Bremen, and the Skuldelev ship remains from Roskilde Fjord. The pros and cons of each individual project were taken into consideration during initial stages of planning the *La Belle* conservation project. In reconstructing the timbers from the *Batavia*, an artifact that is now predominately hull plank and stern construction, staff from the Western Australian Maritime Museum created a very effective supporting frame system by affixing the planks to a steel endoskeleton tied into the adjacent wall.[424] When viewed from the port quarter, the artifact towers over the visitor and leaves an indelible impression. At the Deutches Schiffahrtsmuseum in Bremerhaven Germany, the use of the substantial crossbeams and other structural elements present on the artifact to transfer much of the hull weight to the museum's ceiling, a concept inspired by ship models

[424] Goddard 212-244

hanging from church ceilings in Germany[425] prompted the notion of shifting weight off the cog structure by non-traditional methods.[426] Finally, the Skuldelev ships from the Viking Ship Museum at Roskilde, Denmark and craft of similar clinker construction illustrates how it would be possible to utilize construction details along the underside of the plank lap to install a support system.[427] From each of these examples, we acquired a different perspective to integrate into the support system for *La Belle*.

To begin planning for the system and reassembly, several aspects of the reconstruction were assumed as constant.

- The hull in conservation and on display would not have to endure any intense dynamic loading.
- Second, in order to economize as much possible we decided that the cradle used for conservation would also be modified for the final exhibit and although the two environments in which the cradle would be subjected were extremely different, each would be controlled and relatively consistent.
- Third, the shape of the hull, containing significantly more mass on starboard than port, was not closed at both ends and therefore the amount of longitudinal hull curvature was not extreme enough to cause the planks to spring outboard and some tolerance to slightly alter the structure would be available.

[425] Hoffmann
[426] Wolf-Dieter: 170, 172; Hoffman; 131
[427] Olsen and Crumlin-Pedersen: 97

- Finally, the keel, normally the strong back of any floating structure was too fragile to act as the foundation to carry the weight the existing hull.

When a vessel is afloat, compression of the keel is not generally considered a critical issue as the hydrostatic pressure helps to evenly distribute the load created by the vessel's displacement. Unfortunately, the exact opposite condition occurs on land and the weight must be distributed by point loading. Relieving the compression by lifting the upper works off the keel is essential to preservation. Many times this issue has not been accounted for, and keels have been severely deformed by sagging over the top of cribbing blocks (see discussion regarding the Bremen Cog keel blocks in Chapter 9). Exacerbating the problem of point loading concerning *La Belle'*s keel was the extreme erosion on the bottom surface caused by shipworms, which left very few adequate flat spaces to spread the load. Another daunting challenge was how to counteract the outward splay of the large cantilever created by the starboard frames and planking. Unlike the Bremen Cog, the ceiling in the Bullock Texas State History Museum, Austin, Texas is three stories above where the ship would eventually rest, so transferring weight to the ceiling was not a viable choice. Unlike the *Batavia*, there was not going to be an adjacent wall with which to secure *La Belle*'s starboard side. Concepts drawn from these models assessed with a design spiral that lead to the decision to construct a cradle with a combination of high modulus fiber reinforced plastics (FRPs) and thermally cured pultruded fiberglass that integrated the material into the ship's structure as an endoskeleton. The use of a composite endoskeleton comprised of fiberglass and carbon fiber will halt compression on the keel and provide sufficient rigidity for the timbers on both starboard and port. Moreover, the cradle could be designed to be modular and with the FRP sandwiched between the hull planks and futtocks there would be an unobstructed view of *La Belle*'s lines and exterior construction details. When displayed in the museum, either upright plumb and level or any other desired orientation as the endoskeleton provides enough support that the hull only requires a line of five supports placed under the starboard bilge. The design process is also one of balance and compromise. The most significant compromise that resulted from the endoskeleton cradle design was that the interior timbers would be raised by the thickness of the laminates, or approximately a quarter of an inch (6mm), and therefore not affect the overall reconstruction even though it is not an exact reproduction.

To bring all aspects of several hundred friable, fragmented, and waterlogged pieces into a well supported meaningful unit, and balance that with the representation of significance requires a visual aid that helps to maintain symmetry throughout the elaborate decision making process. Design is an iterative process. Through "systems engineering"[428] or "systems thinking"[429] ideas repeatedly require testing and retesting to determine the best material, manner of fit, construction methodology, and systems compatibility. Over the course of the last half-century the field of naval architecture and marine engineering developed a visual aid in the form of a spiral, also known as the ship design spiral or Evan-Buxton-Andrews spiral (Figure 10 1.1.), to assist the complex design process associated with a multifaceted geometric form that is required to be in motion. First introduced by Evans in 1959, the spokes of the spiral delineate imperative

[428] Gillmer 1982:11-12.
[429] Mistree et al 1990:1.

features that must be integrated within the final solution. Conceptual approaches developed off Evans' original model by Buxton (1972) and Andrews (1981) enhanced the product by accounting for the time and costs associated with the synchronization of systems and subsystems. These additions shifted the focus of the model from a purely functional approach to one that was inclusive of theoretical concepts.

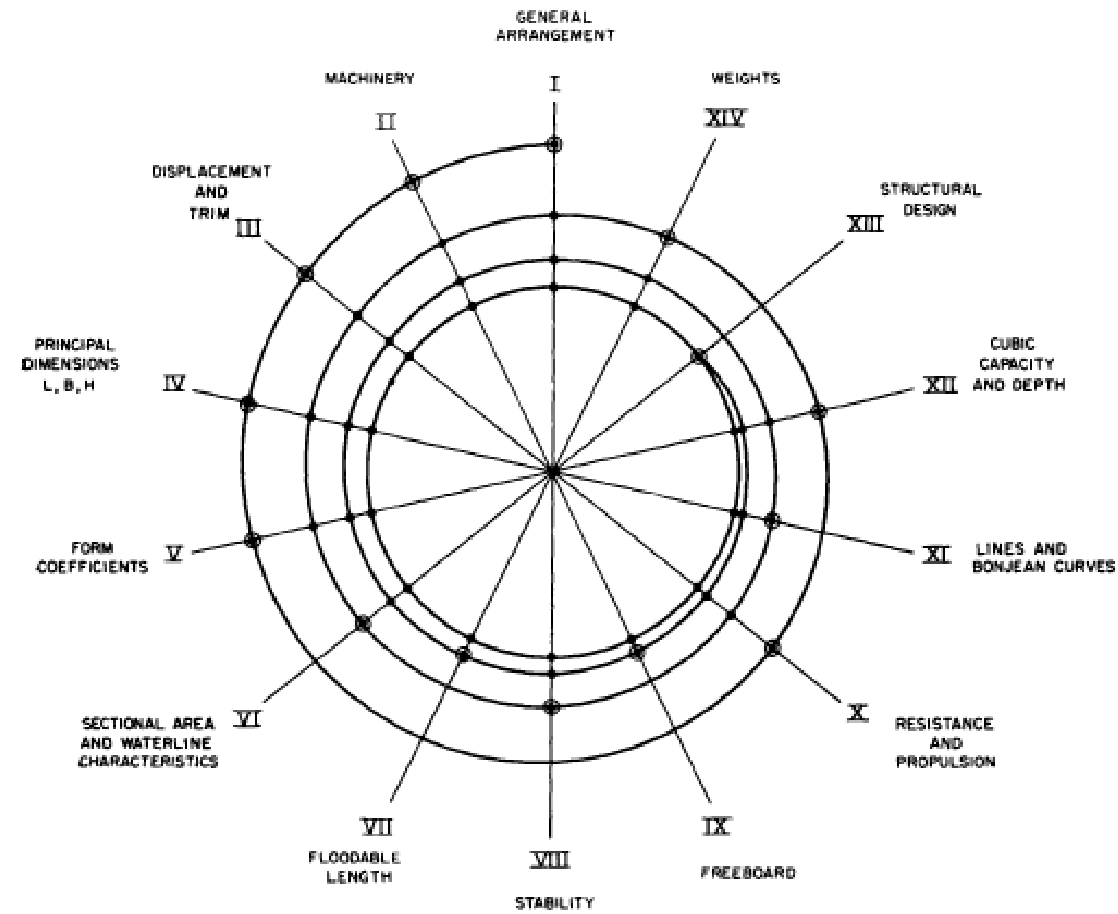

Figure 10.11. The original Evan spiral as published in 1959, which greatly influenced the spiral conceived for *La Belle*. Traced and modified from Mistree et al 1990, 9.

No archaeological reconstruction project can be considered ordinary or the same as another. Since many aspects of the process remain uncertain until work is underway, the spiral developed for the work to be undertaken on *La Belle* concentrated on specific theoretical parameters instead of engineering principles or known construction requirements. These categories included “Flexibility”, “Timber Protection”, “Compression”, “Modularity”, “Accessibility”, “Corrosion Resistance”, “Reuse”, and “Aesthetics”. Throughout the course of the design process, most ideas were run around the spiral to check for suitability.

- **FLEXIBILITY**: Flexible, not in the physical properties of the product, but in the design and construction methodologies. Due to the fact that the inconsistent nature of the material, coupled with the complex geometry of the hull shape there is a high probability that unforeseen challenges would repeatedly arise after reconstruction is underway.
- **TIMBER PROTECTION**: One of the foremost concerns of the project, the development of any system has to be rigid and strong enough to protect against the exertion of excessive point loads that could deform individual components.
- **COMPRESSION**: Similar in theory to timber protection, reaction to compressive forces was sufficiently important to warrant a node in the spiral as the keel, which is never intended to permanently take the full load of the structure, is too degraded to act as the principle longitudinal support for the complete weight of the timber.
- **MODULAR FOAM**: Since the structure was disassembled in the field, reconstruction of the timbers in a manner that allows for future disassembly will provide the greatest amount of safety for long-term preservation and programming.
- **ACCESSIBILITY**: It is important to retain the ability to gain access to portions of the ship during the conservation process of the PEG treatment and to aid in preventative conservation once erected in the museum.
- **CORROSION RESISTANCE**: Since the cradling system will be employed during imbibement of the PEG its construction, material has to resist the effects of immersion in a mildly acid solution and not influence the long-term preservation of the timber or structure.
- **RE-USE:** In order to create an economically efficient system the most desirable outcome is a supporting structure that with only simple alteration can be transferred from the conservation vat to the museum.
- **AESTHETICS**: Construction details, tool marks, furniture and shape are important details to highlight in the exhibit. Equally important is the ability to display the hull

unfettered by elaborate supports thereby allowing the object's massive character to create its sense of place. In order to achieve this effect any support has to be incorporated into the hull and not obscure the visitor's line of sight.

