IBERIAN SHIPBUILDING AND DESIGN IN THE DAYS OF CUTTING-EDGE PROTOSCIENCE (1570-1712)

A Dissertation

By

RICARDO BORRERO L

Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Chair of Committee,	Filipe Castro
Committee Members,	Kevin Crisman
	Alston V. Thoms
	Victor Arizpe
Head of Department,	Darryl De Ruiter

May 2021

Major Subject: Anthropology

ABSTRACT

Out of 155 known shipwrecks around the world dating from 1600 to 1700, more than a third have been confirmed to be Iberian. Among Iberian wrecks, 37 have been destroyed, looted, or salvaged by treasure hunters and only 11 have been the subject of archaeological work. These statistics indicate that seventeenth century Iberian shipwrecks have suffered immence damage and loss. The devastation inflicted on the archaeological legacy of seventeenth-century Iberian shipbuilding, encourages our efforts towards its research and protection.

Ships, the most complex machines built by people of the seventeenth century, embody the broader picture of the Scientific Revolution, which encompassed the recovery of ancient knowledge and groundbreaking new discoveries in astronomy, mathematics and physics. All of this knowledge exerted a direct influence on contemporary nautical sciences. This disseratation explores the poorly acknowledged influence of the transition from synthetic (or Euclidean) geometry to analytical (or Cartesian) geometry on shipbuilding. I emphasize the influence of the wave of inventions of calculating devices and measuring aids in the shipbuilding industry. This period plays a major role in the bifurcation of shipbuilding and ship-design, marking the emergence of naval architecture. The performance of vessels could not be predicted yet, but coefficients, algorithms and the coordinate system made the shapes explicit before the ships were built. I aim to better understand the influence of Cartesianism, at a time when shipbuilders were still attached to empiricism from a philosophical perspective.

I have studied the published shipwrecks, primary and secondary sources to reconstruct the history of naval architecture, tracing the variation in the design and construction of the vessels. My research provides further evidence on the tension between empiricism and rationalism.

DEDICATION

To Ely, Travis and Frida. I know we are in irons as I have been a weak helmsman, but we have not run ashore, we have not wrecked and we will not as long as the wind is blowing, the masts are standing and the hull is watertight. Let us hold steady and maneuver together to move forward as the dream crew we have been when the yards have broken in the worst storms along the course of life.

ACKNOWLEDGEMENTS

There are too many people and too much generosity to acknowledge, but few time and space so I have to start by asking for forgiveness to the ones I leave behind here. Many friends, relatives, colleagues and professors have seen me struggle along my career and have pushed me to continue, thus I am very thankful with all of them, but perhaps I owe the most to my dad, professor, advisor, inseparable friend and colleague Filipe. In or out of Texas A&M University, I aim to continue under your mentorship helping you to raise the heavy flag of Human Rights.

My carrier has been chronologically divided in three periods, each of them guided by generous and professional divers, archaeologists and anthropologists. I aknowledge the support and opportunities given to me in Colombia by Carlos del Cairo and Catalina García, as well as to my professors and friends at the Pontifica Universidad Javeriana and the Universidad de los Andes; to the community of Orica in Isla Grande that hosted me while I was on my Dive Master: José Feliz, Cruz, Agladis el Gallo, Marlenis, Mirna, Odalis, Migue y Nathaly. To the wisest and sweetest guidance in a workforce united by love provided to me by Flor Trejo, Roberto Juanco and Pilar Luna in my Mexican experience. To most members of SAS, especilly Salvador, Josué and the former members Luis and Enrique. Finally, to the Department of Anthropology and the Nautical Archaeology Program at Texas A&M University, emphasizing my ShipLab mates: Marijo Gauthier-Bérubé, Charles Bendig, Rodrigo Torres, Nicholas Budsberg and Kotaro Yamafune. To Richard Hendren, Robin Galloso, José Luis Casaban, Catherine Brooks, Claire Zak, Sheri Kapahnke, Raúl Palomino, Kelsey Rooney, Morgan Smith and my dearest friends in College Station Dan Aurell, Chris Dostal and Carolyn Kennedy. To my friends Ben, Reichel and Ryan in the

Department of Philosophy. I also want to highlight the place of Alston V. Thoms, Michael Alvard, Kevin Crisman, Rebekah Luza and Vaughn Bryant in my personal and professional growth along the PhD. To my palynology lab mates Paloma Cuello and Rossana Paredes. To Juan Pablo Fernandez, Paula Kuzontkoski, Laura Guerrero and Liza Tapiero. To Marco Valadez, Jessica Dangott, Nicole Ellis, Clint Harden and Naomi Rodriquez.

I could not have taken a single step without the unconditional friendship of my blood brother Francisco Borrero and his family, as well as without my brothers and sisters in beer and sadness Alejandro Chaves, Diego Posse, Andrés Baresh, Eduardo Gonzales, Juan Carlos Uribe, Juan Pablo Gaitán, Simón and Sara Cardenas, Laura Morales, Laura Cardona, Luis Eduardo Errasti, Balo Curevo, Delphine Thomes, Magdalena Cubides, Rafael Oliver and Daniel Martinez.

My diving career has been enhanced by many instructors, among them I would like to highlight Fernando Cadena, Deibis Seguro and Laura White. To the Fulbright community in Bryan and College Station, specially to Mary, Alex, Ettorino, Robert, John and Mauricio.

To my mentors, colleagues and friends in the international underwater archaeology community: Nigel Nayling, Xavier Nieto, Ruth Geli, Carlos de Juan, Miguel San Claudio, Garry Momber, Brandon Mason, Christin Heamagi, Nicolás Ciralo, Anita Castelli, Alejo Cordero, Valerio Buffa, Damian Vainstub, Amaru Arguezo, Diego Carabias, Tatiana Villegas, Marc-André Bernier, Rocío Villar, Lorena Palacio and Antonio Jaramillo.

Finally, if there are two people I owe as much as to Filipe, Ely and Travis in this process, they are my mother and father. Exceptional examples of life that I can hardly follow. To my mother for her love, support and patience and to my dad who planted the seed of maritime archaeology and naval history in my arid head and deserves to see the fruits of his days and nights of, sometimes, unfruitful but always passionate and persistent irrigation.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supervised by a dissertation committee consisting of Professors Filipe Castro, Kevin Crisman and Alston V. Thoms of the Department of Anthropology and Professor Victor Arizpe of the Department of Hispanic Studies.

Many students and collaborators helped me to enhance this manuscript by conducting different tasks, such as helping me to illustrate, and to edit its grammar and contents. This list includes, but is not limited to Charles Bendig, Marijo Gauthier-Bérubé, Richard Hendren, Dan Aurrell, Rachel Mathny, Sara Cardenas, Emily Robertson, Isabella Orlando, José Luis Casaban, Chris Dostal, Carolyn Kennedy, Nigel Nayling, Carla Rahn Phillips, Miranda Richardson and Laura Martínez Paris.

Funding Sources

My PhD was funded by a Fulbright-Colciencias Scholarship administered by LASAPU. For the research and dissemination process, I received the support of various internal grants of the Department of Anthropology of Texas A&M University, the Ed and Judy Jelks Travel Award of the Society for Historical Archaeology and a grant of the Institute of Nautical Archaeology (INA). Without the support of this institutions, this dissertation would not have been possible.

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

CHAPTER I

INTRODUCTION

This chapter introduces my dissertation research questions. The second chapter analyzes Iberian shipbuilding of the late 16th and 17th centuries in the light of contemporary philosophical and mathematical thought. Besides a few comments on the work of Gottfried Wilhelm von Leibniz (1646-1716) it mainly focuses on how the work of René Descartes (1596 –1650) builds a suitable theoretical framework to understand the emergence of naval architecture. The second chapter also disscuses briefly to the Iberian philosophy and cosmography of the period and mentions of the ships and the voyages to the New World, a topic which will be treated in greater depth in the third chapter. It offers an overview of the tensions between algebra and geometry, and between rationalism and empiricism, which were the *zeitgeist* of the 17th century. With shipbuilding and naval architecture as guiding axis, the second chapter shows how both paradigms coexisted, instead of rationalism replacing empiricism as most histories of philosophical thought would argue. Finally, this chapter also offers the the hypothesis that by the 17th century there was already some preconception of ship shapes, which were expressed in a coordinate system, algorithms, and coefficients.

The third chapter presents an overview of the history of the whole molding method, exploring the boundaries between empiric practices and the emergence of ship design or naval architecture around the 15th century. The first section explores the transition from "shell-based" to "skeleton-based" construction by describing its implications in terms of the replacement of traditional structural components of the hull, and on the theoretical knowledge derived from (and required for) the adoption of the “skeleton-based” method. It acknowledges that before the 18th century a vessel’s performance could not be predicted before it sailed for the first time and that even by the 17th century the improvement of hull designs still depended exclusively on the experience of the master-shipwright. However, the dissertation challenges the idea that before the 18th century, ships shapes could not be foreseen before vessels were built. The second section of chpater III explains the method of whole molding known at least since mid-15th century, and how it was based in the coefficients of three-to-one and ace-two-three and the algorithms of the half-moon, infinite stick, incremental triangle and sword’s tail. I argue that the combination of rules of thumb with algorithms and coefficients required theoretical knowledge and the capacity to preconceive the shapes and proportions of the hulls.

This must be understood in terms of the scientific method that can be described as a set of techniques to investigate phenomena by applying empirical and meassurable evidence. I argue ship design or naval architecture, as any other scientifically constructed knowledge of the 17th century proceeded by systematic observation, messurment, experimentation, formulation and testing of hypotheses. Ship design was framed in the Scientific Revolution and thus, as it occurred in other sciences it was characterized by the formulation of scientific laws (*rules of thumb).* In 1589 Galileo formulated the laws of gravity and motion of the earth and in 1618 Kepler formulated the laws of planetary motion. The succesfuly combination of this rules by Isaac Newton resulted in the formulation of his own laws. As this widly accepted princples, many other laws were formulated in other fields of knowledge such as naval architecture. As opposed to nature laws, scientifc laws or rules of thumb, reflect, or partially reflect exceptionless regularities in the univers (De Witt 2010:184) and, as ship designers and sailors desired seaworthy vessels, they formulated and applied rules of thumb to be able to reproduce them.

The fourth chapter shows how despite the contemporary imagery surrounding the galleon (*galeón*), its origin, development, and function of this vessel type remain uncertain (Rahn Phillips 1993: 230; Casado Soto 1998: 171). I follow the trail of galleons across time in primary and secondary sources, seeking their first appearances in documentary evidence and to their characteristics across time. I present a description of the 17th century galleon and assess changes in its size and proportions based in the Spanish rules, the Iberian treatises, and other documents across the period I have named the Golden Age of Galleons (1570-1712).

The fifth chapter explains that the archaeological heritage of 17th century Iberian maritime activity has met a devastating reality; of the 55 wrecks around the world that have been identified as Iberian, 37 have either been destroyed, looted, or salvaged by treasure hunters, and just 11 have been subject of archaeological study. Only the *San Diego*, the Green Cabin wreck, the Fuxa wreck, IDM-003, the *Nossa Senhora dos Martires* and the *Santo Antonio de Tanná* have been published. The structural components, planking, fastenings, caulking and other hull remains have been preserved and reported to different degrees of detail. This chapter establishes comparisons within this small sample of hull components, aiming to make visible the existence of a shared trait cluster or even a distinctive Iberian shipbuilding tradition proposed by Oertling (2001, 2005) and Castro (2008). It aims to show that in the 17th century there was already a certain degree of standardization in Iberian shipbuilding.

Chapter VI presents a rigging reconstruction of a galleon, of 22 *codos* (12.65 m) in beam and 1073.33 *toneladas* in tonnage, that is defined in the *Ordenanza* of 1613. The reconstruction is based on the author's research in different shipbuilding treatises and other documentary and iconographic sources, most of them compiled, transcribed and published by Hormaechea et al. (2018), Castro et al. (2018) and Castro (2018). Features under disscusion include: the spar plan; placement, construction process and materials of the masts and yards; the Flemish fish mast (*chapuz*); the trestle-trees and cross-trees, the fid, mast cap, the doubling; and the standing and running rigging are discussed.

The final chapter includes the conclusions, a personal reflection on the completed work, and potential avenues for future research derived from the dissertation.

Description of the Research Problem

Science is understood by Larrie D. Ferreiro (2007: xi) as the skill of prediction, or the "…ability to determine the characteristics and performance of a system before it is built…" and only through such prediction "…technology can be optimized or improved without complete reliance on trial and error." Ferreiro (2007: xi) explains that in the case of shipbuilding, this was not possible until 1746 with the publication of the *Traite de Navire*, written by Pierre Bouguer (1696-1758), a treatise credited with the formulation of ship metacenter theory. Ferreiro's claim is just partially true according to my research,, as coefficients and algorithms were already being applied in ship design since at least the fifteenth century (Bellabarba 1993:284) and by the 17th century Iberian ship design achieved a high degree of accuracy in shape prediction.

Ship design was part of the Scientific Revolution taking place in Europe since the end of the Renaissance. This revolution encompassed the recovery of ancient knowledge as well as groundbreaking new discoveries in biology, chemistry, astronomy, mathematics, and physics, all of which exerted a direct influence upon the nautical sciences. The improvement of the telescope, the invention of the Newtonian reflecting quadrant (1699), and other contemporary discoveries in astronomy exerted a well-recognized influence in high seas navigation. The invention of calculating devices, and measuring aids, and the transition from Euclidean geometry (a hallmark of synthetic geometry) to analytical or Cartesian geometry all greatly influenced the development of Iberian ship design.

From a history of science perspective, it must be acknowledged that neither synthetic geometry nor analytic geometry were an exclusive product of Euclid or Descartes. Both were syntheses of multiple convergent mathematical practices (Hernández 2002: 32), thus instead of referring to them as Euclidian and Cartesian geometry, this dissertation will refer to them as synthetic and analytic geometry respectively.

Synthetic geometry studies figures arithmetically and axiomatically. It does not use coordinate systems, neither does it employ formulas to describe the properties of objects, whereas formulas and coordinate systems are the essence of analytic geometry (Klein *et al.* 1948: 55). Analytic geometry introduced the use of variables and turned points into triple coordinates, in a period when the requirements of commerce forced the introduction of decimal notations and arithmetic that eventually turned these innovations into routines (Smith 2011: 34).

Synthetic geometry was the paradigm of Iberian shipbuilding before Fernando Oliveira (1507- ca.1581) wrote the manuscript *Ars nautica* around 1570, but especially before 1587, when Diego Garcia de Palacio's (1540-1595) *Instruccion Nautica* became the first Iberian shipbuilding treatise to be published. Synthetic geometry had a strong influence on the nautical world in late 16th-century Spain, as the *The Elements* of Euclid was first translated into Spanish in 1576 by Rodrigo Zamorano (1542-1620).

Zamorano was widely known in the naval scientific community, first as a Professor of Cosmography in the *Casa de la Contratación de Sevilla* and in his later appointment as Chief Pilot (1586) of the same institution. He wrote two naval treatises: *Compendio de la Arte de Navegar* (1582) and *Cronologia y Reportorio y de la Razón de los Tiempos* (1585). Zamorano was subsequently criticized for monopolizing scientific positions in the *Consejo de Indias* (Navarro 2005).

By the second half of 17th century ships exclusively designed for war were being built by most European naval powers. These ships were the direct ancestors of the ships of the line, which composed the battlefleets of the 18th and early 19th century. Merchant ship designs increasingly diverged from war vessels and followed the pattern of types such as the fluyt, which could be maneuvered by a few men and had a considerable cargo capacity (Misa 2004). Over the 17th century the Habsburg ruler of Spain and Portugal kept building galleons, a type that better fulfilled the dual purpose of carrying and protecting valuable cargoes across the oceans.

The characteristics of both Iberian galleons, and the Dutch fluyt, mirror the rise of capitalism and its increasing emphasis on economic rationality. These economic aims increased the profit of merchants, satisfying the growing global demand for goods and simultaneously diminishing the cost of transportation by reducing crew size.

Martin (1979) has asserted that the iron fasteners, widely used in shipbuilding by the end of the 16th century allowed the employment of unskilled workers in the shipyards, but as these fasteners corroded, they also made the life span of vessels shorter. These two factors are used by him to suggest that the ship *Trinidad Valencera* of the Spanish Armada of 1588 was built in a period of mass production and competitive pressure in the late-16th century Venice. Unfortunately, Martin's work is permeated by modern-day British nationalism that frequently underestimates Iberian sea power of the period.

Many naval historians and underwater archaeologists argue that as Spain did not develop the ships of the line as early as other naval powers, the kingdom was experiencing a period of technological and scientific backwardness framed in broader general crisis (Usher 1932:193-196, Elliot 1961:67, Odriozola 1998:111). However, Carla Rahn Phillips (1993) and most Spanish researchers disagree, as Iberian ships defended the sea routes and colonies in the New World well into the eighteenth century, while the Netherlands, France, and England were not able to conquer significant territories in the Caribbean, or in South and Central America.

According to my research, by the first quarter of the 17th century analytical geometry started to pervade Iberian shipbuilding treatises in the form of coefficients and algorithms, some of them recovered from ancient knowledge as it could be expected in the Renaissance. The half-moon algorithm used to rise and narrow the frames of some 17th-century hulls was first employed by the ancient Greeks to generate the shape of the columns for terrestrial buildings (Damianidis 1998:232).

The fact that the French philosopher and mathematician René Descartes was living in the Netherlands, contributed to the spread of analytical geometry in the Iberian kingdom.

His influence, beyond pure mathematics, was present in other disciplines and I argue shipbuilding was not the exception. Applied analytical geometry should have encompassed rationalism in the realm of philosophy. However, philosophically, empiricism was still strongly rooted among shipbuilders and designers, at least until 1673, as testified by Jacinto Echeverri in a manuscript on shipbuilding where he asserts the most suitable proportions of a vessel are achieved by the power of experience.

Despite Ferreiro's claims and the arguments of the main school of English-speaking naval historians and archaeologists, Iberian ship design was on the cutting edge science, but it was incipient. It was already based in the coordinate systems propelled by analytical geometry and it slowly abandoned synthetic geometry. The Spanish crown organized and sponsored continuous discussions of experts regarding the shapes and proportions that ships required for the best simultaneous performance in commerce and war. The results of these discussions were published as rules meant to be followed by royal shipbuilders and even by private contractors. They were supposed to be taken into account in each new shipbuilding project to allow the Crown to maintain a reserve of vessels in private hands (Rahn Phillips 1993:234). On the other hand, many shipbuilding treatises were published by Iberians in this period, as I will explain in the third chapter.

Over the 17th century, Iberian vessels were modified to make them faster and more maneuverable for military purposes, without reducing their cargo capacity. Spanish and Portuguese galleons developed on a unique trajectory as multipurpose vessels to fulfill the needs of the Habsburg imperial system (Rahn Phillips 1993:233- 234; Serrano Mangas 1998:231; Odriozola 1998:108; Casaban 2014:267).

Iberian shipbuilding treatises are rich in analytical geometry knowledge, expressed as relations between the keel, beam, overall length, depth in hold, and the flat of the floor. Also, the lengths of the spars were expressed in coefficients and their shapes were foreseen using algorithms (Sarsfield: 1984; Castro 2007). Coefficients also applied to pre-calculate the shape of the turn of the bilge in a cartesian coordinate system, where the X axis is the keel, the Y axis is the rising, and the Z axis is the narrowing. Deeper thoughts on this matter will be exposed in the first and second chapter of this dissertation.

Although coefficients and algorithms were known to naval treatise writers, evidence suggests that they were commonly not well understood by master shipbuilders. Notwithstanding, mathematical knowledge was applied by the use of molds and gauges (*graminhos* in Portuguese, *gálibos* in Spanish) (Castro and Gomez-Dias 2015) divorcing shipbuilding and ship design at this very early date (Martin 2001: 394). I argue this situation marks the emergence of naval architecture.

After this consideration, it is easy to understand why Tome Cano asserted in 1611 that shipbuilders must be arithmeticians. Acting together, the morphological structure and the geometrical proportions made the body shapes explicit (Nowacki 2007: 10-11) before they were actually built. For the previous reasons, I believe that Iberian naval design of the 17th century, framed in the scientific revolution at the end of the Renaissance, should be regarded as an incipient science, although it did not reach its full potential until the following century.

Some of the questions orienting this dissertation are: Which were the scientific, philosophic, geopolitical, and economic factors influencing ship design and construction in the Iberian Peninsula from 1570 to 1712? What motivated the Habsburg Crown to keep building multipurpose vessels, instead of moving towards merchantmen and ships of the line as separate types compared to other countries? Which are the adaptations, variations, and the factors conditioning them?

In an effort to overcome historical particularism in underwater archaeology and turn it into a social science based in generalized hypothesis-testing and the search for general principles, Gould (2012) has suggested the archaeological record contains traces of the socio-economic phenomena of their time. In the quest for de-particularizing underwater archaeology, as proposed by Martin (1979, 2001) and Gould (2012), I suggest in the first chapter that 17th-century shipwrecks and shipbuilding treatises reflect the broader picture of the European scientific revolution and specifically the transition from synthetic to analytic geometry.

My objective is to trace the variations in the design of the hulls of Iberian vessels from 1570 to 1712 through documentary and archaeological evidence. In the second chapter I will explain the coefficients and algorithms behind them. In chapter VI I will describe the rigging and upper works of 17th century Iberian vessels through documentary and iconographical evidence, and show how they were also guided by algorithms.

My hypotheses are that:

1. If there was a scientific interest in 17th century Iberian shipbuilding in standardizing the most desirable shapes and it was successful:

- There should be a cluster of traits that all Iberian vessels share

- There should be coincidences in the sided to molded ratios of the vessels and their structural timbers

2. If ship design was strongly influenced by matemathics, but still attached to empiricism from a philosophical perspective:

- Shipbuilding treatises should show a mixture of references to geometry and experience as the main sources of knowledge for proficient shipbuilders and designers.

This research is justified by the fact that the archaeological record of this period has been seriously affected by systematic looting carried out by treasure hunters and very few archaeological investigations have been conducted to understand Iberian shipbuilding and design as I will explain on the fourth chapter.

In order to answer the questions and test the hypothesis I was planning to conduct research on documentary and iconographical sources gathered in Seville, Madrid, and Lisbon. Visits to the General Archive of the Indies (AGI), the Naval Museums of Seville and Madrid, the *Arquivo Histórico Ultramarino* (AHU), and the *Museu de Marinha* were scheduled for the summer of 2020 with funding granted by the Institute of Nautical Archaeology (INA) and the Department of Anthropology at Texas A&M University. That archival research was not possible given the onset of the the COVID 19 pandemic and, as such the research resultes reported here are dervided from available archaeological reports, as well as secondary and primary sources gathered by other scholars.

CHAPTER II

A CARTESIAN ANALYSIS OF 17TH CENTURY IBERIAN SHIP DESIGN: THE TENSIONS BETWEEN EMPIRICISM AND RATIONALISM, ALGEBRA AND GEOMETRY

Descartes' entire approach to mathematics had problem solving as its foundation (...). He was constructing a new method of mathematical representation that responded to both the new symbolic language of his time (algebra) and to the new technology of his time (mechanical engineering)

Dennis 1997

Hubregste (2017: 223) asserts that "Within the discipline of architecture, there are many instances where a building's aesthetics derive from mathematical concepts" (Hubregste 2017: 223). In the following pages I attempt to demonstrate that 17th century ship design was influenced by Descartes. Gilles Deleuze (1993) suggested in regard to Leibnitz, baroque architecture, can be considered a reflection of the geometrical and philosophical programs of the most prominent intellectuals of the period (This surely included ships as the product of naval architecture). The fact that Descartes and Leibnitz shared a sistematic context of the material culture (ships) and the knowledge required to design and build ships, makes their proposals more suitable than more recent theories of social sciences for understanding the history of this technology as it allows us to explain and understand these subjects in their original context.

Three decades ago, Deleuze (1993) analyzed the curvilinear aesthetics of Baroque art and architecture associated with the infinitesimal calculus of Gottfried Wilhelm Leibnitz.

More recently Hubregste (2017: 224) came to a similar conclusion when he asserted that Baroque and Neo-baroque curvilinear architecture that attempts to elicit movement and excitement, is best analyzed with the aid of Descartes' *Geometry*. In Hubregste's (2017: 224) terms "Descartes' conception of curves and matter can be associated with the physical and structural qualities of buildings". Ship hulls which actually move and are intrinsically curved for hydrodynamic purposes (not just for aesthetics), have not been previously associated with the mathematical and philosophical programs of 17th century thinkers.

Designing ships requires thinking about curves and the 17th century was especially prolific in this regard, as mathematicians were trying to introduce, describe, and define an enormous number of new curves. Boss (1981: 296) explains that curves are study objects we aim to understand if we are to find means of solving problems. Current trust in algebraic symbolisms and how they match geometrical constructions and the translations of 17th century mathematic arguments into analytical symbols, both obscure our understanding of this historical period and the central role that geometry played in the mentality and thought of the Scientific Revolution. However, the widespread trust in algebra did not appear until the 18th century partly due to the early work of Euler, which based in a set of experiments conducted along the 17th century that tested the posibility to represent geometry faithfully using algebra, finally spread the reliance on this last discipline of mathematics as the dominant mathematical forms of representation (Bos 1981:297; Dennis 1997:164).

Ferreiro (2007: xi) defined science as the skill of prediction and description of a system before it is built, and he also asserts this ability brings the possibility to optimize the system without reliance on trial and error. He believes in the case of shipbuilding this was not possible until mid-18th century when the *Traite de Navire* by Pierre Bouguer (1696-1758) formulated the ship metacenter theory. However, coefficients and algorithms were already being applied in ship design since the fifteenth century (Bellabarba, 1993, 1996; Sarsfield, J. P. 1984). I believe that two centuries later an impressive accuracy in shape prediction was being achieved by employing an *ad hoc* version of the cartesian coordinate system.

The historical particularistic approach, arguably the most common in nautical archaeology, usually forgets to frame Early Modern shipbuilding within the broader picture of the Scientific Revolution taking place in Europe. The Scientific Revolution recovered ancient knowledge and entailed prominent new discoveries and inventions in astronomy, mathematics, and physics. It clearly exerted an influence upon the nautical sciences. The accelerated progress of optics and astronomy played a major role in ocean and open seas navigation. This influence can be compared with the poorly studied role played by the wave of inventions of calculating devices, and measuring aids, and the transition from Euclidean geometry (a hallmark of synthetic geometry) to analytical or Cartesian geometry in the development of ship design.

The influence of classic texts on late 16th century and 17th century shipbuilding treatises is obvious in the *Itinerario de Navegación de los Mares y Tierras Occidentales* of Juan Escalante de Mendoza (1575), the *Nautical Instructions* (1587) of García de Palacio, and the *Dialogue between a Biscayne and a mountaineer about the ship factory* attributed to Pedro López de Soto and dated to 1630 (Vicente Maroto 1998). All these treatises were written as successive dialogue between a young or a mountain man eagerly wanting to learn about ships and navigation, and a wise and experienced pilot or shipbuilder. The dialogue style of Escalante (1575:22) imitates the great Greek and Latin philosophers.

Among other classic influences is the recovery of Archimede’s knowledge on the buoyancy principle and his significant advances in the calculation of the equilibrium position of paraboloids, presumably aimed towards improving naval construction. Archimedes' studies of the quadrature of parabolas likely influenced formulas for gauging ship tonnages.

Finally, the synthetic geometry reveled by the first Spanish translation of the *The Elements* (1576) of Euclid (by Rodrigo Zamorano (1542-1620)) likely inspired the nautical world of late 16th-century Spain. As noted earlier, Zamorano was first a Professor of Cosmography in the *Casa de la Contratación de Sevilla* and later occupied the position of Chief Pilot (1586) of the same institution. He also wrote two naval treatises: *Compendio de la Arte de Navegar* (1582) and *Cronologia y Reportorio y de la Razón de los Tiempos* (1585) and was accused of monopolizing scientific positions in the *Consejo de Indias* (Navarro 2005).

Iberian Philosophy, Cosmography, Ships and the Voyages to the New World

Most of the Iberian philosophical thought of the 16th and 17th centuries resulted from the encounter with the Latin-American territories and peoples, commonly but inaccurately known as "the discovery". "There is a strong surge of interest in problems and issues which arise from the historically unique situation posed by the discovery, colonization, and evangelization of the New World" (Gracia 1993: 488). Iberian philosophy of the 16th and 17th centuries was marked by the expelling of the Muslim inhabitants from the Iberian Peninsula and was strongly constrained by the Roman Church. The Inquisition prosecuted Humanists, Reformists, and Skeptics, generating a mainstream current of theological philosophy which was defensive or apologetic. However, there was strong admiration of the Classics, which marked the survival of scholasticism and the emergence of a sort of encyclopedism:

> the encyclopedic emphasis on gathering all available information surrounding a topic became more pronounced. So much had been produced, and it was of such high quality, that it was natural for late Scholastics to feel they had to preserve it and at least take it into account in their own thinking. For this reason, we find during the period much that is primarily expository, and many works whose character is informative (Gracia 1993: 496).

Philosophical thought in the Iberian Peninsula was also very strongly influenced by politics and was regularly utilized as a tool of domination of the colonies and as an argumentative corpus to maintain the *status quo* of the Spanish monarchy (Gracia 1993: 497). In other words, philosophical and cosmographical knowledge constituted the intangible foundation of Iberian colonialism, while ships were the tangible material culture that made it possible. Ships, philosophy, and cosmography were the most complex products of 17th century western thought and thus they developed in a three-dimensional feedback path.

The observation of heavenly bodies, the geometry required to understand their movement, and their importance for high seas navigation have been largely of interest to history of science and naval history (Fernandez Duro 1881, 1895; Haring 1918; Martinez 1983, Nieto 2013). Navigation generated the practical need for such observations and calculations, and ships (the *sine qua non* for navigational knowledge made possible the intercontinental economic and cultural exchange that yielded the first global or world system (Wallerstein 1980).

The history of philosophy has given cosmographers a central role in the development of thought, but few people have wondered whether ship designers had an equivalent intellectual status, sometimes forgetting that ships were frequently a central topic of interest for cosmographers such as Zamorano and Diego Garcia de Palacio (1540-1595). I believe that, as cosmographers or like cosmographers, ship designers were a cultural elite characterized by their prominent education in classics and their access to the most up to date scientific, philosophic and mathematical knowledge of the European Scientific Revolution. In his time Descartes was considered a prominent figure throughout Europe and it is reasonable to think Iberian cultural elites were aware of his work.

Descartes and Ship Design

As the head of one of the world's largest terrestrial and maritime empires, the Spanish Crown continuously promoted discussions between the most experienced ship designers and seafarers regarding the shapes and proportions that ships needed for ideal performance in both commerce and military commitments. The outcomes of technical discussions held in Spain were published as legal documents called *Ordenanzas.* Different sets of ship measurements were issued in 1607, 1613, 1618, with subsequent modifications in 1666 and 1679. The *Ordenanzas* are one of the earliest official attempts to standardize naval and merchant vessels, predating the English naval establishment system by almost a century.

According to Dennis (1997: 165), during the 17th century there was a shift in philosophical and mathematical inspiration from the classical Greek orientation of the Renaissance towards the more pragmatic and stoic approach of the Romans. That is why the geometry of the period, was not merely a theoretical construction, but was closely related to what we would call civil engineering today. It was not concerned with abstract figures, its purpose was to design fortifications, canals, water systems and probably ships. "Descartes' Geometry was not about static constructions and axiomatic proofs, but concerned itself instead with mechanical motions and their possible representation by algebraic equations" (Dennis 1997: 165).

Despite the fact that Descartes' *Geometry* was not widely read until 1657 when it was published with commentaries by Franz van Schooten (Dennis 1997: 173), when we consider the Flemish influence in peninsular shipbuilding, along with the fact that since 1628 the French philosopher and mathematician lived in the Netherlands (ruled by the Habsburg Crown), there is a strong likelihood that his metaphysical and geometrical thought spread throughout the Iberian Peninsula.

Apparently influenced by the translation of Euclid's *The Elements* and specifically by its fifth book, the *Ordenanzas* gave the tonnage of ships (their size) and later used axioms relating the ratios or proportions for overall length, keel, beam, as the standard way to describe ships. All other measurements of ships were given as rule of thumb proportions of these measurements.

> … geometrical proposition represents a train of reasoning carried out according to certain rules connecting certain *a priori* axioms with a certain definite result. As we observed, these axioms and the rules of reasoning applicable to them were originally derived by abstracting certain properties inherent in plain figures (Lindemann 1933:22).

In defining their distinctions between primary and secondary qualities, Galileo, Newton and Descartes all argued that the primary qualities or inherent properties of an object were the extension, the position, and the movement (Losee 1981: 170). Despite the apparent influence of *The Elements*, the ways in which the *Ordenanzas* describe ideal ships is incredibly consistent with the perspectives of Galileo and Newton on primary qualities. Galileo asserted that:

> For, he tells us, it is not a mere line, nor a bare surface, but a body having length, breadth, and depth. Since there are only these three dimensions, the world, having these, has them all, and, having the Whole, is perfect. To be sure, I much wish that Aristotle had proved to me by rigorous deductions that simple length constitutes the dimension which we call a line, which by the addition of breadth becomes a surface; that by further adding altitude or depth to this there results a body, and that after these three dimensions there is no passing farther so that by these three alone, completeness, or, so to speak, wholeness is concluded (Galilei 1629: 9 -10)

A few years later Descartes would complement this idea as he argued things should be investigated through the few aspects of them that can be perceived clearly and distinctly:

> namely, size, or extension in length, breadth, and depth; shape, which arises from the limits of this extension; position, which various things possessing shape have in relation to one another; and motion, or alteration in position (Descartes 1998b: 75).

There are also some coincidences with Leibniz's definition of natural bodies, that according to him "are defined by the forces that influence physical quantitative measures such as shape, size and movement." (Hubregste 2017: 227).

As it is implied in their name, the *Ordenanzas* were a set of rules that closely followed certain statements of Descartes in his *Rules for the Direction of the Mind*: "Rule 13: If we understand a problem perfectly, it should be considered apart from all superfluous concepts, reduced to its simplest form, and divided by enumeration into the smallest possible parts." (Descartes in Dennis 1997: 173)" This was exactly the structure of the narrative of the *Ordenanzas.*

Ship building treatises regularly alternated verbal explanations with illustrations and although this might seem obvious in any work of a designer it faithfully follows: "Rule 14: The same problem should be understood as relating to the actual extension of bodies and at the same time should be completely represented by diagrams to the imagination, for thus will it be much more distinctly perceived by the intellect.” (Descartes in Dennis 1997: 173).

The correlation between Descartes’s procedure of explanation, his conception of extension and the *Ordenanzas* manner of describing ships is clear, but let us that add Descartes (1998a: 24) conceived of extension as “…the property (…) of occupying space, not as an accident, but as its true form and essence; for they cannot deny that it is quite easy to conceive of it in this way.” This is the philosophical foundation of the coordinate system and, although the algebraical notation of curves was not adopted yet among ship designers, as early as 1570 (Oliveira) and 1587(Palacio) there is evidence for the implementation of a graphical *ad hoc* coordinate system that predates the cartesian coordinate system by decades (Fig. 1).

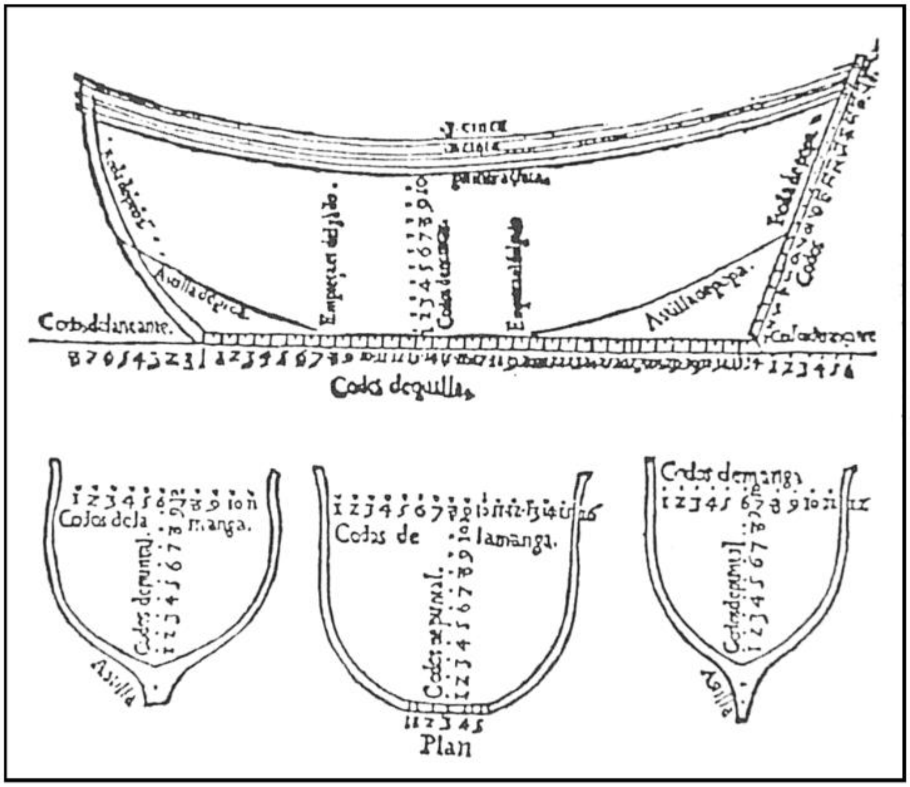

Figure.1. Coordinate system applied to the design of ship shapes by Diego García de Palacio (1587). *Intrvcion navthica para el bven vso, y regimiento de las Naos, su traça, y gouierno conforme à la altura de Mexico.* 1587. X axis is the overall length, Y axis is the depth in hold, Z axis is the beam.

Consistently with Oliveira's and Palacio's (1587) coordinate systems, Descartes wrote in his meditations: "Therefore the only order I could follow was the one typically used by geometers, which is to lay out everything on which a given proposition depends, before concluding anything about it. (Descartes 1998b: 54). Therefore, it could be argued that Palacio proceeded as a geometer in terms of Descartes.

Let us now consider shape, which according to Descartes (1998b: 75) arises from the limits of extension. Shape is understood as the geometric properties and morphological attributes of a class of objects. It is opposite to form, that refers to the specific characteristics of an individual object (Nowacki, 2007: 10-11). It will be recalled that position is what things possessing shape have in relation to one another.

The Cartesian conception of shape, position and extension as clear and distinct aspects of corporeal ideas, is consistent with how ideal ships were described by late 16th and 17th century treatise writers. It shows that by the late 16th century analytical geometric thought started to pervade the mindset of Iberian writers of shipbuilding treatises and, as I will show in the next chapter, it also did so in the form of a coefficients and algorithms.

Coefficients are numerical expressions of a property or characteristic of a body, and they are presented as the relation among two magnitudes. They are morphological attributes and give dimensions to a shape, by explaining the relation with the properties that characterize it in a general pattern of arrangement (connectivity and contiguity of elements). Algorithms are organized combinations of calculations to solve a problem. They are geometric properties expressing the positions of the shape in a suitable reference frame. Geometrical properties explain topological organization by locating the body shape, measuring its size, volume and surface. The morphological structure and the geometrical proportions make a body shape explicit and capable of replication (Nowacki, 2007: 10-11).

Some coefficients and algorithms were recovered from ancient knowledge. The entasis principle applied by the Greeks on the construction of columns (Jones 2009: 99) does not differ from the methods used by late-Renaissance shipbuilders to generate the shapes of masts and yards. Moreover, the half-moon algorithm (Fig. 2) used to precalculate the turn of the bilge line by the rising and narrowing of the frames on 17th century Portuguese ships was first described by the ancient Greeks to generate the shape of the columns for terrestrial buildings (Castro 2007; Damianidis 1998:232).