The design process, while repetitious, is not always sequential, and progressing around a spiral in linear succession from node to node has a tendency to skew a decision due to the complexity of the construction and the interrelationship of the various categories and subtopics. In fact, the interrelationship of subjects, woven thoroughly into

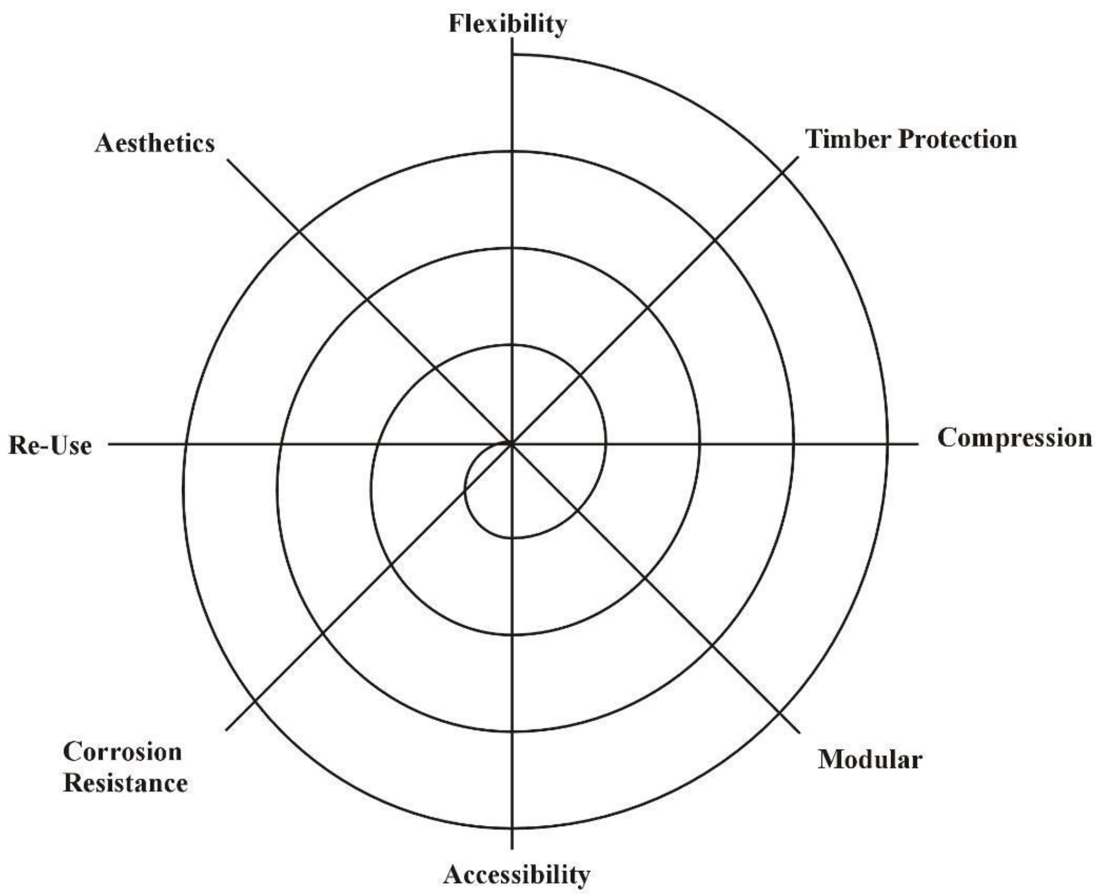

Figure 10.12. The design spiral developed to guide the conservation and reconstruction of *La Belle*. Spiral adapted for archaeological watercraft conservation by P. Fix.

the process, more closely resembles a mesh or web than a linear progression (Figure 10.13). Yet, the compartmentalization of each subject or discipline allows for backward, forward, or side-to-side evaluation of critical concepts. Depending on the questions to be asked, an infinite number of directions can be achieved. Figure 10.12 illustrates several, but not nearly all possible combinations between the various nodes. Later CRL versions of this initial model for other degraded structures included additional nodes, but this one served the Belle project well by helping to incorporate new methodologies into a "living plan".

Composite Endoskeleton Support System

To date, composites have been used sporadically in shipwreck conservation, mainly to document features of the artifact[430] or as interim supports during recovery and conservation.[431] These materials are very well suited for use in reconstruction especially with the further development and decline in price of high modulus materials such as carbon fiber and Kevlar™[432] There are also several companies producing different readymade fiberglass forms, which mimic structural steel shapes including square tube, solid rod, wide flange and "I" beams. These composite materials are strong yet light in comparison to wood or metal, easily fabricated into almost any desired shape, non-corrosive, and possess a considerable resistance to chemical degradation. When completed, the composites can be finished with almost any type of desired surface characteristics and depending on the type of resin system, sealed if needed to reduce

[430] Gregson 1978
[431] Cohen 16-17: Piercy 2000
[432] Lazarus: 1999

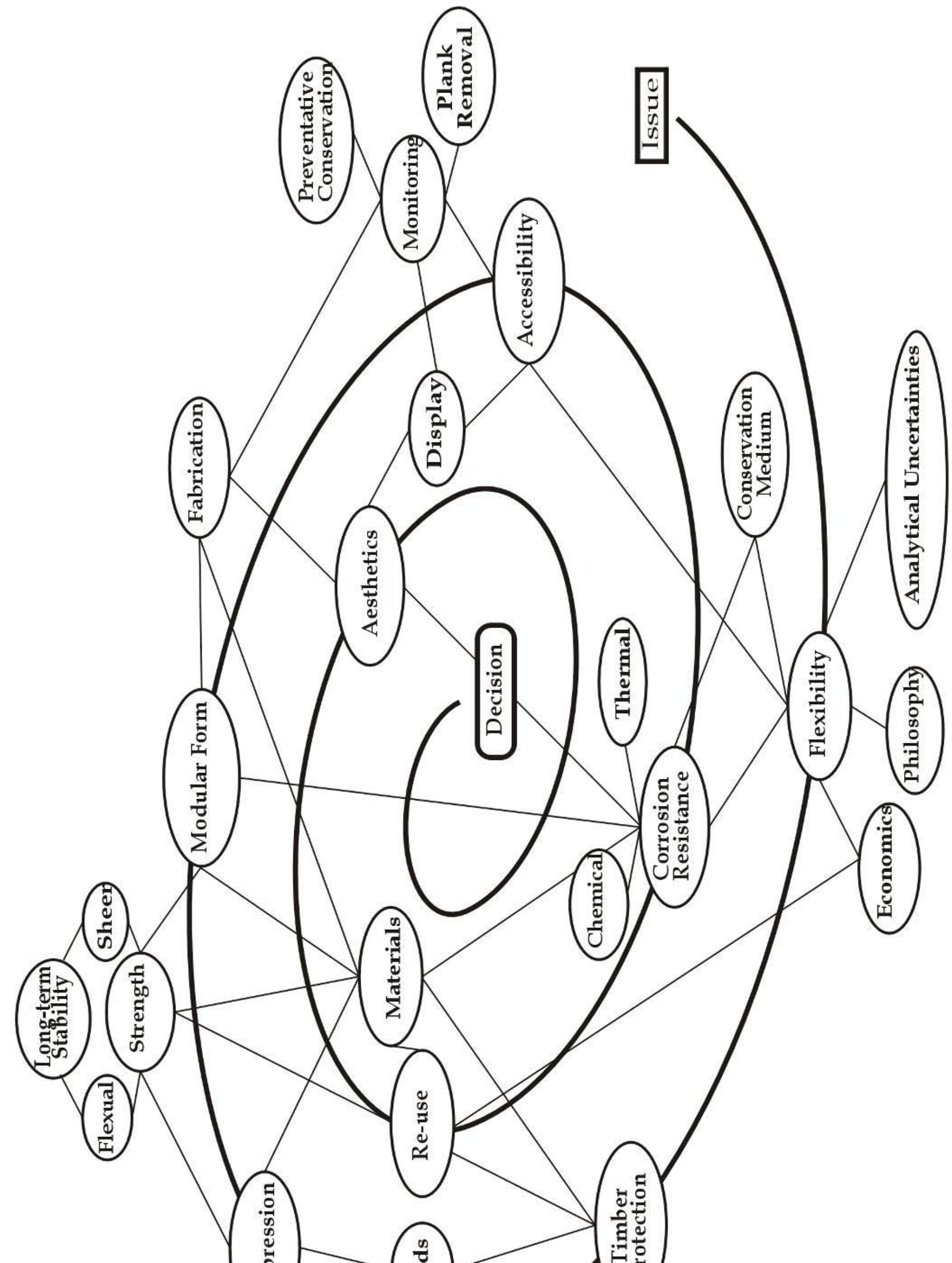

Figure 10.13. The spiral from Figure 10.12. but when shown at an oblique perspective reveals the web of connection points to the primary nodes. Illustration by P. Fix.

VOC (volatile organic compound) emissions that may negatively interact with other artifacts in the museum. We selected a combination of composites to form the cradle for *La Belle* based on the requirements of the hull remains and the noted level of archaeological material degradation.

Conservation Vat, Lift and Pumping System

Of all the previously discussed treatment methods used to conserve large waterlogged artifacts, spraying polyethylene glycol or an emersion best fit the *La Belle* project. Ultimately, the emersion method was initially selected for easier logistics. The vat in which to immerse *La Belle* had to be large enough to manage the size of the hull and allow work to proceed unabated around each side. The overall dimension decided on was 60 feet x 20 feet x 12 feet (18.2m x 6m x 3.7m) where 10 feet (3m) was below grade and two feet (.6m) was above grade (Figure 10.14). Built of steel reinforced cement with one-foot (25.4 cm) thick walls the rating on the vat floor is 3,000 psi (20.68 Mpa).

In order to gain access to the timbers and check on the status of the PEG treatment the vat required the installation of a lifting system. Designed and built by Dynacon, Inc. Bryan Texas, the steel frame platform is controlled by four synchronized winches cantilever from the sides of the vat and is calculated to deflect only one-inch (2.54 cm) over 60 feet (18.2m). This system proved very effective in the reconstruction of the hull. By raising or lowering the platform, the reconstruction team could use the buoyancy created by the water to reduce the weight of the timbers, allowing each to be maneuvered into place by hand with very little effort. This reduced the need for additional lifting equipment. In addition, the ability to lift a ship easily and safely out of the vat, allowed for continued monitoring and documentation while PEG was added to the aqueous solution. A second motive for the lift was to provide occasional public viewing of the timbers during conservation. All too frequently, the public, and in

Figure 10.14. The Conservation Research Lab, ship conservation vat at Texas A&M University. The deck, controlled by four synchro-winches cantilever from the side allows for easy access. Note the gap offset to the right of center (as viewed). The gap delineates the centerline footprint for the boat. Photo courtesy Texas A&M Conservation Research Laboratory and the Texas Historical Commission.

particular potential donors, never really have the opportunity to understand the complexities of the conservation process. Timbers in a PEG vat disappear from view for the time it takes to conserve them or are in an area cordoned off to the public. Our intent has never been to raise the ship constantly from the PEG solution but retain the flexibility should the occasion arise. The decking over the platform is a fiberglass grating manufactured by Fibergrate Composite Structures. A pumping system cycled the water in the vat twice in 24 hours through 10-micron filters; and even though much of the reconstruction took place without a cover constructed over the top of the vat (in order to lower the timber from the storage tanks) of the vat, the pump system continued polishing (removing contaminates as low as 5 microns in size) the water and enhancing underwater visibility over 60 feet (18.2 m).

Cleaning and Documentation

During the dismantling of the hull the field crew removed the majority of encrustation that was coating the timbers.[433] Once moved to the Lab in June 1997, surface encrustation, corroded iron fasteners and the severed treenails were removed between June 1997 and May 1999. A team lead by Peter Hitchcock used many different types of tools ranging from pneumatic air-scribes to nylon wedges and fine brushes in order to loosen and removed the adhering surface contaminates. This process alone was a feat since all the timber surfaces added together equals an estimated 8,000 $ft.^2$ Some of material flaked off quickly; other regions took significantly more effort to remove unwanted debris.

Keel Plate Construction and Pedestal Assembly

The reassembly of the hull began with the keel. One of the earliest discussions during the planning phase concerned how best to present the hull for interpretive purposes, as found listing 68.5° to starboard or upright, plumb and on a level keel. Initially, several factors lead to the decision to reassemble the hull oriented plumb and level. First, is if reassembled on an even keel it would be considerably easier to ensure that the hull was bilaterally balanced, curves were fair, and timbers will not be able to

[433] Carrell 1998.

shift following the listing angle. Second, it would be much easier for us to test different hypotheses regarding the original construction methods. Finally, the change in the attitude of the starboard side to the upright position allowed far better access to the outboard timbers, which enhanced efficiency and facilitated the removal of complete frame sets for laminate casting. Wanting to keep the possibility of future design flexibility in case museum planners someday wanted to lay the hull back to starboard, the design of the cradle incorporated this option with only slight modifications to the future cradle.

Apart from the waterlogged condition of the keel, the cradle had to compensate for the irregularities along the bottom of the keel and alleviate compression from the weight load of the timbers above. The other significant challenge concerning the keel was the significant shipworm erosion. Shipworm riddling of the keel was so extensive in sections of the bow and stern that the lower edge was estimated to have eroded four inches (10.16 cm) above the original bottom surface. The undulating hollows creating the erratic topography along the bottom elevation of the keel required some form of fill to provide a stable, uniform, flat base upon which the keel could rest. A second concern was a crack near frame section “D-8” that either occurred during or prior to removal from the excavation site (Figure 10.15). The damage was not enough to separate the timber completely in two, yet sufficient that when moved under buoyant condition a certain amount of bending occurred and continuous care had to be taken to ensure the timber remained straight. One final point taken under consideration was a slight deformity of the skeg section of the keel. A simple “Z” scarf encompassing frame sets

“A-3” and “A-4” joined the keel and forefoot. Originally constructed with two pieces of oak, the leg of the skeg scarf rode over the top of the forefoot leg. When the bow drooped, the fulcrum was slightly forward of the keel scarf. The aft end of the forefoot exerted an upward force that caused the leading edge of the skeg to curve upward.

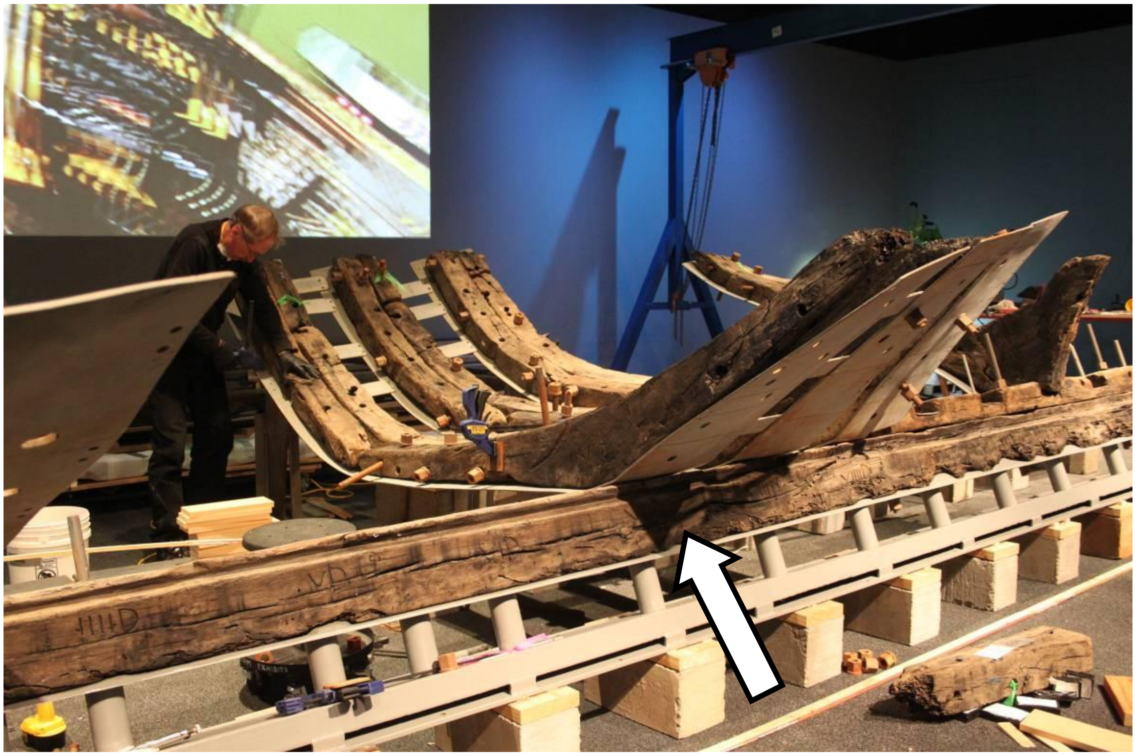

Figure 10.15. Reinstallation of the frame sets on the keel and laminates. In the vicinity framed by the image particular care had to be taken with a diagonal crack in the keel around “D-8.” Location indicated by arrow on image. Photo courtesy Texas A&M Conservation Research Laboratory and the Texas Historical Commission.

Continued ferrous corrosion products permeated the deformity permanently holding it in that form. The slope of the skeg deformation was ½” over 20” (1.27 cm: 50.8 cm). However, this condition had to be managed since a rise in this area would misalign hull and ceiling planks with the floors and futtocks. Fortunately, the curve realigned with only moderately applied pressure.

The first undertaking was to determine the footprint of the hull on the lift platform. With considerably more volume and mass to starboard, the longitudinal centerline needed to shifted two-and-a-half feet (.76 m) to port to compensate for the center of gravity and allow working space to starboard. Along the corrected centerline, we laid a twelve-inch (24.5 cm) wide fifty-eight foot (17.7 m) long iron channel and bolted it to the steel platform to function as a strong-back and moveable base for the longitudinal timbers. In the field, the excavation team had to sever each of the keel bolts in order to dislodge the sandwiched keelson, floor, keel construction. After transport to the CRL, as previously noted, each of the holes was cleared of the corroded fastener, since these same holes would be used to reconstruct the hull. To alleviate the keel compression imposed by the weight of the timbers above, and to orient the floors to the keel, each hole had to accept a one-inch (2.54 cm) fiberglass rod in the original compound angle. During the original construction French carpenters did not drill the fastening holes in the keel plumb. Each is oriented slightly fore-an-aft and side to side creating the compound angle. The design called for transferring the weight of the ship down the centerline, from the keel into twenty-five three-inch (7.62 cm) diameter pultruded, thermal cured, fiberglass rods by inserting the one-inch (2.54 cm) through each frame, its laminate, the keel pultruded fiberglass rods and carbon fiber laminates (Figure 10.16).

A. 1 inch cord fiberglass rod to hold the alignment of the floor.
B. Cut all section of floor.
C. Laminate.
D. Keel.
E. 1 inch fiberglass Rod long enough to extend from a 3 inch deep pocket cut into fiberglass pedestal and extend through to the top of the keel.
F. The molded keel plate.
G. 3 inch diameter fiberglass acts as a base for the structure and eight location to seat one-inch diameter connecting rod (E).
H. 10 inch steel ''C' channel is the

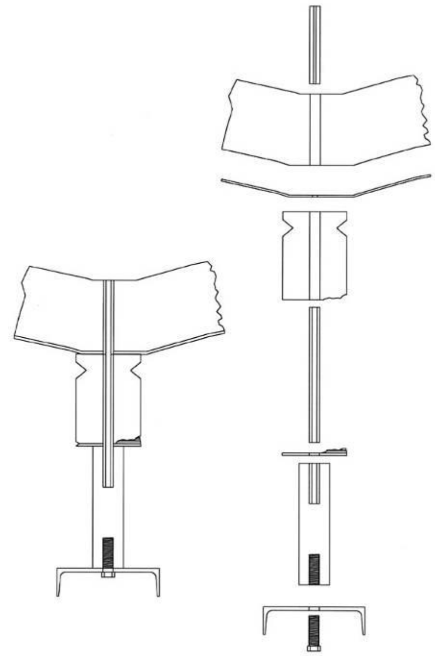

Figure 10.16. A cross-section of the support system down the centerline. Left, all of the components pinned together. Right, the exploded view illustrates the orientation of fiberglass rods and laminate to the timber. (See also Figure 10.15). Drawing by P. Fix.

Unfortunately, no original keel bolt was plumb, level or drilled at the same angle. Each angle ranged from one degree to eight degrees off-center vertically, and up to fourteen degrees off-center along the longitudinal axis. To delineate the compound angle of each keel bolt we laid the keel on its starboard elevation and clamped a string of four-by-four-inch-by eight-foot (10 x 10 cm x 2.438 m) timbers along the bottom of the keel. A ship auger bit was carefully passed though the bolt hole and into the string of 4 x 4s. Once each hole had been drilled and marked the timbers were separated into individual blocks; each was used as a template so a local machine shop could bore a one-and-one-sixteenth inch (2.6988 cm) hole three (7.62 cm) inches deep that acted as a socket to hold the smaller rod. The machinist also drilled a 3-inch (7.62 cm) hole on the opposite end and tapped it with one-in-eight threads to accept a stainless steel bolt that would secure the pedestal to the strong back. Finish work on the pedestals involved sealing all excavated surfaces with marine grade epoxy and the application of two coats of gray epoxy paint. Finally, the pedestals provided anesthetic feature by elevating the entire hull off the strongback.