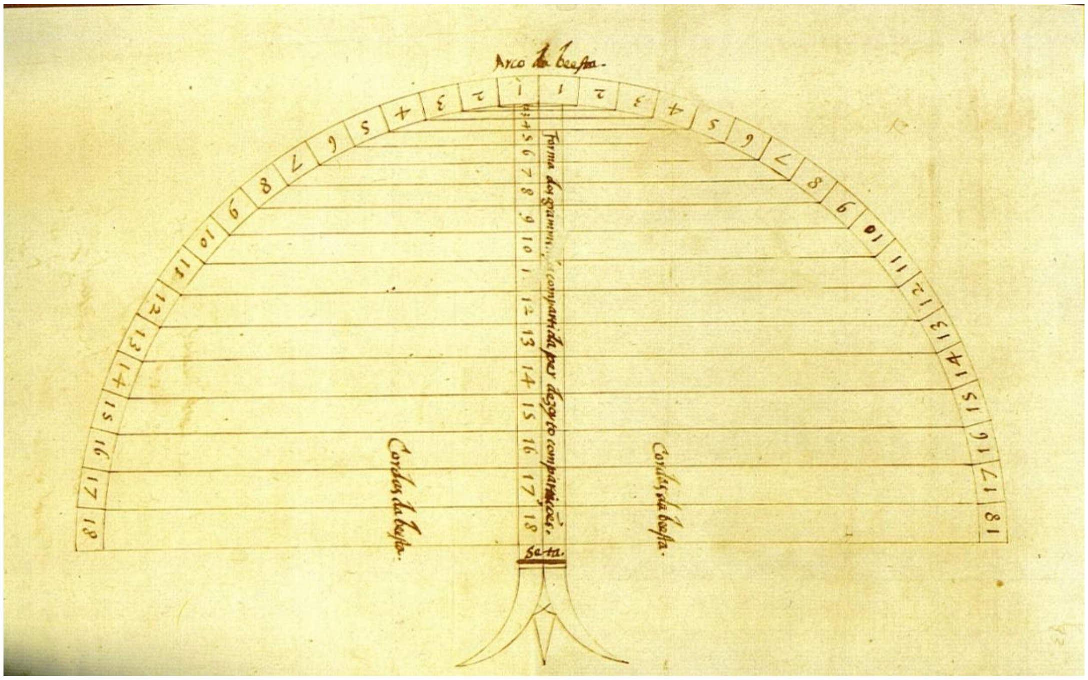

Figure 2. Algorithm of the *Meia Lua* applied in Iberian ship design to calculate the shape of the vessels by Oliveira, Fernando (1580) *O Liuro da Fabrica das Naos,* Fac-simile, transcription and translation into English, Lisboa: Academia de Marinha, 1991. At: http://nautarch.tamu.edu/shiplab/01George/Oliveira.htm, consulted on December 18th, 2020.

A decade ago Pomey (2009:59) formulated the question about the differences in the role and social status of ancient naval architects (*ἀρχιτέκτων*) and shipwrights (*ναυπηγός*). As I have shown here the same question arises in regard to the late 16^{th} and the 17^{th} centuries, and here again there is an apparent bifurcation of shipbuilding and ship design into separate professions. Although the words ship designer or naval architect were not used yet, as was the case in the ancient world, we will apply them to emphasize the suggested distinction.

Graminhos/ Gálibos in a Plethora of Measuring Devices

Evidence shows that treatise writers (architects or designers) understood coefficients and algorithms, but that was not the case of master shipbuilders. However, this mathematical knowledge was synthetized in molds or gauges such as the one shown in Figure 2. The combination of gauges or molds, known as *graminhos* in Portugese and as *gálibos* in Spanish, with simple rules allowed the reproduction of a single model of vessel (shape), but apparently not the correction of mistakes (Castro & Gomes-Dias 2015). Prediction of vessel's performance was not possible yet, although Escalante attests by 1575 there was already some pre-conception of the shapes, materialized in the molds, traces, or designs (*trazas*).

These molds are contemporary with the development of a plethora of measuring aids and calculation devices, such as the logarithm tables introduced by John Napier (1550-1617) and Henry Briggs (1561-1630), the 'Gunter Scale" created by Edmund Gunter (1581-1626), the slide ruler of William Oughtred (1575–1660), Blaise Pascal's mechanical calculator, and the deriving pinwheel calculator developed in 1685 by Gottfried Leibnitz (1646-1716) (Jones 2016).

The inclusion of the tracing machinery to construct the curves of the ships and the specification of the points of the curve in the body of the instrument, are consistent with two of the four methods Descartes used to represent curves. The remaining methods used by Descartes were to specify the continuous motion to trace the curve, and its representation with an equation (Bos 1981: 308). It should also be said that all the known algorithms used to generate the curves of the turn of the bilge of ships in the 17th century (Castro 2007) entailed infinitesimal calculus for the generation of curves, which was Leibnitz's major contribution to the realm of mathematics.

Descartes own geometrical method was consistent with the shape copying procedure of shipbuilders as "After curves had been drawn Descartes introduced coordinates and then analyzed the curve-drawing actions in order to arrive at an equation that represented the curve. Equations did not create curves; curves gave rise to equations" (Dennis 1997: 164). Consistently, ships curves were not based in equations, but were based in the curves of successful ships built previously. This implied an inherent difficulty in correcting mistakes, that might have been overcome with the adoption of algebraic notation of ship curves. However, an algebraic approach to ship lines was not adopted yet. Shipwrights were extremely conservative. It was easier to keep copying seaworthy designs as experimental mistakes were very expensive in lives and revenues.

The Tension Between Algebra and Geometry, Rationalism and Empiricism

Dennis (1997:163) explains that despite the fact that by the beginning of the 17th century it was already possible to represent various arithmetic concepts algebraically, geometry remained the most trusted and reliable form of mathematics throughout the Scientific Revolution. "Questions of appropriate forms of representation dominated the intellectual activities of 17th century Europe, not just in science and mathematics but perhaps even more pervasively in religious, political, legal, and philosophical discussion" (Dennis 1997: 163).

The tension between algebra and geometry is vivid in Descartes own work. At least until 1630 he believed geometry was a more accurate way to answer mathematical and even philosophical questions. It is not until 1630 when algebra prevails in his work and becomes the dominant tool to solve problems and classify curves. (Bos 1981: 298). Not surprisingly, geometry was also the paradigm of ship design in the late 16th and 17th centuries. In 1575 Escalante (1575: 39) affirmed shipwright must be well versed in geometry and by 1611Tome Cano (1611) asserted that shipwrights have to be arithmeticians.

> Geometry, throughout the seventeenth and eighteenth centuries, remained, in the war against empiricism, an impregnable fortress of the idealists. Those who held - as was generally held in the Continent – that certain knowledge, independent of experience, was possible about the real world, had only to point Geometry: none but a madman, they said, would throw doubt on its validity, and none but a fool would deny its objective reference (Russell 1987: 172).

Applied analytical geometry should have encompassed not just the adoption of algebra, but also the transition to rationalism in the realm of philosophy, but this was not the case. Iberian shipbuilders remained attached to empiricism (Contente 2004) until at least 1673 as testified by Jacinto Echeverri in a manuscript on shipbuilding wherein he asserts the most suitable proportions of a vessel are achieved by the power of experience.

Beyond the conservatism of shipbuilders, another plausible reason for the persistence of empiricism among them, might have derived from the fact that Descartes himself was not very successful in linking his mathematical method with his philosophical thought (Shuster 1980, Bos 1981, Domski 2007). By the late 1620 Descartes was already able to resolve geometrical problems using algebraic techniques. However, he was not able to incorporate the same techniques into his philosophical reflections. This is proved by his incomplete attempt to merge his mathematical and philosophical thought in the *Rules for the Direction of the Mind*, which he started in 1619 and abandoned it in 1628. Bos (2001; 270) asserts that from then on there was a divorce between Descarte's mathematical method and his philosophical program. Domski (2007:2) argues that Descartes kept trying to incorporate his mathematical thought in his later writings, particularly in *Le Monde* (1633) and *Geometry* (1637).

> For instance, in the *Meditations*, we find that the certainty of mathematical knowledge no longer rests on our ability to conceive of how mathematical objects are constructed; rather, Descartes focuses on our clear and distinct awareness of their essential properties, or what, loosely speaking, we can call their definitions (Domski 2007: 14).

Descartes ultimately moved towards the proposal that forms or essences are revealed as we attend to innate ideas that rest in our minds and were placed there by God when he created us. This later perspective was not appealing to designers. This is not to say that designers of the period did not credit God for the creation of the world and our creation as beings, however Descartes' earlier writings incarnate the spirit of the scientific revolution, by empowering the designers with a humanistic reliance on science and their capacity to conceive ideas and build things based upon them. Descartes' (1998a:24) early writings are extremely useful for considering design in this period, as he conceives "…a world in which there is nothing that the dullest minds cannot conceive, and which nevertheless could not be created exactly the way I have imagined it." In terms of Domski (2007: 15) "For as we see in the early geometrical works, up to and including the *Geometry*, the investigation of these construction procedures is at the same time the investigation of what the human mind can conceive (Domski 2007: 15)."

In this chapter I illustrated the utility of analyzing historical problems in light of contemporary philosophical thought. There is no irrefutable proof that Descartes actually influenced the thought of Iberian naval architects and how they conceived of ships, but it is clear that his early work contains multiple elements that help us to understand Iberian ship design in its own intellectual context.

I have shown that the tension between algebra and geometry and the tension between rationalism and empiricism were not just present among shipbuilders, they were the *zeitgeist* of the 17th century. This is the opposite of Kuhn's (1996) theory on the paradigms, as one paradigm of thought did not replace the other, they rather coexisted in a permanent tension that has lasted until today.

Finally, I have shown that in 17th century there was already means for preconceving ship shapes, which was expressed in an *ad hoc* coordinate system, in algorithms, and in coefficients. Unlike shipbuilders, ship designers or naval architects possessed this knowledge and it was translated into molds for use by shipbuilders.

CHAPTER III

WHOLE MOULDING AS THE MILESTONE IN THE TRANSTION FROM SHELL TO SKELETON

From Synthetic to Analytic Geometry in the Design of the Hull and the Spars

This chapter is an overview of the bifurcation of ship design or naval architecture and shipbuilding. It explores the boundaries between empiric practices and the emergence of the first attempts at sistematic ship design around the 15th century. It is divided in a brief introduction, two main sections and a conclusion. The first section explores the transition from shell-based to skeleton-based construction by describing its implications for the replacement of traditional structural components of the hull and for the theoretical knowledge derived from (and required for) the adoption of the skeleton-based method. It acknowledges that before the 18th century the performance of a vessel could not be predicted before it sailed for the first time and that even by the 17th century the improvement of hull designs still depended exclusively on the experience of the master-shipwright. The first section also challenges the idea that, before the 18th century ship shapes could not be foreseen before the actual vessels were built. The second section explains the method of whole molding, known at least since mid-15th century, and how it was based in coefficients and algorithms which undeniably entailed an undeniable theoretical knowledge and the capacity to preconceive both the shapes and proportions of hulls.

From Shell to Skeleton

.

Prior to the 1st millennium AD vessels were built shell-first or longitudinally, such that the strakes were installed before the frames and were the timbers that played a significant structural role in the hull. In order to maintain the integrity of vessels this technique required strong connections between the planks, such as the mortise-and-tenon joints or the metal rivets. Frames utilized in this ancient tradition were recognized as "passive" (Basch 1972: 16) and were installed after the hull was already shaped, based in the internal curves of the existing concavity and without any caulking, Mediterranean and Adriatic vessels were made watertight by sinking them, rather than by the use of caulking. Pitch was applied in the interior of the hull and specially over the seams to prevent additional leakage. Scandinavians also built their vessels 'shell first' by an overlapping plank system known as lapstrake; they had their own caulking technique, known as luting (Pomey et al. 2012: 235-236). In the early centuries of shell-based construction shipbuilders proceeded by following the experienced master's eye, which was fed by knowledge transmitted orally and jealously kept by its custodians (Bellabarba 1993: 274). As such, the shape of the ships built in this manner was not known before it was built and the forms of the required timbers were dictated by the ongoing process.

Around the 5th century AD, shipbuilders implemented for the first skeleton first or transversal construction, in which a load-bearing skeleton, composed of transverse frames was attached to the keel to start replacing the planking in its structural role. The skeleton-first method did not require connections between the planks, but the frames needed to be fastened to the keel and, in turn, the planks had to be attached to the frames. Fasteners such as bolts and spikes fulfilled this role. The frames used in this method were described by Basch (1972:16) as “active”. Water-tightness was achieved by caulking, that consisted in the forced introduction of vegetable or animal fibers imbibed in pitch or resin between the seams of the strakes. This created the mechanical compression that was earlier achieved by waterlogging. Caulking also contributed to hull integrity (Pomey et al. 2012: 235-236). Waterlogging a hull after its launchstill helped to achieve impermeability.

The transition from shell to skeleton cannot be explained only in terms of the active or passive role of the frames. The new types of fasteners and new connections, such as those between the frames and the keel and the planks and the frames, were fundamental as well. The reduction and wider spacing of the edge joinery between the strakes continued until these components completely disappeared, resulted in a considerable decrease in longitudinal strength (Steffy 1994: 84). The elimination of edge joinery significantly reduced the amount of labor required to build ships and the employment of bolts, spikes, nails and similar fasteners simultaneously reduced the requirement for a skilled work force (Harpster 1996). However, the increased longitudinal weakness demanded the installation of longitudinal reinforcements such as a keelson, stringers, and clamps. Minor changes in the system required further innovations in the existing components or the introduction of new structures, connections and fasteners to make the vessels seaworthy.

The shapes of the early ships with a load-bearing skeleton tried to imitate shell first vessel forms that proved reliable. This was made generating molds that followed the curves of the strakes of shell first models whose performance at sea was considered outstanding. These molds were used to create a number of pre-designed frames that ultimately determined the shape of the rest of the vessel. The fact that skeleton-based building required preconception of the shape and certain pre-designed components was one of the major achievements of the transition and was paramount for the rise of theorical shipbuilding knowledge. The capacity to anticipate how vessel would look like before it was actually built was a huge step on the path toward a science of naval architecture.

It must be made clear that there was no sudden replacement of the shell-first method by the skeleton-based construction. For many centuries both coexisted. The transition process took more than 1000 years and there were many intermediate stages, represented by hulls that combined structural and non-structural frames (Basch 1972: 29), with lessened and wider spaced edge joinery and longitudinal reinforcements. Some early modern Iberian shipwrecks, such as the San Juan (1565) show evidence of a transitional stage. In the case of San Juan the garboard was made out of the same timber as the keel, while the rest of the planks were installed using the carvel planking method (Grenier et al. 2007). Few other vessels displaying mixed concepts and construction were reported by Pomey et al. (2012).

Social and economic stresses such as the Islamic conquest of part of the eastern Mediterranean in the Byzantine era and the "barbarian" invasions of the western Mediterranean by Vandals, Burgundians, Visigoths and Ostrogoths, played a major role in the transition. Environmental factors such as the altering or depletion of the forests, that supplied timber for shipyards were also among the variables propelling the change. However, further investigations of how these forces influenced the transition are still pending (Pomey et al. 2012: 236). Moreover, violent and nonviolent interactions between geographically distant populations and the observation of ships built in different manners may also have motivated design improvements. The use of predesigned components considerably reduced the waste of wood as trees could be purposely chosen for each ship timber and then shaped with axes and adzes to the desired form after an existing mold, limiting room for mistakes.

Whole Molding

In the case of shipbuilding, making the body shape explicit and fabricable was first possible with the development of whole molding, a method in which molds, gauges and ribbands are utilized to determine a hull's form. It has been asserted that the coefficients and algorithms behind materialized molds, gauges, and simple rules were sometimes not well understood by the master shipbuilders, but the gestures were learned and passed down through generations, and they were explained by writers of naval treatise (Castro and Gomes-Dias 2015:411). In this regard, Martin (2001: 394) comments that treatise writers rarely engaged in actual shipbuilding practice at the dockyards and, in contrast, master shipwrights tended to be illiterate, but this did not constitute a hindrance for their work. This adds further to my hypothesis that designs were being made independently from the ships themselves and that there were two different occupations: one conceiving the ships and the other handcrafting them. The intellectual group was likely an elite and should have been a much smaller community than the craftsmen, as a single mold could be used to produce many vessels, and copying molds must have been a common practice. Off course, there were exceptions such as Gaztañeta and Garrote, treatise writers of the late 17th and early 18th century who actively supervised the building such as of the galleon *San José* (1708) (Rahn Phillips 2007).

Pomey (2009: 137) asserts that since ancient times in the Mediterranean, there was a distinction between the *naupegoi* and *fabri navales* working in the private shipyards, based in their practical experience. State constructors, concerned with the fabrication of the war fleets and unconventional ships, and working without much constraint derived from the limitation of resources and performing in the state shipyards under the supervision of *achitecti navales*, whose "… knowledge belonged to science and allowed the use of drawings and calculations.

First documentary evidence of whole molding

The Venetian document Magliabech manuscript, known as 'La fabrica di galere', has been commonly credited as the first explanation of the whole molding method. The date of the manuscript is uncertain, but a copy made in 1410 is preserved in the Biblioteca Nazionale, Florence. Castro and Gomes-Dias (2015: 410) suggest that the method existed even earlier, arguing that there is evidence in the French archives, dating back to the 14th century (Sosson 1962; Rieth 1998).

Other early evidence can be found in the British Museum manuscript Titus A XXVI, a document written by Zorzi Trombetta or Timbotta da Modone in 1445. It has been suggested that Trombetta received his name from the fact that he was a trumpeter on a ship and that he perhaps did not fully understood the method he was describing. The manuscript is confusing and has certain mistakes (Baroncini 2002). Other early references to the geometrical methods to determine ship shapes can be found in Nicolo Veturi's manuscript of 1489 (Bellabarba 1993:284). The influence of the Italians on Portuguese and Spanish shipbuilders is well documented in many late 16th and early 17th century sources of the (Castro and Gomes-Dias 2015: 410).

Conceiving and Building a Hull through Whole Molding

Whole molding is based in the projection of three longitudinal lines. The first line dictates the shape of the keel, the sternpost and the stem.

> Various methods were used to shape the curved stem and sternposts, while the straight sternpost was raked more or less steeply depending on local preferences. For galleys, many documents show curves built on a triangle, the base of which ran from the scarph of the stem or stempost to the keel to the intersection with the deck line and formed an angle ranging from 34 to 42 degrees. The apex of this triangle lay along the said curve, which in practice was probably drawn with the aid of a flexible wooden batten (Bellabarba 1993: 276)

Once the keel was laid, the stem and sternpost were mounted. The second line defined the junction between the bottom and the sides of the vessel and it is known as the turn of the bilge. To determine it, two or three pre-designed and preassembled midships frames, each composed by a floor timber and two futtocks, were erected amidships. Two possible ways to build the mold for the pre-designed master frame or master frames were known around the 15th century, after the era of molds based in shell first ships.

> …arcs of a circle were generally used to determine the shape of the mainframe. A single arc was enough for galleys while cargo ships needed two or three, or even four if the frame tumbled home at the upper deck level. The arcs of the circles had different centers, so as to give the desired shape. But in Mediterranean shipping, the instructions needed to build the main frame mould were communicated to the shipyard by means of certain measurements of width taken at different heights above the keel (…). On the basis of these measurements, the shipyard prepared an actual size mould, probably joining the various points given in the 'rule' by means of a flexible wooden lath. (Bellabarba 1993: 278)

Progressively narrowing and rising frames were added forward and aft of the midship frames. The turn of the bilge was consistently higher and closer to the centerline of the hull toward the ends of the vessel (Fig. 3).