A plate molded to the irregular undulations along the bottom of the keel was the only way to spread the load generated by the keel and act as a foundation for the rest of the structure. After research and testing on several different materials, we selected an extruded polypropylene honeycomb core fabricated by *Nida-Core®*, Inc. to act as the main component of this element. Honeycomb cores are frequently used in contemporary composite construction to increase the strength and stiffness of a feature without adding a significant amount of weight; however, not as a beam due to the low sheer strength of the core material, 72-psi (.5 Mpa).[434] Since the *Nida-Core®* has very little sheer strength, the application of this material for use on *La Belle* keel plate was not within normal design parameters of the material. The average span between each pedestal however, was only seventeen inches (43 cm) and the estimated load from the keel and deadwood was approximately 8 psi (.05 Mpa). Since the weight of the upper works was transferred to the pedestals, the material was well within the acceptable specifications

[434] Fox 1998.

The dimensions required for the keel plate was six-and-three-eighths-inches by forty-seven-and-a-half-feet (16.193 cm x (14.478 m). Cut from an eight-foot (2.438 m) long sheet each sectional strip received a 45-degree bevel along its length. The bevel allowed the top and bottom plies of reinforcing fabric to bind together without having to bend around a right angle, which could potentially create a hollow or void with little or no epoxy, and weaken the composite. Due to the very flexible nature of the core material, an eighth-inch (.3175 cm) plywood backing was temporarily attached to the bottom to increase rigidity while the topography of the keel was determined. A horizontal "Z" scarf joined each section, with each end slightly tapered to lap the adjacent section. The scarfs were two-inches (4.9 cm) on the face and eight-inches (20.32 cm) along the run and finally connected together with several eighth-inch (.3175 cm) pultruded fiberglass rods inserted at different angles and set in place with low-density epoxy.

To create the underside relief, each eight-foot (2.43 m) section of the core material was approached separately (Figure 10.17). Then, when completed, two adjoining sections were combined, checked for accuracy of fit, and then joined the next pair. When laid directly on the underside of the keel it was easy to observe the numerous voids and extent of erosion especially along the edges and at each end of the keel. The material that would fill the hollows had to integrate well with the core material, resist shrinkage over time to avoid the formation of voids between the reinforcing cloth and the core material, and easy to shape.

The product that met all these criteria was a product called *Matline®*. *Matline®* is actually a filter material made from a non-woven polyester but is used in the modern composites industry as a non-bulking laminate. That is, a material that will readily accept epoxy and increase the thickness of composite construction without adding the same amount of weight as equal thickness of mat-fiberglass or cloth fabric. Our experiments with samples of the product indicated that not only was Matline easy to work with, once wetted-out with epoxy, the shape could readily be adjusted by sanding. Yet, the foam was solid with little anticipated shrinkage due to the permeated epoxy.

Figure 10.17. Image looking at the starboard elevation of the inverted keel, illustrating the creation of the keel plate. The white layers are Mat-line used to recreate the topography of the eroded keel and Nida-Core used as a base. Photo courtesy Conservation Research Laboratory and the Texas Historical Commission.

Pieces of the *Matline*® 200, 2mm thick and *Matline*® 400, 4mm thick, shaped to the contour of the hollow were stacked one on top of the other until the pile reach the bottom surface of the keel. Once satisfied with the outline of the depression we traced each ply of the stack on the lower tier and temporarily tacked them together and to the core material, before returning the pieces to the workshop for impregnation of the foam with epoxy. When applying the epoxy to wet-out the Matline we were careful not to apply too much epoxy to each layer or build the stack too quickly. The composition of the foam rapidly absorbed the liquid resin and in sufficient volume causing the epoxy to harden faster than desired. If the quantity of epoxy to volume of foam was too great, the

Figure 10.18. Peter Hitchcock (left) and Peter Fix (right) sand and grind low-density epoxy filler in order to match the topographical features on the bottom of the keel. Photograph courtesy Conservation Research Laboratory and the Texas Historical Commission.

resulting exothermic reaction produced enough heat to melt thefoam. We learned this detail during initial testing with the material but over loading of epoxy occurred on a couple occasions during the plate construction. These spots had to be recreated or repaired in place as the overheated foam melted, altering the shape of the relief and reducing the strength of the composite. Once the foam hardened, the steps of the relief were filled with a fairing compound made by adding a mixture of fumed silica and

micro-glass bubbles to the epoxy, which altered the density of the epoxy to the constancy of putty or stiff plaster-of Paris. In succession, each area was built up and sanded down repeatedly to obtain the correct shape of the contour (Figure 10.18).

Holes punched in the Nida-Core accepted each of the keel bolts and in several places, Matline had to formed into the area surrounding the keel bolt were ferrous corrosion had enlarged the opening. A PVC (polyvinyl chloride) bushing cut from piping was installed into the plate following the compound angle created by the original keel bolt. When complete the two adjoining plates were fastened together. Then the two plates were fastened to the adjoining two and so on until we had two large plates representing the major run of the keel from the scarf aft and the forefoot. When joined at the final scarf, the plate was 47’6” (14.48 m) long. The aft leg of the keel scarf, which attached to the forefoot was heavily eroded and broken. In order to create one continuous section of the keel plate the forefoot, the timber had to be turned upside down on staging. This allowed for a small shelf to be built that could hold the broken leg while the casting of the undulating bottom continued.

Figure 10.19. Applying vacuum bag technology to create the keel plate. Photo courtesy Conservation Research Laboratory and the Texas Historical Commission.

The next process was to apply the reinforcing fabric. To obtain the best possible result in the composite construction we chose to cure the fiberglass cloth onto keel plate under a vacuum. A continuous table 49 feet (15m) long and one foot (.3048 m) wide was constructed and leveled inside the Conservation Laboratory. On the day of construction, while one team wetted out the bottom plies of the laminate stack with epoxy, the bottom stack included one ply of 9 oz #7781 fabric and two plies of #318 fiberglass roving, another team injected epoxy putty into the scored areas of the *Nida-Core®* to stiffen the construction. The bottom scrim of the core was "buttered" with low density filler added to the epoxy to achieve a similar consistency to butter that enables the mixture to be spread and remain in place), centered and placed on the lower stack. The two upper plies of the composite were of 9-ounce #7725-fiberglass cloth. This bi-directional weave draped over the topography without creating pleats that would significantly alter the strength of the element.

Once completed, the entire composite was sealed inside a plastic film designed for use with vacuums and the air inside evacuated (Figure 10.19). The use of vacuum technology is common in the industries creating FRPs (fiber-reinforced plastics). Pulling a vacuum uniformly clamps the material and raises the neutral axis of the composite, which expels air trapped inside the composite and forces excess epoxy out producing a stronger laminate. Air pressure at sea level is 14.7 pounds per square inch (psi). If in an enclosed environment the air can be removed then the pressure outside the vacuum bag will increase creating a considerable clamping force. Therefore, for every two inches of mercury that can be pulled from the vacuum bag, one pound per square inch of clamping pressure is gained.[435] During the process, we were able to evacuate down to 26 inches of mercury, which equals 327 psi of clamping pressure uniformly spread over the entire composite.

The finish work for the keel plate included repeated sanding, fairing and the repair of a couple of small voids that occurred due to the extreme topography. These areas were ground out and new material added as a patch. Following two coats of epoxy as added sealant, Amercoat 385 was applied as the finish coat. While the epoxy cured

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[435] Anonymous 1999.

and finish work completed, the composite was placed on the strong-back to determine its placement. A taut line was strung from end to end on the channel along the keel plate to

Figure 10.20. The finished keel plate at the bow illustrating the extent that the keel plate needed to rise in order to match the undulating deterioration on the bottom of the keel. Photo courtesy Conservation Research Laboratory and the Texas Historical Commission.

situate the pedestals and drill a hole for the 3-inch long, 1 inch diameter stainless steel bolt that secured the pedestal to the channel (Figure 10.20). When the pedestals were completed and secured the keel plate was installed under the keel and temporary rods were inserted through the keel and into the pedestals to check the accuracy of the keel bolt angle.

Obtaining the Hull Shape

In order to fabricate cast laminates of the frame sets, the floors and futtocks had to be temporarily erected to obtain the fair shape of the hull. We were fortunate that there was no significant deformity associated with the compass timbers and although the broken futtocks were difficult to work with, staff devised interim measures with gussets to reconnect the broken halves. Another factor that made assembly efficient was that the keelson and stringers were all notched over the floors and futtocks so there were ample control points to guide the installation of the timbers and very little tolerance in the structure for misalignment. Owing to this characteristic of the construction, transverse molds of the theoretical hull shape were not fabricated and used as guides in reassembly.

With the keel, deadwood and rising wood in place, the floors were the next timbers placed in the assembly sequence. The information regarding the hull form gleaned by Taras Pevny through his research on the "*sur* marks," allowed us to balance the floors and set them the approximate balanced by and his lines drawing, created by combining and fairing 1:1 timber tracings, indicated that the floors balanced bi-laterally. The floors were first placed in position and the height of each end held in place by a custom-fitting poppet. The first futtock was secured through the original bolt holes that had been cleared of corrosion products with a piece of one inch threaded fiberglass rod, and a second poppet was placed around its centroid. The second futtock attached to the first and the process repeated until the small portion of the third futtock was in place supported by a third poppet.

Due to the sandwiching of the floors between the keel and keelson, the underside of the keelson included a notch in order for the timber to lock down over every floor that it passed. In addition, the clamp on both port and starboard and the three stringers on starboard also notched over the floors and futtocks. Therefore, there was not much tolerance regarding the manner in which the hull timbers would realign and re-create a fair shape. It was our intention from the start to reuse the original fastening hole wherever possible. With the addition of each futtock, a new temporary support inserted underneath maintained the timbers position (Figure 10.21). On starboard, this meant there were three concentric lines of poppets, each at a different angle to the ship. On the

Figure 10.21. Looking aft and across the hull to starboard. The line of rectangular pads marks the location of poppet runs. Between the puppets on starboard the external basket created by rows of buttons is visible with the framesets removed. The hull is being misted with water. Photo courtesy Conservation Research Laboratory and the Texas Historical Commission.

port side, because of the loss of material, only one poppet was required to support the floor and small section of first futtock.

Once the remaining small portions of third futtocks was installed on the starboard side, the reassembly team began to shim each support to hull and ensure that the curvature was fair. When a high level of confidence in the shape of the hull had been reached, the team began to secure all of the poppets, floors and futtocks by first placing battens, which aided in fairing the shape, every 2 feet around the outside elevation of the frame sets. To each batten, a wooden clamp, notched at each end to accept a line that ran from the batten around the futtock and back to the batten. Once secured slight movements occurred in the frame sets position but not significant enough to disrupt the fair curve on the starboard side. With the batten secured in place, molds and braces connected the elements of the basket together and stiffened the whole assemblage.

Development of the Transverse Laminates

To halt compression of the keel transverse members were required to support the weight of the timber from the keel up. We accomplish this by in inserting a 1 inch protruded fiberglass rod through the original keel bolt and into the socket that had been specifically cut to the angle of the passage. This rod stood proud approximately a 16^{th} of an inch above the top elevation of the keel and took the load of the frame sets, removing that weight from the compression equation. The transverse laminates needed to mimic any irregular shape of the frame set’s outboard elevation. In order to achieve this criterion the laminate would need to be strong, thin as possible and be cast directly off the frame.

After considerable testing with coupons made from an assortment of material types and different weaves, we formulated a general layup schedule out of different fabrics. Fabricated at the conservation lab next to where the laminate coupons were being laid up made for a very efficient work scenario. Several formulations could be wetted out and put in a vacuum bag. When the set of coupons had cured sufficiently to allow for cutting and sanding in order to obtain the critical dimensions each was broken and the fracture breaking strength calculated. The machine itself was simple. A bar on a pivot that reached to the coupon holder sitting on a scale at one end, and at the other end a hydraulic jack to apply the required force to the bar (Figure 10.22). The testing pivot worked with a simple formula to determine ultimate breaking stress:

"F = 3 PS/2W x t x t

Where:

F: is the fiber stress in bending at the surface at failure (ultimate stress), in pounds per square inch, or psi;

P: is the load, in pounds, that will read on the scale;

S is the span, in inches, that the specimen is bridging (3 inches, in our case);

W is the specimen width, in inches; and

T is the specimen thickness, in inches."[436]

[436] Marshall 1998,12-10,12-11.

Continued testing of laminates was imperative, as the carbon fiber utilized by the project was an "in-kind" donation from Hexcel Schwebel. The material supplied by the company constituted factory seconds by their standards, as they could not utilize a certain woven product if the pick-count was out by as much as even one pick, or thread, within an inch. Although not within their standards of tolerance, the carbon fiber was more than adequate to create laminate casts to support *La Belle*. The only issue was that

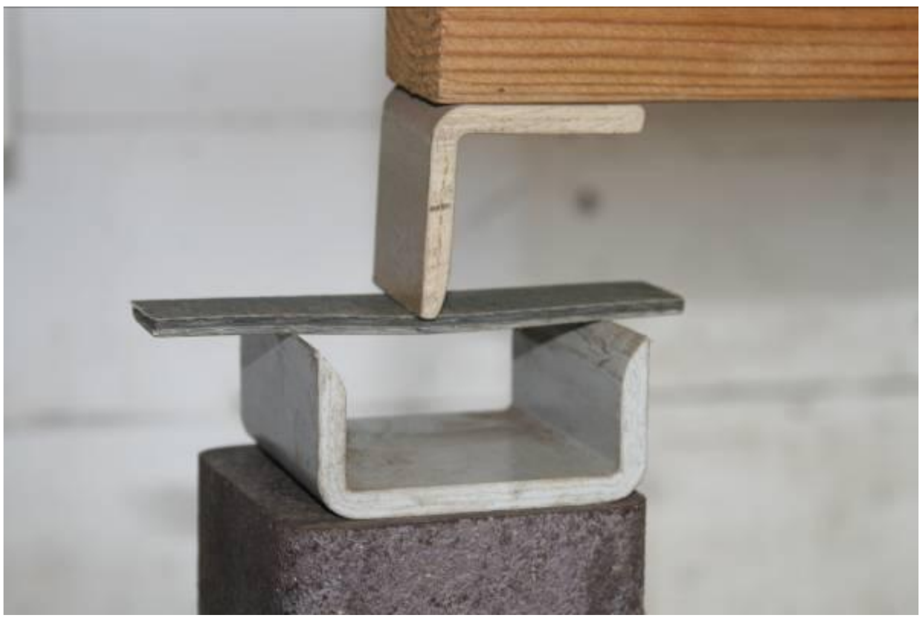

Figure 10.22. Breaking a coupon of carbon fiber and fiberglass composition to test the flexural breaking strength of the laminate stack. Photo courtesy Conservation Research Lab and the Texas Historical Commission.

the company sent what material they had available and we incorporated that into the laminates. This caused some juggling of different thicknesses and weave types in the laminate construction, but by rapidly testing different combinations of cloth in the epoxy, we were able to adjust each laminate to hold roughly the same capabilities and not lose

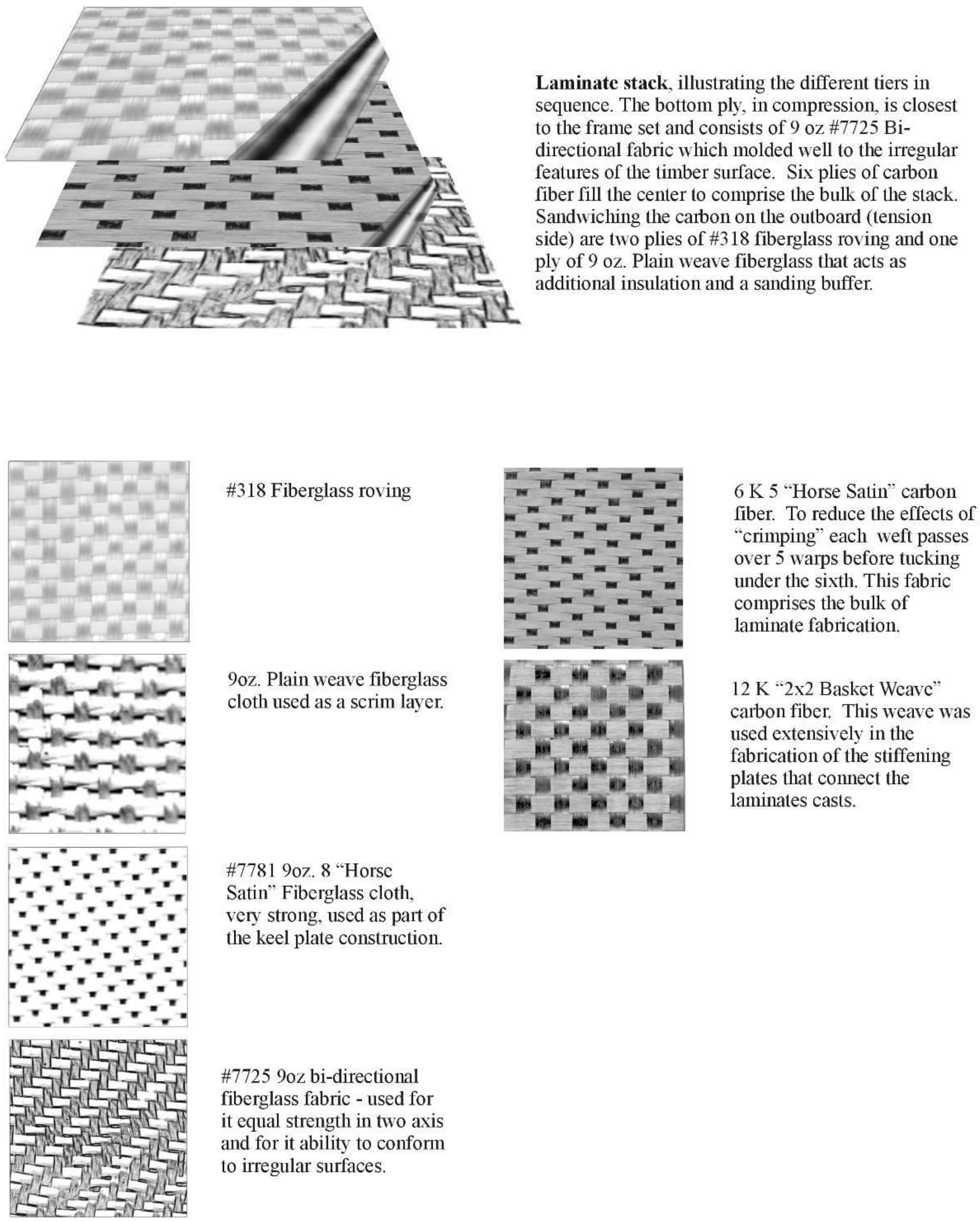

Figure 10.23. Illustration showing the different types of fabric weave in composition. Illustration by P. Fix.

	#7725	6K-5HS	6K-5HS	6K - 5HS	6K - 5HS	6K - 5HS	6K - 5HS	6K - 5HS	6K - 5HS	12K 8HS	12K 2X2	12K 2X2	12K 8HS	#318	#318	6K-5HS	6K - 5HS	#318	#318	#7500
XIIA	A	B	C	D	E	F	G	H	I									J	K	L
XIA	A	B	C	D	E	F	G	H	I									J	K	L
XA	A	B	C	D	E	F	G	H	I									J	K	L
IXA	A	B	C	D	E	F	G	H	I									J	K	L
VIIIA	A	B	C	D	E	F	G	H	I									J	K	L
VIIA	A	B	C	D	E	F	G	H	I									J	K	L
VIA	A	B	C								D	E				F	G	H	I	J
VA	A	B	C								D	E				F	G	H	I	J
IVA	A	B	C	D	E	F					G	H						I	J	K
IIIA	A	B	C								D	E				F	G	H	I	J
IIA	A	B	C								D	E				F	G	H	I	J
IA	A									B	C	D	E					H	I	J
[illegible]	A									B	C	D	E					F	G	H
ID	A									B	C	D	E					H	I	J
IID	A									B	C	D	E					H	I	J
IIID	A									B	C	D	E					F	G	H
IVD	A									B	C	D	E					F	G	H
VD	A									B	C	D	E					H	I	J
VID	A									B	C	D	E	F*	G*			H	I	J
VIID	A									B	C	D	E	F*	G*			H	I	J
VIIID	A									B	C	D	E	F*	G*			H	I	J
IXD	A									B	C	D	E	F*	G*			H	I	J
XD	A	B	C	D	E	F	G	H	I									J	K	L
XID	A	B	C	D	E	F	G	H	I									J	K	L
XIID	A	B	C	D	E	F	G	H	I									J	K	L
XIIID	A	B	C	D	E	F	G	H	I									J	K	L
XIVD	A	B	C	D	E	F	G	H	I									J	K	L
XVD	A	B	C	D	E	F	G	H	I									J	K	L
XVID	A	B	C	D	E	F	G	H	I									J	K	L
XVIID	A	B	C	D	E	F	G	H	I									J	K	L

Figure 10.24. The sequence and type of fiberglass fabric used to construct each laminate.

much time having to experiment. Figures 10.23 and 10.24 illustrate and list the type of materials incorporated into each laminate. The black spaces in the chart represent where fewer layers were employed because the material used in that place was thicker. As mentioned, in the end, the different combination of weaves came close to equaling the same flexural breaking strength and the testing pivot provided flexibility and economy of scale to undertake the large amount required evaluation

To cast the laminates against the outboard elevation of the frame sets posed considerable challenges. First, the frame set would have to be removed from the structure, moved indoors where it would remain for 24 hours without losing shape integrity. In addition, this process would have to be repeated 28 times. The team devised a jig constructed out of pultruded fiberglass structural forms that could be adjusted to the angle and bevel of the frame set and follow the bevel beyond the physical limits of the molded elevations by 3 inches on each side. Once the jig head been constructed, the next task was to determine how to remove safely the frame set and keep it out for the vat for 24 hours. We found that more than adequate hydration could be retained by cocooning the wood in cellophane plastic without significantly altering the shape of the timber to be cast. With the lift dock platform elevated to a height where the base was just above the waterline four people lifted the frame set 6 inches directly intothe air and placed it on padded blocks. This task provided enough room that the cellophane roll could be passed several times around the unit. When completely wrapped the lift dock was lowered to approximately -4 feet and the buoyancy of the water used to move the frame set to the end of the tank where the jig had been previously positioned. Once on the jig, the dock was raised to the top of the vat where a forklift removed the jig and attached frame set (Figure 10.25).