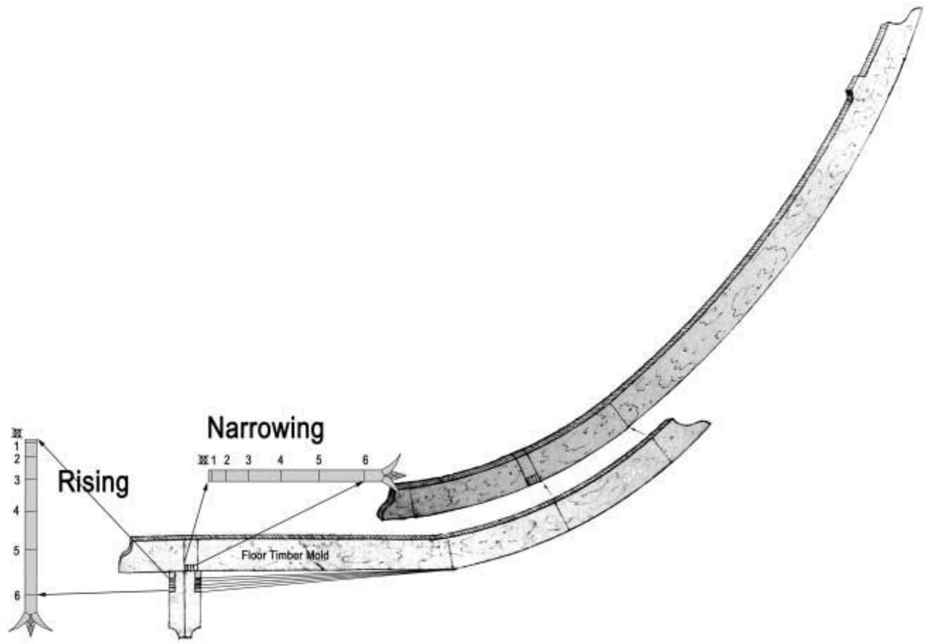

Figure 3. Mediterranean whole molding. From: Castro 2007: 150 Fig. 3, after João Baptista Lavanha)

Preassembled frames fixed to the keel forward and aft of the midship frames were known as tailframes (*almogamas* in Portuguese and *capi de sesto* in Italian) and their shape was determined by the subtraction of the total narrowing and the addition of the total rising to the mainframe shape. Total narrowing and total rising, known in Portuguese as *compartida* and as *partison* in Italian, literally translatable as ‘shared’ or ‘divided’ space, were distributed among the frames between the master frame and the tailframes.

The third line guided the main wale or the caprail. Ribbands (*armadouras* in Portuguese) were installed from bow to stern touching the outer surface of the previously installed frames in particular points. These ribbands determined the curves of the ends and the form of the remaining filling frames (Castro 2007: 148).

The three lines were defined by the shipwright without using any drawings but based in a mold of the master floor-timber, a mold of its first futtock and a couple of gauges, that allowed to modify the shape of every frame to be modified by sliding the molds according to a set of predefined increments (Castro and Gomes-Dias 2015: 412-413). More molds were required for upper futtocks in ships with more than one deck, especially if there was tumblehome to the sides (Bellabarba 1993: 278).

Improvements were made on the shape through a procedure known as hauling down the futtocks (*scorer del sesto* in Italian), which consisted of widening the sides by displacing the head of a futtock outward to compensate for the narrowing. This was undertaken using another gauge with predetermined incremental values. This gauge was called *ramo* in Italian and it measured between one quarter and one-third of the narrowing. Greater increments were used at the bow (Bellabarba 1993: 281). The Italian solution of hauling down the futtock was meant to achieve similar results as the Spanish *embono* proposed in the Spanish *Ordenanzas* of 1607 and prohibited in 1613 when it was substituted by the *joba*, which apparently is exactly the same solution as *scorer del sesto,* as I will show in the next chapter.

It has been asserted that by the 17th century it was still not possible to scale the shapes, but this seems unlikely as the molds could have been reduced or increased in the same proportions. It is possible that improvement was still dependent on the master's memory and his desire to share his experience. If it was not possible to scale the shapes, this technique at least fulfilled the requirement for almost identical vessels demanded by war fleets such as the Mediterranean galley fleets (Bellabarba 1993: 274).

Coefficients

In 16th century Iberian Peninsula skeleton based construction was already the standard and ships were built using five basic measurements: the beam, the keel, the overall length, the depth and the flat of the master floor timber. The first measurement to be determined was either the beam or the keel lenght and the rest of the measurements were obtained applying some simple rules. Variations of the coefficients were applied based in the shipbuilder's experience and knowledge.

The first rule was known as three-to-one, meaning that the length of the vessel should be three times the beam. Another rule that was commonly applied was ace, two, three, referring to the fact that the keel was supposed to be twice the beam, and the overall length, three times the beam. Usually the flat of the floor was one third of the beam. The depth in hold was not always measured from the same height and it was conceived in many different ways.

Table 1 is based on the information gathered by Hormaechea (2017) in primary sources and it summarices rules of proportions listed in treatises of the 16th and 17th century. The red Xs mean that the keel was taken as the main measurement from which the others were derived. In the rest of the cases, the beam was taken by the treatise as the main measurement. Green shows coincidence with the rule of three-to-one, while purple shows convergence with the rule of ace, two, three.

Year	Author	Max. Beam	Keel	Length	Depth	Flat - Floor
1568	Domingo de Busturia	x		3x	(½X) +1 cubit or (½X) +1 ½ cubits	
1570	Nicolò Sagri	x		3x	½ beam at second deck	
1570	Rodrigo de Vargas	x	2x	3x		
1575	Escalante de Mendoza	X	2,3x	3,2x	2 (entry) at first deck	
1580	Fernando Olivera	X		3x		
1587	García de Palacio	X	2x		1/3 (keel)	
1607	Bartolome Crescentino	x		3x		1/3x
1611	Tomé Cano	x	2x	3x	¾ beam at second deck or ½ x	
1610-12	Diego Brochero	x	2x	3x	½ beam at second deck or 2/3x	1/3 x
1648-66	J.A. Echeverry	x	2x	3x	¾ beam at second deck or 2/3x	1/3 x

Table 1. Coefficients for Wooden Shipbuilding in the 16th and 17th centuries. After: Hormaechea 2017.

Algorithms

This section describes the four principal algorithms used to calculate the rising and narrowing of the pre-designed frames. These algorithms have been described previously by other authors (Bloesch 1983; Sarsfield 1984: Bellabarba 1993). Castro (2007) presented the four of them for the first time in a single document.

Half-moon

The method known as *Mezzaluna* in Italian and as *Besta* in Portuguese, was one of the most common procedures to generate the gauges and molds to calculate the turn of the bilge. The first available reference to this method was made by Trombetta in 1445, but it was later explained by Fernando Oliveira in 1580 under the name of *Besta* (crossbow).

This method consisted of tracing one quarter of a circle with a radius equaling the total rising or the total narrowing, which was equal to the 'shared' or 'divided' space. The quarter circle was then divided by the number of pre-designed frames to be installed from the midship frame to the tail-frames. Each section of the circle was supposed to be equal, forming radius at different heights. Once this was done, perpendicular lines were traced from the point where each radius touched the arch to the base of the quarter of circle. The results were engraved in a gauge as shown in Figure 4. (Sarsfield 1984: 87; Bellabarba 1993: 80; Castro 2007: 150).

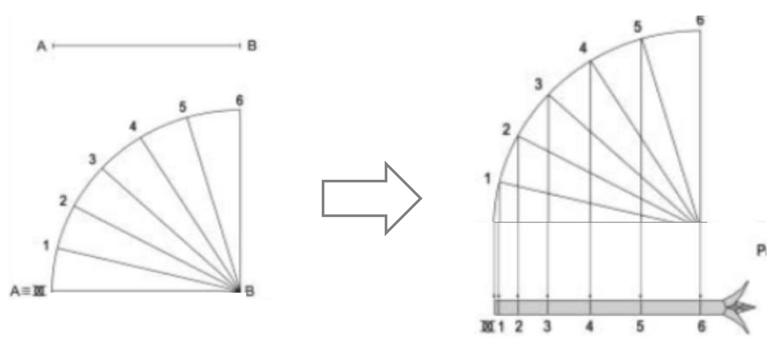

Figure 4. Half-moon. After Castro 2007

<u>Infinite Stick</u>

The second method was known as *saltarelha* in Italian and as *brusca* in Portuguese. According to Castro (2007: 151), Oliveira asserted in 1580 that this method was not suitable for big ships as it generated sharp curves. However, in his *Nautica Mediterranea* (1607)

Bartolomeo Crescenzio disagreed, writing that the *mezzaluna* did not generate regular and continuous curves, and that the infinite stick was more precise. Castro explains this disagreement might derive from the fact that Oliveira building round ships and Crescenzio was building galleys.

The infinite stick consisted in marking a distance X for the first frame, a distance 2x for the second frame, a distance 3x for the third frame and so on, until a line comprising the 'shared' space was divided in the number of pre-designed frames to be installed (Figure 5). Thus, the first frame would be raised or narrowed one interval, the second three intervals and the third six intervals in relation to the main-frame. According to Castro (2007: 151) when the addition of the increments marked in the line of the shared or divided space did not match it exactly, the shipwright needed to start the process again. However, it is more likely, that the measurement of X was previously calculated by a simple division of the shared space in the exact number of required intervals.

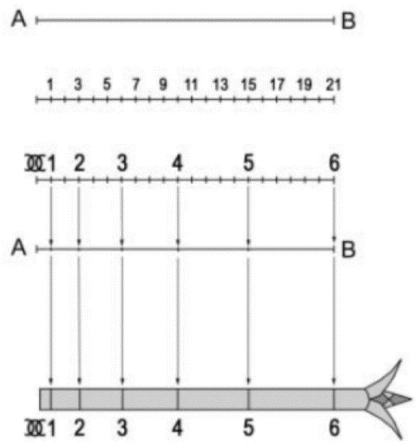

Figure 5. Infinite stick. From Castro 2007.

Incremental Triangle

The incremental triangle, a variation of the infinite stick, was also first described by Trombetta in his manuscript. However, the results obtained with the incremental triangle were different from the ones obtained with the infinite stick.

A line with the measurement of the ‘shared’ space (AB) was traced as the base of triangle. And then an incremental stick (BC), equal in length to the sum of the total incremental values, was drawn perpendicular to this base departing from one of the extremes of the ‘shared’ space line. A third line (AC) was traced joining the end points of the two previous lines to form the right-angle triangle (ABC). Later, from each mark (x, 2x, 3x) on the incremental stick, lines were drawn running parallel to AB and ending in AC. From the points in which these parallel lines touched AC, perpendiculars were traced until they touched the line of the ‘shared’ space (Sarsfield 1984:86-87), which was engraved in a gauge (Figure 6).

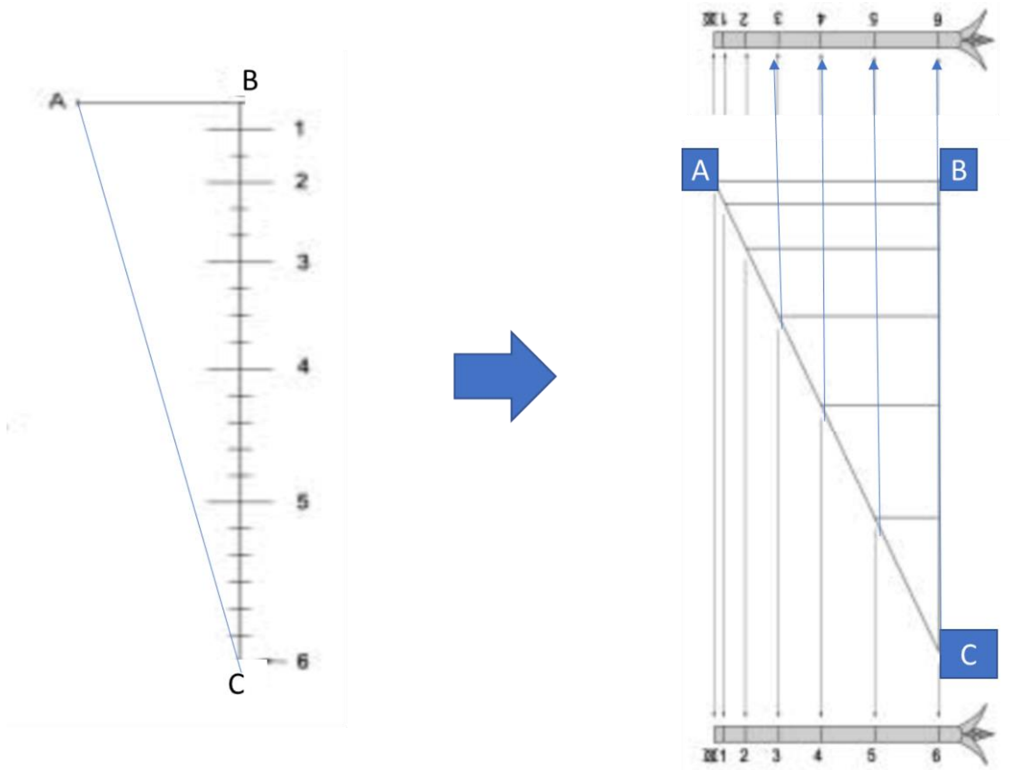

Figure 6. Incremental Triangle. After Castro 2007.

Sword's Tail

Of the known treatises, the only one that describes the sword's tail was the one written by Oliveira and Castro (2007: 153) is the only author who has explained it in a simple way. It was known as *rabo de espada*, meaning literally sword's tail. According to Castro, this method also depended on trial and error. It consisted in tracing a line (AB) with the size of the 'shared' space. A first perpendicular (CD) was added. CD needed to be touched by AB in its exact middle. Another line (EF) perpendicular to the first one, was traced at the opposite extreme. It was touched by AB right in its midpoint once again. This third line (EF) needed to be three times as long as CD. A trapezoid was generated uniting the extremes of the parallel lines, joining DF and CE. Once this was done a quarter of circle with radius AD was drawn using a pair of dividers. Where the circle intersected AB a perpendicular to this line was traced. This last line was used as the radius for another major circle and so on. The center of each circle was later transferred to a gauge (Figure 7).

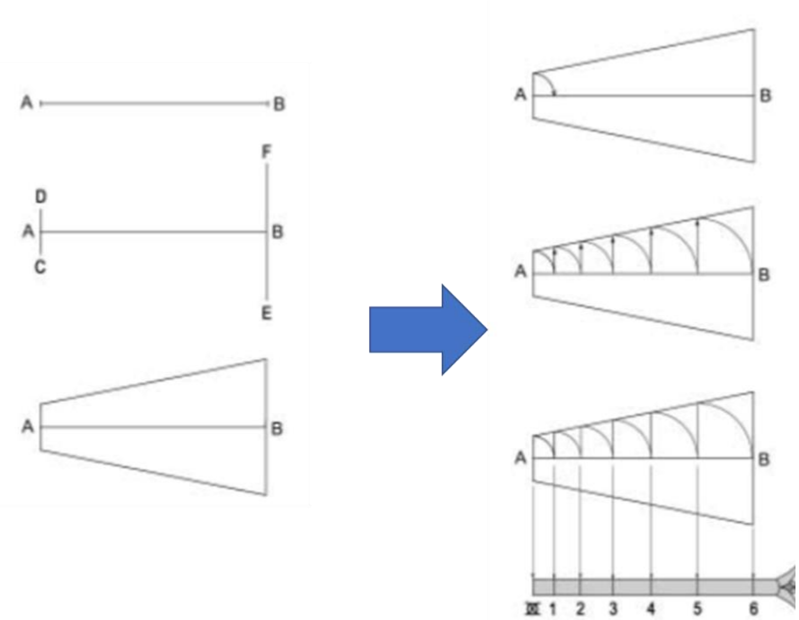

Figure 7. Sword's Tail. From Castro 2007.

In this chapter I have demonstrated that when skeleton-based construction was fully adopted it was possible to foresee the shape of vessels before they were actually built. Deep changes in the conception of ship's structures, as well as innovation in their structural components, arrangements and connections were required. However, the most substantial modifications occurred in the minds of the people who were involved. The three-to-one and the ace, two three rules, as well as the half moon, the infinite stick, the incremental triangles and the sword's tail algorithms testify to a transition from a purely empirical approach to a more rational shipbuilding mentality.

A tempting hypothesis is that this transition from shell-based to skeleton-based construction, and specially the development of the whole molding method, followed the *Zeitgeist.* Beyond the structural changes implied in architecture or engineering, the transition was the product of broader social and environmental variation. Perhaps the transition from shell to skeleton should be also conceived as a reflex of a philosophical paradigm change. Even the world of shipwrights or, at least, that of naval treatise writers between the late 16th century and the mid-17th century, was moving from empiricism to Cartesian analytic geometry. Might there have also been an influence of the Kantian synthesis of empiricism and rationalism in the later development of ship theory that resulted in the institutionalization of naval architecture? These ideas on shipbuilding and design practices as heavily influenced by the historical processes and the *Zeitgeist*, seem very plausible under the light of what has been explained; however, these questions require further and deeper research.

CHAPTER IV

GALLEONS: DEFINITION AND DEVELOPMENT

If there is one vessel type for which Iberian ships of the 16th and 17th centuries are famous, it is the galleon (*galeón*), but despite the imagery surrounding this ships their origin, development, and function remain uncertain (Rahn Phillips 1993: 230; Casado Soto 1998: 171). This chapter follows the trail of galleons across through time using primary and secondary sources to identify their first appearances in documentary evidence and following their changing characteristics and divergent functions across time. I present a contextual description of the 17th century galleon typology and assess changes across the period termed the Golden Age of Galleons (1575-1712).

By the middle of the 17th century, the Netherlands, France, and England had developed and were beginning to standardize ship types exclusively designed for war, in a trend that was producing true ships of the line. Merchant ships, meanwhile, developed in noticeably divergent trajectory, giving rise to ship types such as the Dutch fluyt that had a substantial cargo capacity and could be sailed by a reduced crew. With different needs and subjected to different constraints, the Habsburg Crown, which ruled in Spain and Portugal until 1640 (when the latter became an English protectorate), kept its galleons, designed and built from a long experience in convoying people and merchandise across the Atlantic and Pacific Oceans (Rahn Phillips 1993:234). In the early 1930s this fact was regarded by Abbott Payson Usher (1932:193-196), an economic historian of the United States, as evidence of Spanish technological backwardness in shipbuilding that mirrored a broader socio-political and economic crises. This idea was later popularized by the well-known British hispanist historian, Sir John Huxtable Elliott (1961:67). Today, the misconception is taken for granted by most English-speaking naval historians and maritime archaeologists (Meide 2002:21). Even Spanish historians sometimes support this idea, contradicting the main Spanish narrative (Odriozola 1998:111). On the other hand, widely acclaimed American naval historian Carla Rahn Phillips asserts in unison with most Spanish scholars that Spanish galleons were not laggard at all. Changes were made to their design to make them faster and more agile for military purposes, while at the same time mantaining the excellent cargo capacity. Galleons developed in their own path as multipurpose vessels, in keeping with the demand by the Spanish system (Rahn Phillips 1993:233- 234; Serrano Mangas 1998:231; Odriozola 1998:108; Casaban 2014:267).

Instead of thinking about Iberian society as experiencing a crisis mirrored byantiquated technology, the paths taken by the French, Dutch and British shipbuilding industries should be regarded as the development of progressive societies. Relations of production supported the expansion of industrious forces that were harmonious in terms of the means of production, the social institutions and the prevalent systems of beliefs, while Iberians were more conservative as the social and political factors slowed down the speed of change favoring the largely known technology of galleons (Trigger 2009: 347).

During the 1588 Spanish Armada, there were no galleon losses, despite the dreadful weather conditions these ships had to brave, a fact that demonstrated their seaworthiness and thus making them the standard according to which further ships were supposed to be built (Rahn Phillips 1993:232; Casaban 2014:267). As the head of the world’s largest maritime empire, the Spanish Crown continuously promoted discussions between experienced ship designers and seafarers regarding the proportions that ships needed to reach for the ideal performance in both commerce and military commitments. From an economic perspective, the particular seascapes in conjunction with this dual function were factors within the Iberian culture that favored the adoption, long lasting and extensive use of galleons (Trigger 2009: 322).