Figure 10.25. Upper left, Hitchcock and Pevny setting the gauge for jig. Upper right, reconstruction team in the process of wrapping the midship frame with cellophane plastic. Lower left, the team using buoyancy to help move the framesets to the jig. Lower right, the midship frame sitting on the jig awaiting the casting sequence. Photo courtesy Conservation Research Laboratory and the Texas Historical Commission.

The general schedule that the team followed involved the two full-time staff and one person part-time. For large tasks such as removing the frame from the integrated unit one or two additional staff were pulled from other projects. On the mornings that the layup occurred, the entire lab staff participated. With 2 ½ dedicated people we could maintain a new laminate casting every other day. One week we would cast three laminates in the next only two. On the off days Teras Pevny and Peter Hitchcock would set the jig, and Peter Fix would cut all of the carbon fiber and fiberglass need for that laminate stack.

To expedite setting the jig Pevny and Hitchcock created a large gauge that extended across the width of the ship and could be easily adjusted to form any curvature. When set, the gauge was taken to the jig and the shape sent accordingly. Once the base jig held in the correct form, the team would enter the water and wrap cellophane around the timber and move it to the jig were would remain immersed overnight. The following morning the jig and frame set was removed from the vat by a forklift and taken indoors. The side wings that extended the laminate beyond size of the frame set (in order to secure the laminates together each cast have to be approximately 2 inches wider than its accompanying frame set) were installed as well as half of the vacuum bag (Figure 10.26). To the top of the vacuum bag 1 inch circular disks of thin cardboard were glued over the original empty fastening holes to designate where future perforations would need to be made in the laminate in order to pass new fastenings. All lab staff would assemble and for the next two hours anywhere between 9 and 12 plies of fabric and epoxy would be laid down. When all layers were set mastic was laid along the edge,the top portion of the vacuum bag applied and a vacuum pulled. Almost instantly, compression of the stack caused the epoxy to begin to cure and the vacuum left running until sufficient enough

Figure 10.26. Upper left, the jig with frame set in the process of vacuum bagging the stack. Upper right, the manner in which wings were attached along the side of the framesets in order to create an edge that extended beyond the actual frame. Lower and right, conservation research lab staff and guest work epoxy into the laminate stack the casting sequence. Photo courtesy Conservation Research Laboratory and the Texas Historical Commission.

ime had passed that the initial cure had taken place. The vacuum pump ran for approximately 10 hours until assured that the epoxy had passed the chill stage of cure. Left overnight, in the morning, the laminate would be removed from the top of the frame and the frame returned to the conservation vat where the process would begin all over.

Once all laminates for the 28 frame sets were cast, the next phase of the project was to "finish" the laminates. All of the edges had to be trimmed, flat surface sanded and irregular topography filled with fairing compound. While Fix finished the general surfaces in edges, Hitchcock and Pevny drilled holes in the laminates that followed the hull plank-fastening pattern. After these two tasks were complete, each laminate was sealed with two coats of epoxy resin for added waterproofing and protection against creep, followed by two coats Amercoat 385 two-part urethane paint.

Using tracings made by laying clean plastic on the interior of the hull planks in the field in order to record the plank lines and fastening holes, each hole in the laminate was checked for accuracy and the data was transferred with indelible marker to the outboard elevation of the laminates. Reinstallation of the laminates and frame sets was very quick in fact less than a business week.

The final challenge was to determine the best manner in which to securely hang the planks. Because the hull was designed to be modular and disassembled for its final journey to the museum, the re-fastening of planks could not be permanent. The solution was to create an expansion bolt from a neoprene tube, fiberglass all thread structural forms (Figure 10.27). By removing the nut plate and rubber pad, fiberglass all thread and neoprene tube could be gently tapped into the fastening hole. After replacing the rubber pad and the square fiberglass plate a washer and not was threaded on the all thread and tightened, which compressed the neoprene. The pressure on the neoprene caused the tube to expand inside the hole along its entire length. The minimal amount of friction created was sufficient to hold each of the planks in place. Between the laminates and the expansion bolts, a team of three people were able to reinstall all the ceiling and hull planks in approximately 7 weeks.

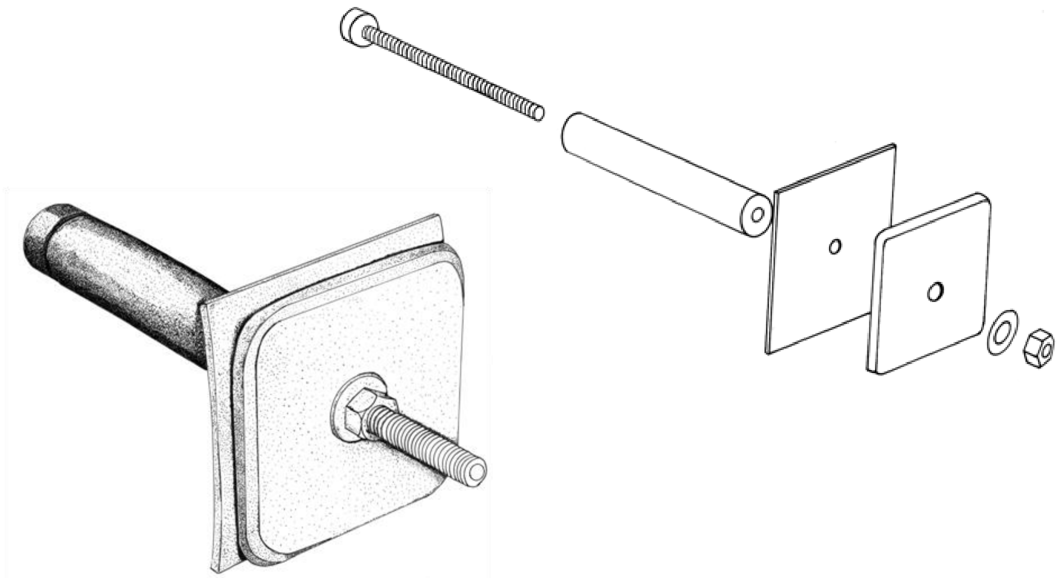

Figure 10.27. Illustration of the expansion bolt developed to temporarily hang the hull and ceiling plank. Illustration by P. Fix.

With the structure up right plum and level, the attention of the conservation staff turned to stabilization of the waterlogged archaeological material. Any component of the ship not strong enough to be incorporated into the hull was secured to racks or placed in stackable trays. The pumping system within the vat was modified to manage the higher viscosities that will be encountered with using PEG and a cover over the entire vat to reduce the amount of sunlight hitting the solution, controlled evaporation and reduce the amount of contaminants entering the system

Conservation with PEG, the Two-Step Method

In late winter 2004, CRL staff mixed the first increment of PEG 200, approximately 3,700 gallons (~14,000 L), into an aqueous solution in *La Belle* vat to make a 5% solution. Since the reconstruction grouped all of the timbers into one unit, conservation strategies had to take into account extreme ranges in the level of preservation between individual timbers. Both Umax analysis along with surface pin testing indicated that some places on the inner core of the timber were not significantly degraded. For that reason, we selected PEG 200 instead of the more widely used PEG 400. The strategy at that time was to take the low molecular weight PEG-200 bath from 5% to approximately 40% by weight. Once we obtained that goal, the second bath of PEG-3350 was planned to reach saturation point of the timbers estimated to be an aqueous solution somewhere between 70 and 80% PEG-3350. Penetration was slow but by mid-2007, the concentration reached close to 32% (on the way to 40%). The timber was slowly taking in the PEG and throughout the process, there were no obvious signs of distortion observed throughout the structure or disarticulated fragments timbers.

Shifting Plans, or Flexibility is the Name of the Conservation Game

During the initial project-planning period in 1998, the Lab Director arranged with a nationally known chemical company a pledge to donate all the PEG required to conserve la *Belle*'s hull. The understanding at that time was that when additions of chemistry would be needed, the company would supply their product. By 2001/2002, following cleaning, post excavation documentation of the timbers, and reconstruction of the hull in advance of the PEG immersion, the company was no longer in a financial position to support the project as planned. CRL staff proposed alternative strategies for timber stabilization that would require far less product, but the majority of members of a worldwide peer review group organized by the Texas Historical Commission adamantly opposed the plan, and recommended instead to move forward with the safest course of action - the standard “two-step” treatment with PEG for saturation of the wood with PEG.

After a lengthy renegotiation in late 2003, officials of the company stated they would sell the PEG-200 and PEG-3350 at cost - \$.35 and \$.50 respectively. Both PEG products would be shipped as a liquid, the PEG-200 in pure form and PEG-3350 is a 70% aqueous solution, because the local Texas plant did not normally produce PEG-3350. When the project reached the second stage, the company was going to turn over production at the plant and produce a complete run of PEG-3350 in the required amount. After the second purchase of PEG-200, the company informed the Conservation Research Lab that it could no longer sustain their promise of providing the product at the production cost. As a result, acquisition has been managed in a very tight market that has driven the price ever higher. The first budget was zero. Then, \$120,000.00 had been budgeted for PEG-200. By 2008, approximately \$170,000.00 had been spent to reach 80 % of the goal. Also by 2008, the per-unit price of PEG 3350 had ranged upward to 4.5 times the “at cost” price of \$.50. Savings could be achieved by ordering in bulk; however that would require a sizable immediate outlay in chemical product and the prompt need for additional storage capacity, (the complete supply of PEG-3350 required to achieve a minimum 70% solution would be over 12,000, 50-pound bags). With no end in sight to the rise petroleum products, the cost of purchasing the PEG 3350, the second bath, based on an average of received price quotations, would have required $1,680,000.

CRL Staff worked feverishly to aid the Texas Historical Commission in developing an alternative plan. The original *La Belle* spiral and failure trees were repeatedly used to test ideas and suggestions for suitability. In spring of 2009, four different scenarios were presented to a small peer review group assembled by members of the THC.

Option #1

CONTINUE WITH THE IMPREGNATION OF PEG VIA TWO-STEP METHOD. NO CHANGE IN CURRENT PLAN.

Option #2

CONTINUE WITH TWO-STEP METHOD, BUT ENGINEER A NEW SHELTER THAT CAN SUPPORT DISPLACEMENT MATERIALS OVER AND AROUND THE HULL.

Option #3

REDUCE THE CURRENT PEG-200 PERCENTAGE. CREATE A SECOND REDUCED PERCENTAGE BATH OF PEG-3350. CONVERT THE VAT TO A LARGE FREEZER AND INDUCE SUBLIMATION UNDER AMBIENT CONDITIONS.

Option #4

REDUCE THE CURRENT PEG-200 PERCENTAGE. DISASSEMBLE THE HULL AND PLACE PIECES (MOLDED TO HOLD THE CORRECT HULL SHAPE) INTO A LARGE VACUUM FREEZE-DRIER FOR SUBLIMATION."[437]

After lengthy discussions, the unanimous opinion of the assembled group was that either Option #1 or Option #4 would offer acceptable results to the situation, but Option #4 (PEG reduction, hull disassembly and vacuum freeze-drying on molds) would be preferable. Consultation with French colleagues at A.R.C. Nucléart, Grenoble France solidified the selection of Option #4. Comparing the costs of Option #1 and #4 the estimated projected savings was in the $1.1 million, and approximately $800,000 of that figure was the cost of over 550,000 pounds of PEG-3350. The widely accepted belief was that, the benefits would extend beyond cost savings in that the new procedure would be more in line with standard practice, produce a much less dense material and more aesthetically pleasing.

Challenges Associated with Freeze-Drying an Integrated Structure

With the acceptance of the plans, suddenly there was a lot of work to do and very little time to accomplish it in order to keep up with the plan schedule for installation in the museum. The percentage of PEG-200 had to be reduced below a 5% aqueous solution, specifications for a custom-built freeze dryer to develop, the ship to disassemble, and once in smaller vats chelation of ferrous compounds and impregnation with PEG-3350. The timber scantlings from *La Belle* were within a sufficient dimension

[437] Fix and Hamilton 2009.

to freeze dry and most were moderately to heavily degraded. The chief concern was how to manage the change in ductility of freeze-dried archaeological timber versus timber saturated with PEG. In many locations along the plank runs (both hull and ceiling), the timbers not only followed the curvature of the hull but also twisted along the molded dimension. If the shape of the planks exiting the freeze dryer were not closely aligned to the faired shape of the hull, there was a strong possibly realignment with the futtocks and floors would not occur. By 2008, we had the good fortune to be able to draw on several case studies for examples of freeze-drying watercraft constructed from component parts. The design spiral again proved invaluable that working to reduce the risk and ensure that every aspect of freeze-drying the ship timbers would be contemplated. Working our way around the spiral, we decided that due to the scantlings of the timbers every attempt would be made to mold the correct shape before the planks entered the freeze-drying product chamber and only use a jig if significant distortions emerged that could hinder the reconstruction.

PEG Reduction

The first steps in altering the conservation regime was to immediately begin lowering the percentage of PEG-200 in the large reconstruction vat and enhance the lab facilities in order to manage disassembly of the ship. Since the level of PEG-200 in the solution reached 32% at its highest point, we decided to reduce the amount of PEG solution in 5% increments. This would create gradient between the PEG 200 already absorbed into the wood and the solution in the vat, which would constantly keep pressure on the flow of PEG 200 out of the wood. 11 months were required to reduce the amount of PEG 200 in the timber down to approximately 3-5%, and once that level was achieved the timbers remained in stasis for an additional two months to acclimate to reach new equilibrium levels.

Hull Disassembly

Hull disassembly actually began with three-dimensional digital documentation of the reconstructed hull shape, and in particular, the shape and location the ceiling plank (Figure 10.28). Comparisons made between the reconstructed lines drawings in the actual reconstructed shape were very close demonstrating both that the hybrid laminate castings were the correct shape and also were supporting the reassembled ship in the plum and level orientation with little deflection. The ceiling planks however, had their own twists and curves that would need to be mimicked on molds in the freeze dryer. Due to differences in the scantlings of timbers from the reconstructed lines we could not simply subtract timber and laminate thicknesses and be confident with the shape. A complete three-dimensional scan of the structure was undertaken by Center for Heritage Conservation at Texas A&M University, but it was difficult to slice and pull the correct angle and bevel data from compiled scan. Instead the team decided to set up a total station and pull three dimensional points from along the ceiling plank runs. Plank by plank selecting only the points that were specifically needed the team quickly gained the basic shape of the ceiling timbers and the interior “bowl” shape of the structure.

Figure 10.28. Using a total station to pick point the ceiling runs of *La Belle* before disassembly. Photograph courtesy Conservation Research Laboratory

Figure 10.29. CRL graduate student staff make final adjustments in preparation for raising the keel skeg and completing the disassembly process. Photograph courtesy Conservation Research Laboratory.

The hull planking on starboard were the first timbers to be removed during the disassembly. Working first down from the upper works until reaching the line of puppets under the bilge and then starting from the garboard plank and working outboard toward the bilge, the team numbering between four and seven people removed, re-cleaned, inventoried in stored the timbers in new vats awaiting chelation and PEG-3350 impregnation. Once complete with starboard, the team moved to the port planking and removed it working outboard in. With the aid of gravity, all of the hull planks fell away from the structure with ease.

Ensured that the data concerning the twists, curves and locations of the ceiling plank runs was acceptable the ceiling planking and stringers were removed from the structure in similar fashion to the planking. Working outboard on port towards the center line the planks did not release from the neoprene sleeves as easily as the whole planking and a sawz-all was required in many locations to cut the fiberglass all-thread fastener and release the neoprene sleeve. Once at the centerline, the three sections of the keelson were lifted with aid of a gantry and spreader bar, and then the rest of the starboard ceiling was removed working centerline outboard. The final timbers to be removed were the futtocks and floors followed by the deadwood, forefoot and keel skeg (Figure 10.29).

Chelation

Since the hull was disassembled and placed in smaller vats for PEG 3350 pretreatment, one of the added benefits with the structure again in component parts was that chelation of the impregnated iron corrosion product could occur. During the initial conservation and reassembly planning in the late 1990s, CRL staff were aware of the negative effects of pyrite, sulfur and acid hydrolysis,[438] but some of the planking had degraded to such an extent that impregnated ferrous corrosion product and encrustation filled the soft matrix creating a material that could best be described as fiber-reinforced concrete or petrified wood. Since there was a strong concern that removing the density would inhibit the ability of the component to work within integrated structure we made a decision to forgo chelation at that point. Upon completion of the PEG saturation, process ammonia gas could be used to convert any remaining iron corrosion to a more stable state.[439] The CRL staff, like many other conservators at that time did not fully appreciate the problems associated with iron impregnation in the wood. The intensive investigation following precipitation of iron salts from the *Vasa*[440] altered our opinion and following reduction of the PEG-200 and disassembly the timbers from *La Belle* received two aqueous baths of 2% ammonium citrate over an eight-month period to chelate the iron. When satisfied with the reduction in ferrous species the timbers were rinsed and soaked in several baths of rainwater and reverse osmosis water. We were then ready to treat the wood in a larger molecular weight PEG 3350, the more heavily degraded surfaces and had some additional material to the interior matrix where possible for additional mechanical strength.

PEG-3350 Impregnation

In order to maintain consistent osmotic pressures with what remained of the PEG-200, the percentage (wt/wt) of the starting PEG-3350 solution was 15% and additional

[438] Jespersen 1989; MacLeod and Kenna. 1991.
[439] MacLeod 1990.
[440] Sandström et al. 2003.

5% (wt/wt) increments were made based on dehydration of the water content. Over the next 18-23 months the PEG-3350 in solution finally reached its intended target of 40% (wt/wt).

Freeze-Drying Component Parts

The first timbers treated in the freeze dryer were small thin elements and fragments of the planking and selected these pieces for two reasons. First, because they were not as thick, they reached the required impregnation of PEG-3350 faster than the larger denser timber. Second, is that although CRL staff had run several test batches in the product chamber before attempting to work with *La Belle* timber critical to the reconstructed shape, there was concern that all the engineering irregularities had not yet been worked out of the system. With exhibit deadlines looming however, additional time could not be created and therefore the staff determined it would be best to use the planking fragments since they would have to be reassembled, pieced and glued back together. If anything did go wrong with the freeze-drying process, these pieces would be the easiest to aesthetically manage, repair, and inhibit the reconstructed shape.

Once comfortable with operating the new, computer-controlled freeze dryer, understanding the software and the particular drying characteristics or patterns within the product chamber, batches of larger timbers began to be sublimated. In all, the timbers from *La Belle* required five product loads in the freeze dryer (Figure 10.30). Each load, as best as possible, was homogenous to the type of material (i.e. planks in one batch,

Figure 10.30. CRL staff loading the keel and its base onto the freeze-drying rack system. In order to ensure that the irregular surface on the underside of the keel remained consistent during the drying process the fiberglass plate was left attached to the timber. Photograph courtesy Conservation Research Laboratory and the Texas Historical Commission.

frames and futtocks in another) in order to keep a schedule based on the largest pieces in that batch. The entire cycle of loading, sublimating, unloading, cleaning and maintenance of the unit ranged anywhere from 3-3/4 to 6 months. The size, shape and level of preservation for the frames and futtocks required little in the way of molds or preventive apparatus to deter movement during sublimation. Those planks that required molding were placed on plywood stretchers to establish a stable base that could be shimmed and leveled on the product chamber racks. The curvature or twist required by each plank was created by forming molds out of Styrofoam sheets build up into the unit holding the correct height and then carve to shape the required angle or bevel.