On one hand galleons and their crews warranted the delivery of remittances to Europe and although scholars often argue that Spain lacked ships specifically designed for war, the fact is that its galleons mantained their empire well into the 18th century. None of the efforts by Holland, France, or England were successful in completely controlling the Caribbean, conquering significant territories in South and Central America, or stopped Spain's convoys worldwide. This shows the reciprocal impact of war, global tarde and particular environmental conditions in galleon designs, that in turn exerted an influence on these broader factors for more than two centuries. The fact remains that the hull mass confered by greater cargo capacity contributes to fighting capacity and, what is even more important, the measurements were applied to all newly-built vessels, so the Crown maintained a significant reserve of potential war vessels in private hands (Rahn Phillips 1993:234). The results of the technical discussions held in Spain were published as legal documents called *Ordenanzas.* Different sets of measurements were issued by the crown in 1607, 1613, 1618, with subsequent modifications in 1666 and 1679. The *Ordenanzas* were one of the earliest official attempts to standardize naval and merchant vessels, predating the English Naval Establishment system by almost one century.

The previous explanation is consistent with Childe's proposal, when he suggested that broad economic and and political contexts influence innovation instead of interpreting cultural change as a result of technology (Trigger 2009: 325). It is even more convergent with the Marxist idea explained by Trigger (2009: 332) in the following terms: "...technological change must be understood in a social context. Although new technologies bring about social and political changes, they themselves are the products of specific social contexts that influence what innovations are likely or unlikely to occur." This is why I have attempted to reconstruct the context of the scientific revolution and the society that produced these ships beyond simply describing these vessels. I have endeavored to define the modes of production and distribution, the social organization and the ideological concepts of this society, instead of focusing exclusively on a particular technology produced by it (Trigger 2009:334).

Shipbuilding Treatises and Technical Documents

By the second half of the 16th century there was a growing interest between shipbuilders around the world to spread their legacy and set the ideal measurements to standardize shipbuilding through naval treatises. The very first Spanish treatise was the *Itinerario de navegación*, written by Juan Escalante de Menzoa in 1575, and Diego Garcia de Palacio's *Instrucción náutica para navegar* was the first such work to be published in 1587. Portuguese shipwrights were no less prolific. A decade before the 1588 Armada, Fernando de Oliveira wrote his *Livro da fabrica das naos* and around the same time, the anonymous *Livro náutico* or *Meio practico da construção de navios e gales antigas* was being written (Rahn Phillips 2000:7-8). Further treatises were written in Iberian domains across the following centuries. Around 1610 the *Livro Primeiro de Arquitectura Naval*, written by João Baptista Lavanha, made an appearance and, around the same time, Tomé Cano wrote his "*Arte para fabricar, aparejar naos de guerra y merchantes*". In 1616, Manoel Fernandez wrote "*O Livro de Tracas de Carpinteria*" and between 1621-1627 Gonçalo de Sousa compiled the results of meetings regarding the subject in the *Junta da fabricas*. In 1632 and 1671, Lopez de Soto and Vetia Linage made their own contributions, in 1688 Gaztañeta wrote his *Arte de fabricar reales*, and the century closes with the treatise written by Garrote in 1691. Gaztañeta finished his *Proporción de las medidas arregladas a la construcción de un bajel de guerra de setenta codos de quilla* in 1712, which introduced the ships of the line to the Iberian world. Around this time, ships of the line slowly start to replace the galleon and become the standard naval warship. Its design and construction will be based in another treatise written by Gaztañeta in 1720.

One of the main characteristics of the Spanish galleons was their the shallow draft. During the 16th century, these vessels traded in ports with shallow bars, such as the ones in France and Flanders (Casado Soto 1998:186).The sand banks of San Lucar de Barrameda at the entrance of Seville and the reef system surrounding Veracruz were some of the major reasons why galleons were selected for the Indies run over the following century. Shallow waters thus limited the draft of vessels (Serrano Mangas 1992:22; Rahn Phillips 1993:234; Apestegui 1998:240). This limit to the draft represented an obstacle for the desired cargo capacities; increasing the beam made ships clumsy to handle, which is why galleons were lengthened instead (Rahn Phillips 1993:233).

After 1607, the disproportional enlargement of vessel lenght turned into a stability problem, but shipwrights came up with a solution called *embono*. This was a girdling system consisting of additional planks below the main wale, but it added to the weight and draft of vessels and thus was prohibited in 1613. In the *Ordenanza* of 1613, the beam was broadened, providing seafarers with new difficulties in maneuvering the wider vessels. Complaints by the mariners opened a new discussion that resulted in the *Ordenanzas* of 1618 (Casaban 2014:268). It has been said that the *Ordenanzas* of the first four decades were written against the interest of private shipbuilders, as the compulsion for military performance prevailed which was not the main objective of merchant contractors. Private shipbuilders were taken into account in each new set of rules and by 1645, the merchant concerns started to prevail (Serrano Mangas 1998:229). Such changing problems and their solutions, reflected in the ship proportions, give us a glimpse into the reasons for Iberian ship shapes. Theoretical discussions between experts and feedback from the practical experiences of sailors and merchants were the main components in the development of Iberian ship design across the 17th century (Rahn Phillips 1993:235).

Origin and Function of the Galleon

Catalonian linguist Juan Corominas (1905-1997), one of the most recognized researchers of Castilian Spanish etymology, asserts that the word *galeón* (galleon) derives from the Spanish word *galera* (galley), which in turn comes from the Byzantine Greek word *galéa*, given to various selachian fish species similar to the shark, whose movements and aggressiveness were imitated by a certain type vessel around the 8th century A.D.. Corominas stated the term *Galea* was adopted by Catalonians around 1120 A.D. and entered into Castilian Spanish at the beginning of the 13th century. By the second quarter of the 14th century, this word was replaced by the term *Galera* and multiple names of Spanish ship types derived from it: *Galeota* (1260 B.C); *Galeaza* (second quarter of the 15th century); *Galeote* (1490); and, finally, *Galeón* (1528), strongly related to the term *Galion* used in France since the end of the 13th century (Corominas 1987:288). By the first half of the 16th century, several inflections of the term *galeón* were being utilized in Spain, for example *gallyon* and *galion*, which coincides exactly with the French word (Barkham 1998:202).

Non-academic sources such as web forums and Wikipedia trace the origin of galleons in the "*Annali Genovesi*" started by Cafarus in the A.D. 12th century and finished by Jacoppo Doria in A.D. 13th century. The popular sources declare Cafarus mentions the utilization of galleons of 80, 64, and 60 oars in certain missions, taking advantage of the speed and maneuverability of the vessel. The current author was not able to confirm such statements, but certainly the five volumes of the *Annali Genovesi* regarding the foundation of Genoa contain several terms related to the ship type of our concern, such as *galeis, galeram, galeam, galea* and the plural *galee* (Cafarus et al. 1890).

Rahn Phillips agrees that the name may have derived from medieval Mediterranean oared galleys employed for warfare and she also assert that vessels with this name were used on the southern and eastern coasts of the Iberian Peninsula as early as the 13th century. (Rahn Phillips 1993:230). On the other hand, Barkham supports that galleons may have originated in medieval ships developed by the Basques for whale hunting purposes (Barkham 1998:206).

The earliest outcome of a simple search of the word "galeón" in the Portal of Spanish Archives (PARES) is a document entitled "*Al corregidor de Almería que desembargue las mercaderias tomadas de un galeón, que son de Agustín Italiano y de Martín Centurión,* *mercaderes genoveses estantes en Málaga*". The document is in the General Archive of Simancas (AGS). It dates to 1493 and, across its three sheets, two Genoese merchants are requesting the lift of an embargo of merchandise brought in a galleon. It is deliberated if the merchants were trying to introduce weapons to Berbería, Reyes. Even though the ship is not described, the Genoese origin of the merchants and the cargo function of the vessel are worthy of mention. In the same century, oared *galleoni* were being used in the river patrols of Venice (Rahn Phillips 1993:230). This difference in function contrasts with the archival research of Casado Soto, who found that in 1469 the word *galeón* was used to refer to all the fishing ships of San Vicente de la Barquera, Spain and a few years later, the term denoted an undescribed fishing vessel type in San Sebastian, Spain. In 1513 the vessels of the fishing fleet of Santander were named *galeón* (Casado Soto 1998:187).

According to Barkham, at the beginning of the 16th century, the word galleon and its aforementioned inflections were mainly used to describe a type of oared and sailed minor vessel without decks. These boats were commonly employed for coastal net fishing of sardines and other species, as well as whale hunting along the Basque, Asturian and Galician coasts. When fishing the boats carried a crew of five men and when whaling they carried up to ten men. Galleons in charge of fishing sardines were the same as those hunting whales. Documentary description of whale hunters found by Barkham indicate that when a whale approached fishermen on land or occupied with sardine fishing, immediately engaged in whaling. They expected to share the benefits of the hunt with the crews of other vessels. These vessels were also sporadically used for the coastal transportation of goods, but their reduced size made them less suitable for this purpose than *pinaza*s (Barkham 1998:202-206).

Across the first four decades of the 16th century sailors from the Basque region in northern Sapin and southwestern Frence transported the timber for unfinished galleons across the Atlantic to North America (Terranova) on board bigger ships. The galleons were thereafter assembled to engage in cod fishing and whale hunting. According to archival research carried by Barkham, a caravel of 100 tons could carry up to three galleons on a voyage to Terranova. This reference should indicate how small these ships were by the first four decades of the 16th century (Barkham 1998:208). Contrastingly, ten years later, documentary evidence referred to galleons as merchant vessels used for the transport of wool from Seville to France and Flanders. These galleons had an average cargo capacity of 300 *toneles* (barrels) (Casado Soto 1998:181). Even before 1530 full-rigged varieties of galleons were common in Italy and Spain (Rahn Phillips 1993: 230).

A census carried out in Gipuzkoa in 1534 utilizes the words *carabela* (caravel) and *galeón* (galleon) to refer to the same ship (Barkham 1998:201). Barkham asserts that during the first half of the 16th century, the term was employed along the Basque coast to describe large vessels, but that it did not become generalized until the second half of the century, when Basques abandoned the use of the term *galeón* to refer to small and open fishing vessels. At this point, notarial sources show no distinction between *nao* and *galeón*; both refered to medium and large tonnage offshore merchant ships (Barkham 1998: 209). The imprecise term usage reflect the confusion of notarial officers who were scarcely involved with maritime matters, however, it makes the typology even more murky.

Built for merchant and fishing purposes, small- and medium-sized galleons certainly contrast with those mentioned by Castro, according to whom the primary function of galleons in the first decade of the 16th century was warfare. He describes them as having two or three decks and up to four masts (Castro 2008: 8). Certainly, 1509 marked the first known enlistment of a galleon for warfare in this century. A vessel with this name was selected by officers of the Spanish Crown to serve in the conquest of Orán in North Africa, but this vessel had different characteristics from those recognized in the south or the north of the Peninsula at such an early date (Casado Soto 1998:176).

Speed and maneuverability were two of the main qualities of galleys and both characteristics were expected in a reliable war vessel. Thus in 1540, inspired by galleys, Álvaro Bazán designed the shallow draft "galleon of new invention", a ship propelled by oars and sails and which included a better placement of artillery. Bazán's design had a heavily reinforced hull and better topmast yards. The oar propulsion idea was abandoned, but it seems the other characteristics remained for later vessels designated as galleons (Rahn Phillips 1993:230).

The first galleon enlisted for war was a 120 *toneles* (barrels) vessel, but the temptation to define Spanish galleons of the first half of the 16th century by their cargo capacity, as well as attempts to sort them by shape or function, shows equally disappointing results. In the fourth decade of the 16th century, out of the eight galleons in the offshore fleet of Gipuzkoa, five had a tonnage of around 143 *toneles*, but the remaining three were 900, 630, and 450 *toneles* respectively (Casado Soto 1998:177). Notwithstanding, Casado Soto shows that in 1536 the galleons in Asturias, Spain had 50% less tonnage than the *naos*, despite the fact that *naos* were medium size vessels (Casado Soto 1998:179). Further documentary evidence analyzed by the same author suggest that between 1545-1551 the average *nao* was capable of carrying two and a half times the amount of wool that an average galleon could carry (Casado Soto 1998:181).

The answer to this confusion may rest in the fact that by the first decades of the 16th century, the word *galeón* was still being used to name different kinds of vessels in different regions of the Peninsula or even multiple types in the same region. In the north, the word *galeón* was used for open fishing vessels, while in the south it designated an oared *fusta*, a minor *galera* (galley) of the family of the *saetía*, the *bergantín* (brigantine), and the *fragata* (frigates) of that time (Casado Soto 1998:176). It was also possible to employ terms referring to what we now consider as different ship types, to designate a single vessel, or even more confusing, to utilize it as a generic word to refer to multiple ship types (Casado Soto 1998:171; Casado Soto 2006:21).

What is significant is that sail-propelled cargo vessels were being enlisted for military commitments by the second half of the century. The number of galleons selected for this purpose start to increase at the same time as they grow in size, but shallow draft remains one of the main characteristics of galleons.

According to Barkham, during the second half of the 16th century, the Spanish monarchy started to order the fabrication of big war vessels for the Atlantic and these ships were based in the models of Basque galleons mainly built in the shipyards of Biscay, Gipuzkoa, and a few in Santander (Barkham 1998:209). The tendency towards building galleons specifically for naval purposes might be the case in the second half of the 16th century, but in the following century the Spanish Crown started to confiscate merchant galleons that were overhauled and outfitted with artillery to serve for naval purposes. The owners of these ships periodically received a compensatory amount of money (Serrano Mangas 1992:74; Casaban 2014:268). It is also true that by the end of the 16th century and into the 17th century the Crown built a small quantity of war galleons.

A deeper treatment of this ship type is being prepared as a chapter of a book by Castro and José Virgílio Pissarra and me. Pissarra's (2016) dissertation also deals with the subject in greater detail.

The Fleets and Galleons System

Prior to 1543, the trade between Spain and the American colonies was carried out by isolated ships or by small groups of vessels. This non-regulated scheme of transportation started to show its vulnerability in 1522, when Jean Fleury, an Italian corsair in the service of France (known in Spain as Juan Florín or Juan Florentino), captured the ship sent by Hernan Cortés with treasure taken from the Aztecs. This episode prompted the Crown to advise that merchantman should always sail as part of a bigger convoy. Initially, this warning was disregarded, on one hand because the risk of piracy was low, and on the other for immediate profit from the promising lands on the other side of the Atlantic. In 1543, the Crown prohibited the solitary navigation and ordered that all merchantmen must travel in two annual fleets escorted by an armed vessel. The expenses occasioned by the escort were to be paid with a tax on the merchandise carried by the merchantmen. It was called the *avería* and the amount increased in times of war to provide better protection. Complaints by the merchants led the Crown to establish a fix sum of 790,000 ducats in 1660. Fleets were composed of at least 10 ships of 100 tons and they were supposed to depart in March and September. Once in the Caribbean, each fleet and sailed to separate ports and the escort vessel began hunting potential enemies with Havana as its base port. The divided fleets were supposed to gather three months later in Havana to set sail for the return voyage to the Iberian Peninsula (Lucena 1996:5).

Convoying greatly slowed departure and transit time and required more time and effort to gather and maintain a continuous traffic of precious metals, so that in 1552 some adjustments were made to this system. The idea of the escort vessel was abandoned and instead each merchant ship was armed to make the single units less vulnerable to pirate or privateer attacks. Two navies were created. The first was intended to patrol the Caribbean with its home port at Santo Domingo. The second fleet was based in Seville and was in charge of protecting the Andalusian coasts. One year later, the original idea of escorting vessels was resumed and four ships were assigned to each fleet. Once in America, two of the naval vessels convoyed the merchants going to New Spain, one joined the merchantmen destined for Terra Firme, and the remaining protected the ships traveling to Santo Domingo and the surrounding islands. On the return voyage, the royal treasure was supposed to be carried in the war vessels (Lucena 1996:7).

In 1569, there were two differentiated fleets a year. While they occasionally traveled together, but each under the command of its own general captain and admiral. The first fleet was destined for New Spain, which comprehended the North American and the northern Central American territories of the Spanish Crown. It was commonly named *La Flota* (The Fleet) and its main port was Veracruz. The second fleet, called *Los Galeones* (The Galleons), covered the southern Central America and the South American territories. Its main ports were Nombre de Dios, later substituted by Portobello, and Cartagena de Indias (Lucena 1996:8).

At this point, Seville was well established as the only home port port for the fleets.

Despite the security offered to ships at the bay of Seville, Cadiz was a deeper port along the Atlantic coastline. Two incursions by the English at Cadiz in the last two decades of the 16th century made the Crown distrust in the easier accessibility of this port. Seville's monopoly as the principal port of the Spanish fleets was supported by the crown until 1680, when Cadiz became the official entry port for New World shipping (Serrano Mangas 1992:35-40)

During the second half of the 16th century, the size of galleons notably increased. The banks of the Guadalquivir River which led to Seville were already known as ship traps, but because of the increase in the size of ships, losses at this point rose dramatically. Serrano Mangas reports over a dozen losses on these sand banks between 1622 and 1630. Merchants fruitlessly requested that the *Casa de la Contratación* and Duke of Medina Sidonia relocate of the main port of the Indies fleets. Two Italian merchants named Grillo and Lomelín, intentionally increased the draft and tonnage of a galleon they provided, seeking its intentional loss at the sand banks of the Guadalquivir River (Serrano Mangas 1992:28).

In 1625, Cadiz successfully repelled an Anglo-Dutch attack led by Lord Wimbledon, establishing a more trustworthy image of the fortified city and even with the lack of success for even tough it was not the main Indies port, in 1622 the Marquis of Cadereyeta was authorized to direct his convoy to Cadiz. This exceptions became more and more common until 1675 when the Crown started to reject them, assuming that smuggling was easier in Cadiz, as governmental oversight was based in Seville (Serrano Mangas 1992:35-40). The decision to maintain Seville as the unique port across most of the 17th century severely affected the size and design of galleons until 1680 (Serrano Mangas 1992: 22; Rahn Phillips 1993: 234; Apestegui 1998: 240).

The name of the Terra Firme fleet – *Los Galeones* - does not imply that it was the only one composed of galleons, for by the second half of the 16th century the name galleon was applied to all the ships charged with protecting the merchant fleets and transporting precious metals from the New World to Spain (Serrano Mangas, 1998:223). As asserted before, in other countries of Europe, warships and merchant ships developed along significantly different paths. Spanish galleons also changed, seeking more speed and agility for military proposes, but still avoiding the sacrifice of cargo capacity. The development of galleons as multipurpose vessels was based in theoretical discussions promoted by the Crown, but also in the practical experiences of seafarers (Rahn Phillips 1993: 233- 234).

Besides the earliest Spanish sources containing the term *galeón*, the simple search in the Portal de Archivos Españoles online (PARES) also shows that while the results for the second half of the 16th century are significant the majority of the documentary evidence produced around galleons dates to the 17th century. Eighteenth-century documents dealing with galleons are much scarcer. Archival search results match the regional reality of ship production in Guipuzkoa, presented by Odriozola, who asserts that the prevailing type of ship built in this province by the 16th century was the *nao* (a total of 183 vessels). These more than twice the number of galleons (80), which was the second type in production. By the 17th century, galleons take the lead with 150 vessels, almost three times the amount of *naos* which was the second most common type (45). In the 18th century *navíos* forged ahead with a total of 71 vessels, when combining the merchants and the ones designed for war. In the 18th century, the galleon occupies the 11th place on the list, with a reduced number of 5 ships (Odrizola 1998: 105-108).

Another interesting fact from Guipuzkoa, presented by Odriozola (1998:108), is that the province produced 357 vessels overall in the 16th century, 381 in the 17th century, and just 289 in the 18th century. These numbers refer to the quantity of ships produced and do not provide evidence for or against the hypothesis of the technological backwardness plaguing the Spanish shipbuilding industry in the 17th century. However, the fact that this period was quantitatively the most productive certainly shows that the shipyards were likely not facing a crisis as has been asserted, although it might be a coincidence deriving from the existing and explored sources.