After the primary stage of freeze-drying that sublimated the water from the wood, a secondary stage slowly brought the timber under vacuum to ambient temperatures in order to acclimate the material before removal from the product chamber. Comparisons of timber dimensions made following lyophilization and initial 1:1 drawings indicate that shrinkage for over 95 % of the timbers evaluated was less than 2%. When the floors and futtocks were compared against the previously created carbon fiber laminates fastening holes once again realigned each component to one another. When removed from the molds and supports the shape of the plank also held the desired shape and orientation. Very little significant cross grain checking has been observed on any of the timbers that could be associated with the freeze-drying process. There were however, some inexplicable areas of timber shrinkage and collapse, but do not affect the overall integrated structure. In particular, the aft end of the keel shrank longitudinally approximately ¾ of an inch over the last foot the timber. Also, close observations of some of the interior sided elevations of the futtocks showed slight cellular collapse that developed minor hollowing of the top elevation. Although pieces are friable, as is the case with most freeze dry material, repairs can be easily undertaken to reattach fragments.

Figure 10.31. The reconstruction of *La Belle* at the Bullock Texas State History Museum. Photograph courtesy Conservation Research Lab. and the Texas Historical Commission.

Following acclamation during the secondary stage of the freeze-drying the timbers were removed from the product chamber and received an initial cleaning of any residual PEG remain on the timber surface. They were recorded, packaged in foam sheets and plastic, and stored for shipment to the museum approximately 100 miles from the conservation lab. Upon arrival at the museum the keel plate assembly, keel and forefoot were quickly mounted and set forth the opening of the living exhibit that features the reconstruction of *La Belle* over an seven-month period (Figure 10.31).

CHAPTER XI

CONCLUSION: PAST REALITIES AND NEW POSSIBILITIES

When humans form a relationship with an object, exhibit and promote its meaning through iconography and symbolism, they automatically imbue the object with some form of value. The greater the value, the more pleasure derived from the object, which is analogous to the "pleasure" described by Kortum (Chapter 2.). Of course, any value assigned to cultural or patrimonial objects, just as with artifact biographies and semiotics, is culture based and dependent upon the individual or collective for interpretation. The creators of historic monuments did not invent or build structures in order for the contemporary culture to assign value and significance as a memorial. That is a continual process for each subsequent generation to uphold or discard. Over time, due to changing generational perceptions, the value of certain objects often declines. With over eight to nine millennia of use, and with the retention of that relationship even as the practical use of the object continues to decline, it is obvious, watercraft have not lost their value. They have assumed new value, that of the preserved monument.

The act of saving is a symbolic act proclaiming to all "we were first!" "We did this too!" "We were there!" Through the projection of our image, we declare to all who visit the place where we choose to erect and display these monuments, who we are, who we think we are, or who we want to be. An analysis of what we save supports the statement. Humans forged a relationship with the watercraft millennia ago and nurtured that linkage by forming its representation into iconography and symbols involving some of the most poignant aspects of human belief systems–life and death. During that time, within the maritime landscape, specific cultures formed around and depended on its use, while others employed watercraft to help build countries and national identities. Similarly, as with the many meanings and representations of a particular object, or class of objects, one object can encapsulate a host of values all of which overlay one another according to a particular significance, creating layers of intertwined stratification. Whether we are drawn to watercraft because they have an innate soul as argued by Igor Medelev-Mead (p. 24), or the connection is due to emblematic representation of a phallus, weapon or coffin as argued by Joe Flatman (p. 24), strong linkages to watercraft persist and the desire to save vestiges of the connection are ever present and will continue.

When discovered as part of archaeological survey or during excavations of a civil works project, all of the factors that imbued the artifact with value and form its biography frequently come together and create a driving force that when coupled with the euphoria of finding "hidden treasure" prompt many to want to rescue the artifact for conservation and curation. It is difficult to say how many ships and boats were lost in the years prior to the 1950s and 1960s when cultural laws around the world began to take effect, public perception began to change and modern museum and conservation practices enhanced the longevity of artifacts. Destroyed craft such as the Bruges vessel in Belgium relayed by Marsden (p.59), the watercraft remains recently discovered under the 1967 foundations of the World Trade Center that had been cut in two by a retaining wall, or a percentage of the estimated 500 craft pulled from Swiss lakes during the 19th and early 20-centuries and recorded by Ramseyer and Vonlanthen (p. 199), indicate that the volume of loss has been high. Since cultural laws were enacted, the number of saved watercraft has been steadily on the rise even though many authorities are aware of the high costs involved with stabilization and curation. Even if other acceptable methods, such as *in situ* reburial are available, very often there is strong interest in stabilization for future display. Ultimately, one of the very premises of these laws, the initiative to slow the process and consider the consequences of mitigation is the reason for the tremendous growth. After its unveiling from years out of sight, during the slight pause while authorities determine how best to manage the cultural or historic property, there is ample time for stakeholders, both public and private, to motivate, assemble and develop momentum to save the item. It is doubtful that the laws will revised and therefore the archaeological and conservation communities should anticipate a steady or growing number of excavated find in the years to come.

Although what may be considered the first scientifically conducted waterlogged archaeological wood preservation project occurred in the 1860s, it was not until the 1950s and 1960s that the conservation community had enough collected data to begin applying that knowledge to enhance processes and achieve satisfactory results. In relation to archaeological watercraft preservation, the insights developed in data collected from hundreds of projects especially the *Vasa*, *Mary Rose*, Cog of Bremen and the Skuldelev ships, are now being reprocessed, reassessed and creative solutions incorporated into a new generation of ship conservation projects. Over the last 50 to 60 years, the community of conservators charged with the stabilization has greatly increased their knowledge and ability to handle watercraft conservation projects.

A direct result of the complex nature of watercraft construction, coupled with variables in original material selected for the hull, the manner of substrate degradation, and desires concerning re-presentation, no two archaeological watercraft conservation projects can ever be exactly the same. In undertaking the conservation of the timbers from *La Belle* and seeing the project through to the reassembly in the museum space where is will remain for at least the next 90 years, the staff of the Conservation Research Lab relied heavily on work conducted in the previous decades. In return, the conservation of *La Belle* will provide methodology that hopefully will be absorbed by the conservation community in future projects. The four primary additions to the corpus of data include:

1. The application of high modulus laminates and structural shapes for endoskeletal support.
2. The use of vacuum freeze-drying for moderately thick timbers and a preliminary methodology for successfully holding complex curves of timber during sublimation.
3. The adaptation of design aids and processes found in marine engineering to the stabilization of waterlogged archaeological marine structure.
4. Planning for and taking the reassembly of the timbers to the public.

These four aspects of the *La Belle* project all demonstrated a high level of success.

The hybrid carbon fiber/fiberglass laminate in a epoxy matrix and the use of pultruded glass/resin structural shapes provided the ability to successfully re-present structure as a meaningful unit that is uniformly supported and has the ability to be exhibited with an unobstructed view of the timbers. The non-homogenous level of preservation of the timbers is no longer a factor because each of the major structural timbers has unifying support. The viseo-elastic qualities of the wood will not be a factor in the future as holding strength of the laminate stacks are far greater than the load placed upon them. Freeze-drying compound, medium sized timber on molds was proven to work prior to the conservation of *La Belle*, however the methodology demonstrates that the hull must be rebuilt first (in the wet state) or on a computer in order to obtain the actual, not theoretical shape. Only on standardized drawings do all timbers run plumb and level. Many of *La Belle*'s frames sets sag and twist, yet they faired perfectly. Had we not had the benefit of seeing the actual shape before re-lifting the lines and creating molds for freeze-drying, we may have not achieved such a high level of success. As it stands, timbers still align plank and frame with only a small discrepancy in a scattering of fastening holes.

The adaptation of design aids was a great cost savings to the project that provided flexibility to the work and the final re-presentation. The modified Andrew's design spiral has already been employed with success on the Doel Kogge conservation project. The State of Texas decided that the *La Belle* would be a "world-class" museum display and spared little expense for exhibit planning and construction. The conservation approach easily fit within their vision and the result will be a dynamic museum re-presentations.

That display is over a year away from the time of writing this conclusion, but the "living" reassembly has been an overwhelming success!

There are aspects of each of these four topics that would benefit from further investigation, application and adaptation of developed methodologies.

1. Digital scanning of the timbers and the practical ability to build the hull piece-by-piece on a computer would have expedited the treatment regime and reduced the amount of handling of the timber throughout the process.
    a. The fabrication of the 28 hybrid laminates required wrapping each assembled frame set in a thin cocoon of plastic wrap, transferring it to a pre-set jig, moving the jig and frame indoors and casting the laminate. At best, the CRL staff could hold to a schedule of two laminate casts one week and one cast the next. If a mold could be cut from the computer reconstruction on a C&C router first, the time needed to shape and secure the timber entering the freeze dryer could theortically be reduced by two-thirds.
    b. Within reasonable costs, and depending on the size of the structure, if would be possible to recreate all the timbers in another medium (Styrofoam perhaps) to practice the reconstruction without the potential of causing damage to the fragile timbers.
    c. Determining the shape of molds for the timber was very labor intensive. The shape had to be lofted off scaled drawings and then foam blocks had to be carved or stacked to hold the timber in the correct shape during

freeze-drying. Similarly to using a C&C router for making large molds that mimic the complete frame sets, the molds required line could to shape the timbers during freeze-drying could be established on a computer and then cut on a C&C router, which again would reduce the time required to complete conservation.

2. Considerable work has been conducted in the last 15 years to understand the interaction of iron/sulfur and acid hydrolysis in archaeological waterlogged wood. While considerable progress has been made in understanding methods to chelate the iron out of the wood, the concretion that formed during the electochemcial process remains in the wood. Albeit theoretically inert, .expansion of the concretion during drying has the potential to expand inside the wood. In some cases, even three years after completion of conservation, no products of the oxidation of pyrite have been noticed. Yet, one issue noted was the expansion of internal seams of concretion that damaged some of the multi-degraded timber during the drying process.
   a. Methodologies and materials to dissolve or reduce the effects of the internal concretion expansion on the fragile wood are a necessity.
3. The Andrews deign spiral was a crucial factor in the success of conserving *La Belle* by ensuring all aspects of planning were included and that none of the proposed plan overlapped. There are many additional design aids, such as failure trees or human recourse management that could have specific application to watercraft conservation projects and should be investigated.

4. Too frequently, to reduce budgets, reconstruction occurs away from the public eye, and the hull only emerges to be seen as a finished project. In the case of *La Belle*, the reconstruction has been turned into a spectacle for visitors to share all aspect of archaeology, conservation, and museology. It has opened a door to dialogue not normally provided and inspired further visitor discovery.
    a. Thorough visitor and general audience surveys should be conducted to determine how to better utilize the watercraft artifact in the museum and what is required by the visitor in order to enhance the linkages between artifact and the public.

The list provides some direction for future research and undoubtedly, corollary and tangent concepts should develop from their further exploration.

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