These last two arguments might be based on the result of a local phenomenon, but as it has been asserted by Serrano Mangas (1998: 231), the Basque shipbuilding industry represents almost the entirety of Spanish shipbuilding as whole. The short continental shelf along the Cantabrian sea, along with the fact that the fish species in this area were pelagic, drove the inhabitants of the coastal region to build vessels suitable for transoceanic voyages more resistant to ocean action than those seen in the Mediterranean. At the same time, sailors of the region were more used to facing rough weather at sea. The combination of these circumstances made the Atlantic vessels and sailors more suitable to pursue transoceanic navigation (Casado Soto 1998:169). By that time, the Cantabrian province included the current Basque territories of Vizcaya and Guipuzkoa. When dealing with vessels coming from these places, authors who originate from the Basque country prefer to refer most vessels as Basque in origin, while Cantabrian authors prefer to claim a Cantabrian production.

The Development of Galleons Across the 17^{th} Century

The biggest sample of measurements from galleons that is available in the documentary record comes from the Spanish Armada that was assembled to invade England in 1588. Among the Armada's total of 130 ships, 20 considered as galleons were officially measured, listing the beam, the depth in the hold, and the length. Most of the ships that received the name *galeón* in Spanish sources were built in Cantabria, but others were built in Portugal, the Spanish Mediterranean, France, and other countries. Galleons from Portugal had a 3.35:1 length-to-beam ratio and a 0.53:1 depth-to-beam ratio. Cantabrian galleons were longer and deeper than the Portuguese ones, with a 3.5:1 length-to-beam ratio and a 0.65:1 depth-to-beam ratio. The smaller Castilian galleons were longer and shallower (3.6:1 and 0.63:1) than the Cantabrian ones, but deeper in hold than the Portuguese. The one French galleon was 3.75: 1 and 0.58: 1, and the galleon from Florence was 3.85: 1 and 0.62: 1. Both the French and the Florentine ships were significantly longer than the Iberian ones. The scarce information available regarding the English ships suggests that they were longer and shallower than Spanish vessels (Rahn Phillips 1993:232).

Putting aside the galleons of other nations, by the end of the 16th century Spanish galleons represented a more or less uniform type. A standard description of them shows vessels with contrasting fore and aft castles. The aft castle was significantly higher and it was composed by a half-deck, a quarter-deck, and a poop deck. They had a square tuck with the ship's name indicated at the top. The forecastle was low and set-back from the stem. Between the castles was a shallow open area or waist. Below the bowsprit was a remnant of the ramming beakhead of medieval galleys, which was shortened and curved upwards. This beakhead did not serve any ramming purpose, but was instead a working platform which also supported the decorative figurehead. Besides the bowsprit, which larger 17th century ships supported a small spritsail top mast, the galleon regularly carried three masts. The mainmast and foremast had at least two courses of square or trapezoidal sails, and the mizzen mast, which carried a fore-and-aft lateen sail. In some cases, there was an extra mast aft of the mizzen, called the bonaventure mast (Rahn Phillips 1993:231; Rahn Phillips 2007:6; Castro 2008:80). I will deal with the rigging of these vessels in greater depth in chapter V.

At the very beginning of the 17th century, there were two kinds of galleons: The Ocean Sea Galleons built to patrol the coasts of the Iberian Peninsula, and the Silver Galleons designed to travel across the Atlantic and the Caribbean. They had certain differences in the thickness of timbers and planks, the number of decks, the draft, and the artillery. In keeping with their cargo transportation function, Silver Galleons had a deeper draft, carried fewer guns, had three decks, and bigger bellies (greater cargo capacity). Their timbers were thicker and their hulls were lead-sheathed to resist biofouling attacks. By this time, there was a professed distrust in the employment of ships in transatlantic trade. Thus, notwithstanding the differences between the two classes, by 1626 the scarcity of Silver Galleons forced the crown to employ some Ocean Sea Galleons in the Indies Run. After this period this became a common practice and the differences between the two types became almost imperceptible (Serrano Mangas 1992:16-17).

As I explained in the previous chapter the building process of a galleon may be described as follows: the keel was laid, together with the sternpost and the stem. Predesigned and preassembled frames were mounted over the keel. Ribbands were temporarily fastened along the frames and at predefined heights on the posts. These ribbands dictated the shape of the missing frames fore and aft of the pre-designed central frames and, after mounting floors and futtocks, the planking was fastened in place. Depending on the size of the vessel one or more (master) frames were flat over the keel and these flat portions were generally a third or a half of the maximum breadth. Based on the geometric algorithm explained in chapter II, the outer tips of the frames placed aft and before the master frames became gradually higher and narrower to shape the hull. There were typically 18 frames fore and aft the three master frames. The outermost frames were known as tailframes or *almogamas* in Iberian languages (Castro 2003:16).

Regarding the development of galleon design, Rahn-Phillips has shown that by 1613 the length-to-beam ratio increased in comparison to the ships built in the previous century. In the case of the biggest galleons, it was 3.2:1 and in the smaller galleons it was 3.6:1. Rahn-Phillips has also shown that the depth-in-hold changed from three fourths of the beam in 1607, to half in 1613. In 1607, 567 tons was set as the maximum tonnage for galleons. Six years later, the rules contemplated vessels of over 1,000 tons, but in 1618 the size was restricted once again to 600 tons. By 1613, the aftcastle was supposed to be lowered and the stern galleries, characterizing the ship type in previous years, were suppressed (Rahn Phillips 1993: 233). To improve stability, in the case of military vessels, the main deck where the guns were mounted was located half a cubit above the maximum breadth. In merchantmen it coincided with the maximum breadth. The traditional solution of girdling (*embono*) to broaden the ships was prohibited and the *joba* was introduced. The *joba* was a scale combined with the breadth, the rising, and the narrowing of the head of the floor to conveniently dictate the location of the head of the futtock without modifying the curve of its lower portion, which was predesigned with *graminho/gálibo*. Such was the new procedure used to determine the shape of the hull, seeking to increase the beam and employing less ballast in order to produce lighter and more stable vessels (Casaban 2014:268). Apparently the *joba* is exactly the same procedure as what Italians called *scorer del sesto.*

In her analysis, Rahn-Phillips (1993) considered the measurements dictated by the crown in 1618 and asserted that longer and shallower vessels with even less superstructures were ordered. However, the measurements of this year have to be taken carefully, as all the vessels in this *Ordenanza* were rated as *navíos.* As the English translation for “ship” the Spanish word *navío* is still used today as a general term and, at the same time, it refers a particular type of vessel. The most suitable hypothesis is that in 1618 the term was used as a generic for watercraft and does not mean that the crown intended to replace the galleons by the type *navío*, but it still remains as a possibility. The term galleon would prevail once again in the later *Ordenanzas*.

There is a large gap in the data between 1616 and 1666, for lack of available documents, but according to Serrano Mangas, starting in 1645, the commercial interests finally prevailed over the well-armed vessel and the designs of Diaz Pimienta turned back to the models of 1611-1613, differing from the shapes of 1620- 40 (Serrano Mangas 1998: 229). Scant information has been published for the second half of the 17th century. Notwithstanding, Apestegui asserts that with the *Ordenanza* of 1679 and the promotion of Cádiz as the main port of the fleets, the previously imposed size and draft limits were discarded and the galleons grew to over 1,000 tons. The three-decked galleon was introduced and the freeboard and upperworks widely increased, resulting in new stability problems. Therefore, girdling and higher amounts of ballast were reintroduced (Apestegui 1998: 240).

While most research on galleons has been qualitatively oriented, a considerable set of measurements of actual ships and ideal measurements (most of them proposed in treatises and rules) has been compiled (Rahn Phillips 1993:236-238; Rahn Phillips 2000:20-25; Apestegui 1998:254-262). Direct comparisons of the measurements have yielded interesting conclusions, most of them summarized in this chapter. A systematic statistical analysis and ensuing graphical representations of the results are pending.

New and contrasting conclusions might arise from quantitative research and thus a paper on the subject is being prepared by Andrés Succolotto, Patricia Schwindinger and me. Gathering a larger sample size of measurements may result in groundbreaking conclusions. The systematic statistical analysis conducted so far on the subject has shown to be of remarkable value. Contrasting the ideal and real measurements from the latter reconstructions of shipwrecks in the archaeological record and ships described in documentary sources might even result in a dating procedure by running a multivariable analysis when the length, the beam and the depth of the vessels are known values.

Although it has high potential, it must be taken into account that the research on hull dimensions has a limited range. Changes in the rigging, the upper works, the placing of decks, and the number of decks (Serrano Mangas 1992:32-35), were also very important factors in the discussions of the period, but are beyond the scope of this project. Iconographical research may help to fill the gap on the freeboard, upper works, and rigging. A reconstruction of a 17th century Iberian rig will be presented in Chapter VI of this dissertation.

This chapter presented the origin, development, and changing functions of galleons. It has been shown that it is inaccurate to refer to the galleon as a unified ship type before the mid-16th century. Even in the same location, the term was used to designate vessels of variable features, sizes, and functions. Galleons probably originated in the region of modern Italy, adopting some qualities of galleys and later integrating features of Basque whalers. Before being gradually replaced by *navíos,* galleons emerged as multipurpose vessels that performed in both merchant and naval roles.

For more than a century galleons succeeded in transatlantic trade, transporting and defending the valuable income of the Spanish empire and making it possible to keep control of the overseas colonies of the Spanish empire. Despite the sustained willingness of the Crown to listen to practical experience and technical expertise, the shape of the hulls did not require significant modifications, but adjustments were made to designs. This period should be regarded as the Golden Age of Galleons (1570-1712).

A complementary analysis of iconography will help to clarify the development of the freeboard and upper works of galleons, as well as to complement the rigging reconstruction presented in Chapter V, which complements the Hormaechea et al. 2018 contribution to the understanding of this subject.

Rahn Philips (1993: 234) and Serrano Mangas (1992: 25-32) present diametrically opposed perspectives on whether shipbuilders were following the regulations or not. This can be the result of the fact that Rahn Phillips is referring to the first 14 years of the century and Serrano Mangas makes reference to the period running from 1618 on. The process of gauging or measuring ships that were already built, known in Spain by the time as *arqueo,* was as largely discussed as the proportions that the vessels should have, because beyond the method by which shipbuilders charged for their work, it was the base of taxation, becoming a matter of major interest for the government. Many different methods, with divergent results are described in the documentary sources. Despite how different they are in future research, we will conduct systematic statistical comparisons of a set of measurements of ideal galleons and a data set of galleons that were actually built and gauged. This second set of measurements was kindly provided by Dr. Rahn Phillips. Beyond the previously mentioned problems, systematic statistical analysis and comparison can provide us with some further insight in the discussion of whether or not the regulations were being followed or not. This is a quarry of primary importance for nautical archaeologists as it will show on the extent to which we can rely on treatises and regulations when pursuing our reconstructions.

There are no known formulas for the calculation of tonnage in Portugal in this period. The tonnage seems to have been established by a team of experts with standard barrel hoops and gauges after ships were built (Castro 2003:18)

CHAPTER V

ARCHAEOLOGY OF 17TH-CENTURY IBERIAN SHIPWRECKS: REASSESSMENT AND COMPARISON OF EXCAVATED, RECORDED, AND PUBLISHED HULL REMAINS[1]

That galleon designs were modified across time can be easily attested by glancing at the documentary and iconographical evidence. Unfortunately the archaeological record of galleons of this period has suffered comparatively more harm than that of any other ship type or period, mainly due to systematic looting carried out by treasure hunters. This is especially true of 17th century galleons, which had the reputation of carrying cargos of gold, silver, and precious stones from America (Casaban 2014:267).

The Early Modern Shipwreck Database created by Filipe Castro at the J. Richard Steffy Ship Reconstruction Laboratory (ShipLAB) of the Nautical Archaeology Program (NAP) at Texas A&M University, contains 155 entries for shipwrecks dating from 1600 to 1700 (Early Modern Shipwrecks Database [EMSD]: nadl.tamu.edu). More than one-third (55) of these wrecks have been confirmed as Iberian in origin. Among them, 37 have either been destroyed, looted, or salvaged by treasure hunters, and just 11 have been subject to archaeological study. Of these, five were surveyed after having been looted, three were

[1] Elements of this chapter were previously published in the *International Journal of Nautical Archaeology (IJNA)*. 49 (1): 155-178.

surveyed in normal circumstances, and only three have been excavated. These statistics reveal the archaeological reality of 17th-century Iberian naval heritage. The wide distribution of the published wrecks, encompassing the Americas, Africa, Asia, and Europe, speaks of the frequently underestimated 17th-century naval power of Spain and Portugal (Fig. 8).

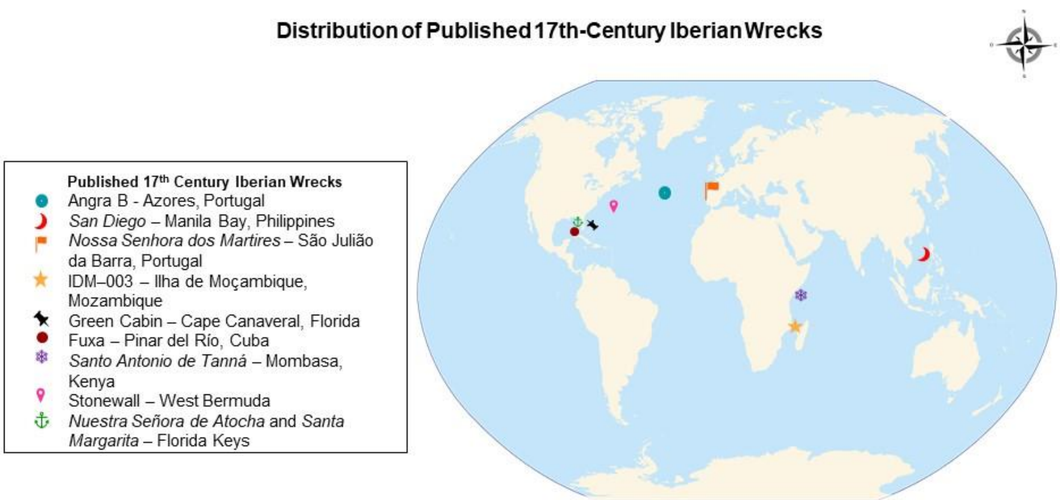

Figure. 8. Distribution of published 17th-century Iberian wrecks. (Issabella Orlando and Emily Robertson. Source: https://commons.wikimedia.org/wiki/File:World_map_longlat-simple.svg/)

Even though based on a small sample, this chapter aims to build on existing theoretical frameworks to better understand 17th-century Iberian shipbuilding practices by comparing the structural components, planking, fastenings, and caulking methods of the seven available published wrecks. It is structured following points 2 to 11 of a checklist for recording shipwrecks published by Castro et al. (2018: 4), based on a previous publication by Steffy (1995). It also assesses if the hulls share the traits proposed as 'architectural signatures' of Early Modern Iberian Shipbuilding by Thomas Oertling (2001: 234) and

Castro (2008: 77) and considers the features included in the most recent version of the trait cluster published by Hormaechea et al. (2018: 64–65). This last is specifically applicable to the 17th century as it is based on documentary sources of the period with special emphasis on the 1618 *Ordenanza*. The hulls have been preserved, recorded, and published to different levels of detail and thus cannot be presented in a consistent way. This study examines the remains of the following vessels: the Angra B wreck sunk in the Angra do Heroísmo Bay, Terceira Island, Azores, Portugal and recorded by a team of the Institute of Nautical Archaeology (INA) in 1996 and later studied by CHAM between 2006 and 2008. It is not clear whether this ship was lost in the last decades of the 16th century or in the first decades of the 17th century, but some characteristics suggest it was an ocean-going Biscayan-built vessel (Crisman, 1999; Bettencourt and Carvalho, 2010; Bettencourt, 2011); the *San Diego*, was lost in 1600 south of Luzon, Philippines, salvaged by Frank Goddio (1994), and published by Michel L'Hour (1994; 1998). The *Nossa Senhora dos Martires* or Pepper Wreck lost off São Julião da Barra at the entrance of the Tagus River in Portugal in 1606, which was partially excavated and extensively published by Filipe Castro (2003; 2005). IDM–003 wrecked off *Ilha de Moçambique*, Mozambique, tentatively identified as *Nossa Senhora da Consolação* was salvaged by treasure hunters but recorded and published by Alejandro Mirabal (2013). The Green Cabin wreck, identified as the *San Martin*, was lost in Florida in 1618 and salvaged by treasure hunters (Moore and Muir, 1987). The Fuxa shipwreck, not yet identified, but probably sunk after 1610 off the north coast of Cuba, was fully excavated and raised in the 1990s (Lopez Perez and Sanson, 1992; 1993). *Santo Antonio de Tanná*, lost in 1697 off Mombasa, Kenya was partially excavated and published by Robin Piercy in the late 1970s and early 1980s (1977; 1978; 1979; 1981). Studies of the hull analysis of *Santo Antonio de Tanná* were not published until 20 years later by Jordan (2001) and Fraga (2007; 2008). Some comments on other wrecks are included, based on the available information. These include the Stonewall wreck, thought to be the Spanish ship *Ragusan* sunk off Bermuda in 1648 and partially published by Dethlefsen et al. (1977) and the Spanish galleons *Nuestra Señora de Atocha* and *Santa Margarita* lost off the Florida Keys in 1622 and salvaged by American treasure hunters led by Mel Fisher (Table 2). Although Oertling's (1989b) original proposal on the Atlantic vessel 'class' was not unanimously accepted by nautical archaeologists, in a later article, he clarified some of the main issues raised (2001: 237). Concerns raised by J.P. Sarsfield and others included the inappropriate use of the word 'class', which is why Oertling (2001) and Castro (2008) adopted the concept of shipbuilding tradition. Some of these concerns and an alternative model were later put forward by Loureiro (2012). The following pages build upon Oertling's 2001 clarifications to address these concerns.

A 'shipbuilding tradition' was defined by Eric Rieth (1998: 178–180) as a considerable number of shared traits comprising 'architectural signatures' in a group of ships. This does not deny the existence of regional specificities and the need to better understand the development of the shipbuilding traditions and their evolving characteristics, encompassing external influences, local practices, changes in the typologies responding to specific purposes and hydrographic conditions, as proposed by Loureiro (2012). Moreover, it complements Oertling's classificatory scheme that seeks to simplify the complexity of a multidimensional reality (Loureiro, 2012: 27). Each ship is unique, but architectural signatures allow us to source the ships to a common cultural origin. Although an individual trait, or more, can be shared by vessels produced by other cultures, what makes a tradition unique is the cluster of many, if not all, of the traits within a series of ship finds (Castro, 2008: 78).

Site	**Lost**	**Max. beam (m)**	**Keel length (m)**	**Length overall (m)**	**L to B ratio**	**K to L ratio**	**K to B ratio**
Angra B	–	–	–	–	–	–	–
San Diego	1600	11.3	–	37.5	3.32	–	–
Pepper wreck	1606	12.3	27.7	39.3	3.19	1.42	2.25
IDM-003	1608	13.9	27.7	39.3	2.83	1.42	2.00
Fuxa	1610	8.6	17.1	25.7	3.00	1.50	2.00
Green Cabin	1618	8.1	21.6	–	–	–	2.65
Nuestra Señora de Atocha	1622	10.1	26.5	33.8	3.36	1.28	2.63
Santo Antonio de Tanná	1697	11.3	32.5	37.5	3.32	1.15	2.88
Stonewall Shipwreck	1700	12.8	–	45.7	3.57	–	–

Table 2. Keel, Beam, Length and Ratios of published 17th-century Iberian shipwrecks (after Early Modern Shipwrecks Database)

The 17th century has been regarded by some scholars as a dynamic period in Iberian ship design. Casaban (2014: 268) highlighted the abandonment of girdling (*embono*) and the introduction of the displacement of the futtocks, using the head of the floor as rotating axis, to increase the beam at the height of the wales (*joba*), in conjunction with an increase of the deadrise (*astilla muerta*). Apestegui (2001) has recognized five major periods: ‘the search for a multipurpose vessel’ (1600–1610), ‘the formulation of proportions’ (1610–1621), ‘times of need’ (1621–1645), ‘the recovery of the naval system’ (1645–1660), and ‘rupture with the traditional system’ (1660–1712). He has further subdivided these periods into stages and has described each of them. However, the trait cluster proposed by Oertling (1989b; 2001) does not refer to ship design; rather, the focus is on the techniques of ship construction which must be seen as a separate aspect of shipbuilding (Oertling, 2001: 238).

Despite changes propelled by developments in Iberian ship design across the period running from 1570 to 1712, the *Ordenanzas* issued in 1607, 1613, 1618, with subsequent modifications in 1666 and 1679, constitute the earliest official attempts of any European monarchy to standardize merchant and naval vessels. In addition, many shipbuilding treatises were produced in the Iberian domains between 1570 and 1712 (Table 3). (the latter date is when Jose Antonio de Gaztaneta (1656–1728) finished his *Proporción de las medidas arregladas a la construccio´n de un bajel de guerra de setenta codos de quilla*, which introduced major changes to Iberian ship design).

Date	**Author**	**Title**	**Country**
*c.*1570	Oliveira, Fernando	*Ars nautica*	Portugal
1575	Mendoza, Juan de Escalante de	*Itinerario de Navegacion de los Mares y Tierras Occidentales*	Spain
1575-1625	Anonymous	*Livro náutico*	Portugal
*c.*1580	Oliveira, Fernando	*Livro da fabrica das naus*	Portugal
1587	Palacio, Diego Garcia de	*Intrvcion navthica para el bven vso, y regimiento de las Naos, su traça, y gouierno conforme à la altura de Mexico*	Spain
1588-1633	Ataíde, D. António de	Harvard Codices	Portugal
1598	Sebastião Themudo	*Traça de uma não da India ordenada por Sebastião Themudo*	Portugal

Table 3. Iberian Texts on Shipbuilding (after Castro et al., 2017)

Date	**Author**	**Title**	**Country**
1598	Roiz, Gonçalo	*Traça de uma não para a India ordenada por Gonçalo Roiz conforme a não Conceição*	Portugal
*c.*1600	Lavanha, João Baptista	*Livro primeiro de arquitectura naval*	Portugal
1607	Anonymous	*Ordenanzas*	Spain
1611	Cano, Tomé	*Arte para fabricar, fortificar y aparejar naos*	Spain
1613	Anonymous	*Ordenanzas*	Spain
1616	Fernandez, Manoel	*Livro de traças de carpintaria*	Portugal
1618	Anonymous	*Ordenanzas*	Spain
*c.*1630	Sousa, Gonçalo de	*Coriosidades de Gonçalo de Sousa*	Portugal
1640-1641	Aguilar, Marcos Cerveira de	*Advertências de navegantes*	Portugal
*c.*1630	Anonymous	*Memorial das varias coisas importantes*	Portugal
1631-1632	Soto, Pedro Lopez de	*The Dialogos entre un Vizcaino y un montañez*	Spain / Basque Country
1688	Gaztañeta, José Antonio de	*Arte de fabricar Reales*	Spain / Basque Country
1691	António Garrote	*Fabrica de Baseles*	Spain
1712	Gaztañeta, José Antonio de	*Proporción de las medidas arregladas a la construcción de un bajel de guerra de setenta codos de quilla*	Spain

Table 3 Continued. Iberian Texts on Shipbuilding (after Castro et al., 2017)

The selection of the 17th century as a research period is justified as the interest shipbuilders had in spreading their knowledge grew exponentially this era, while the first official efforts to standardize designs were made. Equivalent standardization processes could be expected for the fabrication of structural timbers. Shipwrights are considered some of the most conservative, or even arguably traditionalist communities, so changes in shipbuilding generally occur at a very slow rate. Finding the same traits across two centuries is not surprising. Features such as the dovetail joints used for frames, or mast-steps made from an expanded keelson notched over the floortimbers and reinforced by buttresses, proved to be successful structural solutions and thus remained in use for at least two centuries. This is why Carla Rahn Phillips (1993: 235) asserted shipbuilding changed even more warily and slowly than ship design. The risks entailed by radical change were too great to be taken easily. Simultaneously, the ruling classes

> ...prevented technological changes that might threaten their control of society. They did this not only by the use of force but also by monopolizing surplus wealth, exercising bureaucratic control over craftsmen, inhibiting the pursuit of technical knowledge... (Trigger 209: 347)

A fairly consistent set of traits can be found in 17th-century Iberian vessels that are unrelated to size, purpose, or geographic location of the known wrecks, given the expansion of Iberian shipbuilding around the World. Structural solutions were accepted over the centuries by Iberian shipbuilders and they were equally applied to caravels, naos, and galleons, as specific seagoing ship timbers were intended to resist the same or very similar forces in all ship types (Oertling, 2001: 237) (Table 4). This lends credence to the argument that the architectural signature of early modern shipbuilding prevails well into the end of the 17th century, as noted by Hormaechea et al. (2018: 65).

	Angra B	*San Diego*	*Nossa Senhora dos Martires*	IDM-003	Fuxa wreck	Green Cabin wreck	*Santo Antonio de Tanná*
1.Preassembled central frames and dovetail joints	Not reported	Yes	Yes	Yes	Yes	Yes	Yes
2.Carvel planking/Iron fasteners	Iron nails and treenails	Yes	Yes	Yes	Yes	Iron nails and treenails	Yes
3.Sternpost scarphed to upper arm of stern knee	Yes	Yes	Not preserved	Not preserved	Not preserved	Not preserved	Not preserved
4.A single piece deadwood knee timber sits on top of the keel	Not preserved	Not preserved	Not preserved	Not preserved	Yes	Not Preserved	Yes
5.Y-frames tabbed into the deadwood knee	Not preserved	Not preserved	Not preserved	Not preserved	Yes	Not preserved	Yes
6. Keelson notched over floor-timbers	Yes	Yes	Not preserved	Yes	Yes	Yes	Yes
7. Mast-step is expanded part of the keelson	Not reported	Yes	Not Preserved	Yes	Yes	Yes	Yes
8. The mast-step is supported by buttresses/ bilge stringers/fish plank	Not reported	Yes	No	Yes	Yes	No	No
9. Ceiling extending only over the floors, the last strake notched to receive filler planks	Yes	Not Preserved	Not Preserved	Yes	Not Preserved	Not Preserved	No
10. Teardrop-shaped iron strop to accept a heartblock or deadeye	Not reported	Not Preserved	Not Preserved	Not Preserved	Not Preserved	Not Preserved	Not Preserved
11. Flat transom	Not reported	Not Preserved	Not Preserved	Not Preserved	Not Preserved	Not Preserved	Not Preserved

Table 4. Characteristics of 17th-century shipwrecks defining the Iberian shipbuilding tradition (after Oertling, 2001)

	Angra B	*San Diego*	*Nossa Senhora dos Martires*	IDM-003	Fuxa wreck	Green Cabin wreck	*Santo Antonio de Tanná*
12. the face to which the futtocks are attached to floor-timbers changes fore and aft of the master frame or master frames	Not reported	Yes	Yes	Yes	Yes	Yes	Yes
13. Lime and gravel mortar as primary ballast filling the spaces between the frames	Yes	Yes	Not reported	Yes	Not reported	Yes	Not reported

Table 4 Continued. Characteristics of 17th-century shipwrecks defining the Iberian shipbuilding tradition (after Oertling, 2001)

The Ships: History and Discovery

Angra B (late 16th–early 17th century)

It is not clear whether the Angra B wreck was lost in the last decades of the 16th century or the first decades of the 17th century, but some traits, such as the T-section keel and the combination of wooden and iron fasteners, suggest it was an ocean-going Biscayan vessel built in the 16th century. The wreck was probably known since the beginning of SCUBA diving in the Azores, Portugal in the 1960s, but it was not until 1996 that it was recorded by a team from the INA (Crisman, 1999). Further studies were carried on by CHAM between 2006 and 2008 (Bettencourt and Carvalho, 2010; Bettencourt, 2011), but the site has not yet been fully published. It was submerged in Angra Bay, Terceira Island, Azores, Portugal at a depth of 5 m, near to rock formations that constitute a hazard for navigation. The wreck rested 100 m north of Cabo da Figuerinha and 90 m from the shore. Despite intense wave action, the ballast pile, and post depositional sedimentation covering the site have enabled two separate areas of timbers to be preserved. The remains were around 11 m wide and 18 m long, comprising one side of the vessel from the keel up to the third futtocks, including some ceiling planking, stringers, and external hull planking. North-east of the site a small iron artillery piece and some other concretions were located. Olive jar fragments were found on site and the bottom of a wooden bowl was recovered beneath the structure.

San Diego, 1600

The *San Diego*, formerly known as *San Antonio*, was a Spanish galleon built in Cebu, Philippines under the direction of Iberian shipbuilders. It sunk 14 December 1600 in an engagement with the Dutch ship *Mauritius* commanded by Olivier van Noort, who, according to Spanish sources, was attempting to conquer Manila. The *San Diego* was hurriedly armed with 14 guns to defend the city of Manila and was commissioned to repel the Dutch attack. The reasons and circumstances of its sinking are still not clear, as Spanish and Dutch sources present contradictory information (L'Hour, 1994: 122– 123). Goddio (1994: 39) argues that the ship was fully laden, and the weight of the cannons caused water to enter through the portholes, which forced the Vice- Governor and Admiral Antonio de Morga Sanchez Garay to order a retreat. The ship sunk on its way back to port with 350 lives lost in the process. After intensive archival research, a magnetometer survey led to the discovery of the vessel in 1991, in 50 m of water, by Franck Goddio, who was supported by the National Museum of Manila. The wreck rested on a slope and the site measured 26.75 8.80 m. A great many timbers were preserved.

Nossa Senhora dos Martires, 1606

After a nine-month voyage from Cochin, India, including a three-month layover in the Azores, *Nossa Senhora dos Martires* arrived off Lisbon on 13 September 1606 with a cargo of peppercorns. Stormy weather forced Captain Manuel Barreto Rolim to anchor near a village a few kilometers away from the mouth of the Tagus River, in Portugal. On 15 September 1606, the vessel tried to enter the river but hit a rock and sank in a matter of hours adjacent to the fortress of São Julião da Barra leaving a drift of peppercorns floating up and down the coast on the tide for days after the event. In 1996 and 1997, archaeological excavation of the wreck, known as SJB2 or 'the Pepper wreck', yielded porcelain, three astrolabes, two pairs of dividers, various styles of ceramic wares, metal, and organic remains among other finds. Survivors' testimonies were found during archival research and, in 1999 and 2000, excavation of the hull was carried on by members of the *Centro Nacional de Arqueologia Naútica e Subaquática* of the *Instituto Português de Arqueologia* and the NAP of Texas A&M University. A section of the keel, the apron, 11 frames, and some of the planking were recorded. The preserved portion of the vessel encompasses the area forward of the midships frames (Castro, 2003: 6–11).

IDM-003, 1608

In 2001 IDM-003 was found on the north side of the channel off the Cabeceira reef in *Ilha de Mozambique*, Republic of Mozambique. It rested at a depth of 5 m, 1110 m from the *São Sebastião* fortress. The wreck, already extensively salvaged at that point, was tentatively identified as the Portuguese Indiaman *Nossa Senhora da Consolação*, which sank off the island during a Dutch siege in 1608; 16th- and 17th-century material culture was recovered from the site. The partially preserved hull was recorded and published by Alejandro Mirabal (2013). The hull survived to a length of 32.5 m and a width of 12.9 m, including part of the midships bottom and a portion of the starboard side, encompassing the twin decks. Part of a clamp from the gun deck was also found.

Fuxa wreck, 1610

The Fuxa wreck was found while searching for the nao *Nuestra Señora del Rosario*, which sank in 1589 on the reef of Los Colorados between Punta Tabaco and Buenavista, in Cuba. It came to rest in the Quebrado de Fuxa, north-east of the Cayo Rapado. An anchor, two demi-culverins, and fragments of olive jars of the 'mid style' were the first remains located. Later on, many late 16th-century finds were located as a result of a magnetometer survey. The archaeological evidence and the geographical location of the wreck led to its initial identification as *Nuestra Señora del Rosario*, but material dating post 1610 was later found that disproved this initial identification (Filipe Castro, pers. comm.). The report mentions that the wreck was in an outstanding state of preservation and a very interesting find as some of the timbers used for the construction of the ship were from the Americas, including cocus wood or Jamaican ebony (*Brya Ebenus*), Honduras redwood (*Erythroxylum areolatum L.*) and Lemonwood (*Calycophyllum candidissimum*) (InsideWood, 2004; Wheeler, 2011). However, most structural pieces are thought to have been cut from timbers from northern Spain (Lopez Perez and Sanson, 1992). It has been interpreted that the vessel was built in the Basque country and was repaired in the Americas. The hull structure was disassembled, raised and preserved using sucrose (Lopez Perez and Sanson, 1992: 12), but the entire structure was later discarded at an unknown location.

Green Cabin wreck, 1618

Known locally as the Green Cabin wreck and listed in the Florida State site file as 8IR22, this vessel was preliminarily identified as the 300-ton Biscayan-built nao or small galleon *San Martin*. The ship completed two voyages to the West Indies before 1617. Chosen as the *almiranta* (Admiral ship) of the Honduras Fleet of 1618, *San Martin* departed from Trujillo carrying indigo, cochineal, hides, and precious metals. In September, after stopping in Havana, Cuba, where it joined the *Terra Firme* fleet, *San Martin* wrecked on the coast of Florida. The wreck was found in the 1960s by treasure hunters, when four bronze guns were recovered. One of them is now displayed at Fort Caroline, near Jacksonville, Florida and it bears the inscribed date of 1594. Five adittional guns (material is not reported), some measuring more than 3 m in length, were later found on the site and preliminarily identified as 12-pounders. A sixth smaller gun was also found. The wreck lies in a depression on the reef line that acted as a sediment trap so that the remains were covered and protected from the high-energy environment. The 10.66 m-long hull remains represent approximately half of the keel length, probably located towards the bow (Moore and Muir, 1987: 188).

Santo Antonio de Tanná, 1697

The *Santo Antonio de Tanná* was built by an order of the Portuguese Crown issued in 1678. It was constructed as a 42-gun frigate in Bassein, India, an important shipyard close to Bombay (modern-day Mumbai). The hull was built under the supervision of master shipbuilder Manuel da Costa and rigged in Goa. It became part of the vice royal fleet in 1681 and completed at least one voyage to Lisbon and back. In 1697, it was commissioned to be the flagship of a squadron to deliver supplies to São Jesus, a fort in Mombasa, Kenya, which was under siege by Omani forces. It successfully accomplished this mission and was sent again as flagship of a squadron to relieve the fortress. While moored in front of the fort, it was struck by the Omani artillery, lost its mooring lines, and ran aground near the Omani battery after suffering further damage during the confrontation. In the following high tide, the crew towed the vessel to the fort. After assessing the damage, the officers decided to salvage the frigate, but it sank before this could be carried out. Judging by the number of finds on the wreck, an accidental sinking after the salvage of some guns seems likely. The wreck was discovered in the 1960s by scuba divers Conway Plough and Peter Philips in the old Mombasa harbor and excavations took place between 1976 and 1980 by archaeologists from the Institute of Nautical Archaeology (INA) and the Fort Jesus Museum. The hull was neither disassembled nor recovered, but a site plan was drawn and cross-sections were taken over the length of the wreck. Photographic recording was also carried out and more than 15,000 artefacts were recovered (Fraga, 2007: 45–52).

Archaeological evidence

<u>The keels (Table 5)</u>

When a shipwreck is sitting on the seafloor upright without listing to the sides or having capsized, the study of the keel regularly entails disassembling the remains, thus the information about the keels of 17th-century Iberian shipwrecks is limited (Table 5). The keel of the Angra B shipwreck was visible in the southern extreme, but its full length has not been determined as yet (Bettencourt and Carvalho, 2010: 78). The keel of the *San Diego* was not exhaustively studied for lack of time (L'Hour 1998: 238). Just an exposed portion of the keel in the south- west area of the Green Cabin wreck was recorded. Only the keels of the Pepper Wreck and the Fuxa wreck were studied to their full preserved dimensions.

Site	**Keel Length (m)**	**Keel Sided (cm)**	**Keel Molded (cm)**	**L to S ratio**	**L to M ratio**	**S to M ratio**
Angra B	–	24.5–27	–	–	–	–
San Diego	23.7	30.0	36.0 (including false keel)	79	65.8	0.83
Pepper wreck	27.7	25.0	46.0	110	60	0.54
IDM-003	27.7	28.0	–	98.9	–	–
Fuxa	17.1	25.0	30.0	68.4	57	0.83
Green Cabin	21.3	–	–	–	–	–
Nuestra Senora de Atocha	26.5	–	–	–	–	–
Santo Antonio de Tanná	32.5	–	–	–	–	–

Table 5. The keels of published 17th century Iberian shipwrecks (After Early Modern Shipwrecks Database)

The southern extremity of the keel of the Angra B wreck has a T-section, resembling 16th-century Iberian vessels such as the *San Juan*, the *Corpo Santo* shipwreck, and the Padre Island vessel (Oertling, 2001: 236). This feature has been interpreted as a step in the transition from shell-first to skeleton-first built vessels and suggests the Angra B shipwreck was built in the 16th century, rather than in the 17th century. Evidence suggests that the keel of the Angra B wreck was lead sheathed (Bettencourt, 2011: 221). Two types of fasteners have been recorded on the keel of the Angra B wreck: 10 mm square-section iron nails and 3 mm-diameter bolts. In close proximity to this wreck a stern knee was found. It is not clear if this timber belonged to this wreck as it was redeposited over the iron sheets of a more recent vessel. This timber shows a close resemblance to the stern knee of the *San Juan*, the Ria Aveiro A wreck, and the *Corpo Santo*, and matches the specifications of the shipbuilding treatise of João Baptista Lavanha (c.1600) (Bettencourt and Carvalho, 2010: 80; Bettencourt, 2011: 225). The timber is rabbeted to receive the hull planking and was tabbed to receive at least one Y-frame. It presents strong similarities with the stern assembly of the *San Diego*.

The keel of the *San Diego* was not extensively studied, as the salvors did not disassemble the ceiling and frames. It appeared almost complete from the heel of the stern knee to the base of the stem. Its wood type was identified as *Calophyllum inophyllum*, known as Philippine *bitaog*. Trees of this species can grow up to 40 m tall, although it is not known whether the keel was made of a single piece. Its archaeologically reported length is 23.39 m, equivalent to 42 Spanish *codos* (cubits)—a measurement equivalent to 557 mm used by the shipwrights of the period. Its molded dimension at 0.3 m, seems somewhat small, but this was compensated with the false keel adding 0.21 m to the structure's molded dimension. This is the only false keel reported among the published vessel, was fixed with the same bolts that ran through the keelson, the floor- timbers, and the keel (L'Hour, 1994: 146–147). The after end of *San Diego*'s keel was fastened to a stern knee, similar to those identified in Iberian wrecks of the previous century, such as the *San Esteban* and the *San Juan*. This timber made the transition between the keel and the sternpost. The rising section of the stern knee was 1.10 m in length (L'Hour, 1994: 146–147).

The keel and the apron of the Pepper Wreck were made of cork oak (*Quercus suber*), a wood commonly used in the 16th and 17th century in the shipyards of Portugal. Its sided dimension closely coincided with 1 *palmo de Goa* (257 mm), a measurement used by Portuguese shipbuilders of the time. Its full molded dimension was not preserved, but a preserved bolt suggested it was 460 mm. The keel was made using very short sections fastened together by flat vertical scarfs with two transverse spikes to secure them. The scarf tables were caulked with animal felt. The keel had rabbets measuring 50 mm in depth and 90 mm in height. The apron was bolted atop the keel and was notched to fit the frames. Round-headed bolts were driven from underneath the keel to secure the keelson (Castro, 2003: 12).

The keel of IDM-003 was preserved to a length of at least 20.55 m and its total estimated length was based on the Oliveira treatise's, description of a *nau* of 18 *rumos* (a unit used by Portuguese shipwrights of the period equivalent to 1.54 m). Its molded dimensions have not been determined. Apparently, it was made of the same wood type as the frames, the keelson, and the deck clamps (Mirabal, 2013: 64).

The keel of the Fuxa wreck was 17.1 m long, 0.25 m sided and 0.30 molded, but was not reported in greater detail. Apparently, it was not rabbeted for the garboard (Lopez Perez and Sanson, 1992: 25).

The length of the keel of the Green Cabin could not be measured, but it was calculated by Moore and Muir at 21.6 m (1987: 191). It ended abruptly at the bow with a butt, which was 89 mm thick, but there might have been a broken scarf at this location.

The keel of the *Santo Antonio de Tanná* was not recorded, as it was not accessible during the excavations. However, its length has been estimated by Fraga as 21 *rumos* (32.5 m) (Fraga, 2007: 128).

According to different documentary sources consulted by Hormaechea et al. (2018: 70), in 17th-century Spanish ships, the keel sections were jointed with butt scarfs; however, butt scarfs have not been reported in any of the wrecks compiled here. Unlike Spanish documents, the Portuguese Lavanha (*c.* 1600) wrote that keel sections should be joined with vertical flat scarfs, which is the case of the Pepper wreck. So far, only one common trait has been recognized among the keels of published Iberian vessels of the 17th century and that is the sided to molded ratio of *San Diego* and the Fuxa wreck, being 0.83 m in both cases (Table 5). No consistent construction traits have been noted: some are rabbeted for the garboard, but the Fuxa wreck seems to suggest that Iberian ships' keels were not always rabbeted for the garboard. The Angra B wreck seems different from the others as the T-section, eliminates the need for rabbet (Hormaechea et al., 2018: 65). Whether the decision to rabbet the keel or not was a difference between Portuguese and Spanish vessels, or if this changed in the second quarter of the century are questions that deserve further investigation. It also might have been a difference between shipyards, or between cheaply built or more methodically built vessels. The number of pieces used for the keels might have also varied. No reference to tapered or rockered keels has been reported.

Keelsons and mast-steps

Site	Lost	Keel Length (m)	Keelson Sided (mm)	Keelson Molded (mm)	Keelson Length (m)	L to S ratio	L to M ratio	S to M ratio	Keel L to Keelson L ratio
Angra B	–	–	–	–	–	–	–	–	–
San Diego	1600	23.7	200-250	250-350	17.50	70–87.50	70.00	0.80	1.35
Pepper wreck	1606	27.7	–	–	–	–	–	–	–
IDM-003	1608	27.7	210-240	340	12.95	53.9–61.6	38	0.61-0.7	2.1
Fuxa	1625	17.1	280-450	280-450	3.83	8.51-13.68	13.68	1.00	4.46
Green Cabin	1618	21.3	300-430	250	5.79	13.47-19.30	23.16	1.20	3.68
Santo Antonio de Tanná	1697	32.5	275-340	307	29.68	87.29-107.85	96.61	0.90	1.10

Table 6. The keelsons of published 17th century Iberian shipwrecks (After Early Modern Shipwrecks Database)

Site	Mast-step Length (m)	Mast-step Sided (mm)	Mast-step Molded (mm)	Mast-Mortise Length (mm)	Mast-Mortise Width (mm)	Mast-Mortise Depth (mm)
Angra B	–	–	–	–	–	–
San Diego	3.40	350	300	310	170	165
Pepper wreck	–	–	–	–	–	–

Table 7. The mast-steps and mast mortises of published 17th century Iberian (After Lopez Perez and Sanson, 1993; L'Hour, 1994; Fraga, 2007; Mirabal, 2013)

Site	Mast-step Length (m)	Mast-step Sided (mm)	Mast-step Molded (mm)	Mast-Mortise Length (mm)	Mast-Mortise Width (mm)	Mast-Mortise Depth (mm)
IDM-003	–	210-390	340	700	230	170
Fuxa	1.70	450	400	600	140	200
Green Cabin	–	–	–	–	–	–
Santo Antonio de Tanná	3.2	500	–	480	210	154

Table 7 Continued. The mast-steps and mast mortises of published 17th century Iberian (After Lopez Perez and Sanson, 1993; L'Hour, 1994; Fraga, 2007; Mirabal, 2013)

Keelsons are one of the most important longitudinal structural components of a vessel (Tables 6 and 7). Most of the keelsons of the 17th-century Iberian shipwrecks were preserved and reported although the Angra B shipwreck has not yet been reported and in the case of the Pepper wreck this important structural component was not preserved. The keelson of *San Diego* was made out of a single log. It was found broken in three pieces. The mainmast step was integrated into the keelson. The wood was identified as *Terminalia microcarpa*. This wood is resistant and easy to work, is rarely attacked by insects and is still in use among shipbuilders in the Philippines. The keelson was massive and roughly squared. It was bolted to the floor-timbers, the false keel, and the keel. The bolts were driven from its upper surface into almost all floor timbers, but seven. Three of the unbolted frames correspond to the area of the mast- mortise on the integrated mainmast-step. There is no apparent reason why it is not bolted to the other four frames. The mainmast mortise was located towards the aft portion of the mast step. It was around 1.5 m abaft the two midship frames and 11.10 m before the after end of the keel. *San* Diego's keelson also had eight mortises for stanchions. One of the mortises was only partially carved into the keelson; it has been suggested that the shipbuilders decided to relocate the corresponding stanchion (L'Hour, 1994: 148–149).

The keelson of the *Nossa Senhora dos Martires* was not preserved and no traces of the mast-step were found. However, it was apparently fastened with an iron bolt afore and baft of each keel scarf that runs through the floor-timbers. In contrast to the *San Diego*, the bolts were driven from underneath the keel (Castro, 2003: 12).

The keelson of IDM-003 was close to 1 *palmo de Goa* (256 mm) sided. It also widened in the area of the mast-step (Fig 9). The keelson was composed of five pieces joined using what Mirabal (2013: 65) named swallow-tail scarfs (Table 8). Observing the detailed illustrations (Mirabal, 2013: 68, 71, 72) and following Steffy's glossary (1994: 295) they were in fact hook scarfs. The general illustration of the keelson (Mirabal, 2013: 66) shows what Steffy called curved scarfs. The keelson had notches on its underside to fit over the floor-timbers. The notches varied between 210 mm and 290 mm deep. The upper face of IDM-003's keelson had six mortises for deck stanchions, with wooden wedges affixed with bolts and made out of a different wood type than the one used for the keelson. Mirabal (2013: 65) suggested that they were used to support the orlop deck. The keelson had 32 bolt holes classified in three types; circular section with a diameter of 30 mm, square section 20 mm per side, and square section of 10 mm per side. Rusted fragments of the bolts indicated they were made of iron.

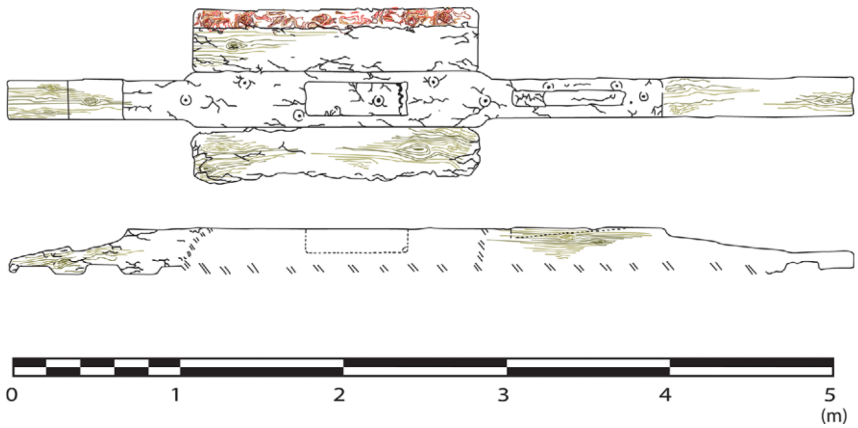

Figure 9. Mast-step of IDM-003. Approximated Scale. (Laura Martínez Paris. After Mirabal, 2013).

IDM-003 keelson section	**Length (m)**	**Sided (mm)**	**Molded (mm)**	**Notes**
K1	1.35	230	300	The most northern piece of the keelson. Its southern portion was connected with K2 using what Mirabal (2013: 65) called wedge scarf. A slanted mortise was recorded along the centre of its upper surface. It had four bolt perforations and one of those reached beyond the body of the floor-timber to fit the keel.
K2	5.60	210-230	340	Expanded in the area of the mast-step. It had hook scarfs to fit K1 and K3 from below. A mortise and part of a second one were noticeable in its upper surface, which also contained the mast mortise, located at its centre. The interior width of the mast-mortise narrowed towards the northern extreme and it ended in a trammel. Eight bolt perforations were observed in K2.
K3	3.27	240	310	Joined with hook scarfs to K2 and K4. It had the overlapping portion of the scarf in both ends. Two stanchion mortises were visible in its upper surface and it had seven bolt perforations.
K4	5.28	220-240	290	Second biggest piece of the keelson. Its lower face was notched for 11 floor-timbers. It presented two stanchion mortises in its upper surface and hook scarfs to fit K3 and K5. The scarfs had a length of 78 cm and 76 cm. It had 10 bolt perforations that coincided with the floor-timbers underneath.
K5	1.25	230	–	Southern end of the keelson. It was so degraded that its dimensions could not be properly measured. No stanchion mortises were reported and it had a hook scarf to fit K4. It was notched over at least one frame. Two bolt perforations were reported.

Table 8. IDM-003 keelson sections. (After Mirabal, 2013)

The keelson of the Fuxa wreck was made of *Quercus pubescens*. It is the shortest of the reported keelsons, but even so it was formed by three rectangular sections of different dimensions (Table 9). It was notched on its underside for the floor-timbers with each notch adjusted to the corresponding frame below (there are differences among the heights of the frames). A total of 13 notches were counted for the floor-timbers between frame 74 and the 101. It was also notched for the riders and scarfed for what the report called the false keel but should probably be understood as part of the keelson itself.

Fuxa keelson section	Length (m)	Sided (mm)	Molded (mm)
A	1.30	280	250
B	1.70	450	400
C	0.85	280	280

Table 9. Fuxa wreck keelson sections (After Lopez Perez and Sanson, 1993)

Section A was the aftermost section of the keelson and it ends at what the authors have called the false keel (23) and the rider (241). It had four notches and a scarf for the 'false keel'. In the scarf, there was a hole all the way through (0.30 m), which might have served to join the 'false keel' to the keelson with a bolt. The notch that was observed over floortimber 165 also had a similar hole which according to the authors (Lopez Perez and Sanson, 1993: 16), might have served to join these two members with a bolt, but there was no other evidence of this. Rectangular grooves on this section have been interpreted as mortises for stanchions.

Section B of the Fuxa Wreck contained the mast-step (Fig. 10). Its mortise was a rectangular opening, with a connected mast chock wedge mortise measuring 0.20 mm long by 70 m wide and 10 mm deep. The maststep timber was notched over just four floortimbers.

The base of the bilge pump was found in association with this piece and was 200 x 170 x 30 mm, with four holes for bolts of 5 mm diameter. A quadrangular 60 x 60 mm mortise was reported on this piece. It was apparently for the stanchion that supported the mast partner.

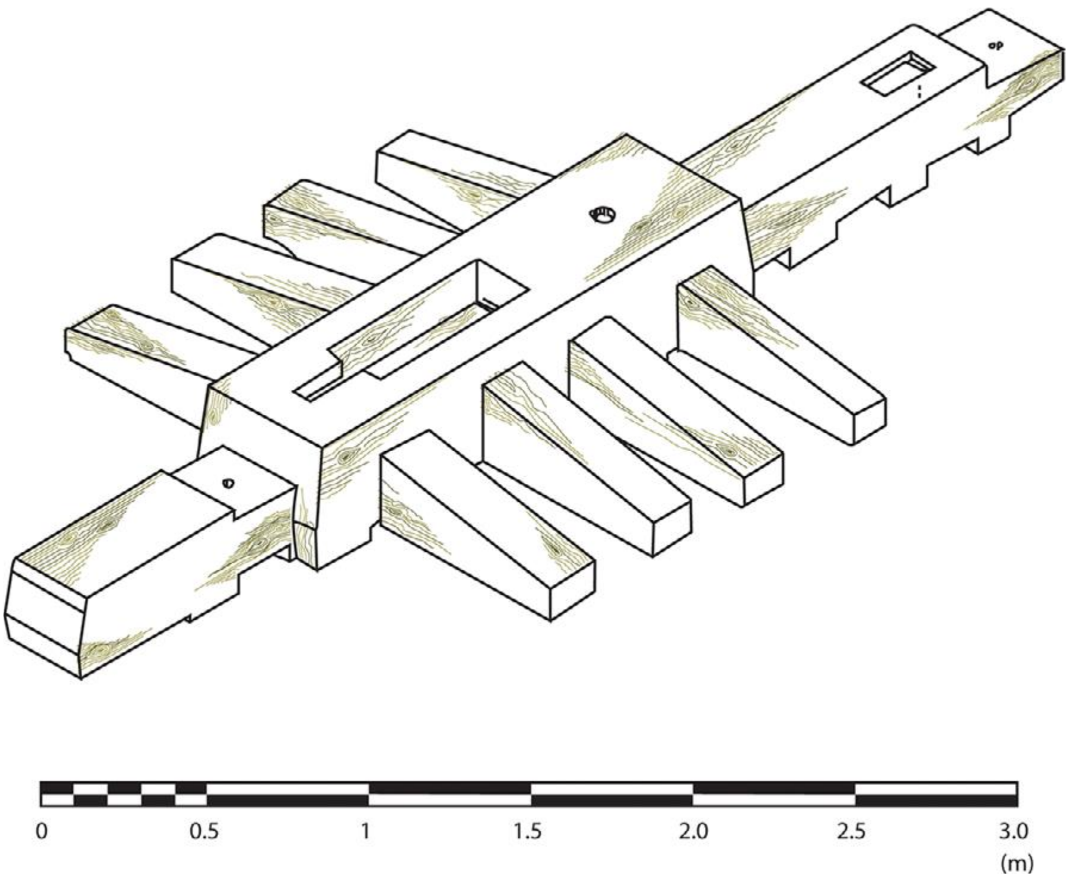

Figure 10. Reconstruction of the maststep of the Fuxa wreck. Approximated Scale. (Laura Martínez Paris. After Lopez Perez and Sanson, 1993: fig.14).

Section C, located toward the foreward end of the Fuxa Wreck, ended at the rider (129). It was notched for two frames and had an additional notch on the upper surface to fit a rider. A hole joined the rider and the keelson at this point. Six iron bars of between 0.88 m and 0.98 m in length were found on the starboard side of this piece; the bars were 80-120 mm wide and 70-80 mm thick and their function is unknown.

The keelson of the Green Cabin wreck was preserved over a length of 5.79 m. Its length listed in Table 6 is an estimate, and the molded dimension was indicated by drift bolts (Moore and Muir, 1987: 1991). The keelson tapered towards the bow and it was notched to fit floortimbers 1 through 13. It had its thickest point over floor-timber 8, and tapered to its minimum over floortimber 1.

The keelson of the *Santo Antonio de Tanná* was composed of three pieces (Table 10) connected by horizontal rounded butt scarfs. The two convex surfaces of the scarf abaft the maststep pointed to the bow and those afore the mast-step pointed to the stern. This was described by Fraga (2007: 133) as unusual. The first section of the keelson towards the stern was complete. The second comprised the mast-step. The third section was incomplete. It was attached to the mast-step and tapered towards the bow. The keelson was fastened to each frame with two iron bolts, of which only concretion remained. Notwithstanding, some bolts appeared to have missed the frames.

***Santo Antonio de Tanná* keelson sections**	**Length (m)**	**Sided (m)**	**Molded (m)**
1	18.88	–	–
2	–	–	–
3	8.12	0.275	–

Table 10. *Santo Antonio de Tanná* wreck keelson sections. (After: Fraga, 2007)

The maststep of the *Santo Antonio de Tanná* was an expanded keelson and its sides were reinforced using a fish plank on each side. These planks were 3 m long and 0.10 m thick. No evidence of fastenings was recorded. The depth of the mastmortise was not reported, but Fraga estimated it as 0.15 m, which seems shallow when compared to the other wrecks. Two additional mortises for stanchions were reported, one fore and one aft of the mast-mortise. They were 0.25 by 0.05 m and were located 1.3 m apart. One stanchion might have supported the deck beam that served as the mast partner. Six additional stanchion mortises were reported, three forward and three aft of the mast-step. Aft of the mast-step they were spaced 2.3 m apart. The spacing of the mortises forward the mast- step increased with intervals of 2.6 m, 3.2 m and 4.9 m recorded. These mortises were 0.20 m long by 0.05 m wide. Their depths were not reported. Researchers also described two holes for the pump tubes aft of the mast-step but not on the mast-step timber directly. The starboard pump hole was partially covered by ceiling planking, so it was probably not in use.

All the described keelsons widened to integrate the mast step, which is the seventh trait of Early Modern Iberian vessels as outlined by Oertling (2001: 236) and Castro (2008: 78). This trait is ubiquitous in Iberian shipbuilding treatises, being first mentioned by Tomé Cano in 1611 and still present in the descriptions of Garrote (1691) 80 years later (Hormaechea et al., 2018: 143–144). The sixth trait is a notched keelson, but this cannot be regarded as uniquely Iberian as it has been observed in ships from other regions. Hormaechea et al. (2018: 104) confirmed keelson were notched for the floor timbers and added that keelsons were always fastened by bolts inserted from below the keel and crossing the floor-timbers. *San Diego* represents an exception, as in most Iberian vessels the lower face of the keel had countersinks for the heads of the bolts and the tips of the bolts were riveted with a washer and a forelock over the keelson. Based on archival and secondary sources Hormaechea et al. (2018: 108) have suggested there was a bolt every other floor-timber and the bolts were not placed in the centerline of the keel. Bolt location alternated to port and starboard forming a zig-zag pattern. Closer attention must be payed to recording these features—where present—in future archaeological hull research. Several points of similarity can be noted between the keelsons of the six wrecks, but few features are shared by them all. The keelsons of *Santo Antonio de Tanná* and *San Diego* were considerably longer than the others. Although shorter, the keelson of IDM-003 was also very long in comparison to the remaining wrecks.

One similarity is that the keelsons of the Fuxa wreck and the Green Cabin wreck were notched over exactly the same number of floor-timbers, 13 in total. Notches were also reported in the case of IDM-003 and, even though they have not been reported, in the case of *Santo Antonio de Tanná* nothing in the report suggests the keelson was not notched. Although very different, the keelsons of the Fuxa wreck and *Santo Antonio de Tanná* were composed of three pieces. The keelson of the Angra D wreck, another Early Modern Iberian vessel found in the Bay of Angra do Heroísmo, also had three pieces (García and Monteiro, 1998: 442). Unlike these wrecks, the keelson of IDM-003, was made up of five pieces. In all cases the keelsons are bolted through the frames. No conformity in scarfs used to join the pieces can be reported.

Hormaechea et al. (2018: 130) mention there was much variation in the number and location of the stanchions in Iberian vessels of the 17th and 18th centuries. However, both the *Santo Antonio de Tanná* and the *San Diego* have eight over the keelson. A slight overlap in the ranges of the length to sided ratios of the keelsons of *San Diego* and *Santo Antonio de Tanná* can be noted. In the cases of the Fuxa wreck and *San Martin*, the ratio for the keelsons also overlaps, but again by a minimal margin. The sided to molded ratios vary greatly. However, the sided and molded dimensions of the keelsons of the *San Diego* and IDM-003 were similar, as were the depths of their mast mortises. No other patterns have been discerned in the available data.

Buttresses

Iberian shipwrecks of the 16th century often had mast steps formed by a wider portion of the keelson and were laterally shored with buttresses (Oertling, 2001: 236).

IDM-003 had buttresses, although the author refers them as mast step braces (Mirabal, 2013: 75). There were two pieces with a trapezoidal transverse section holding the mast step in place (Fig. 9). The west buttress was described as 2.34 m long, 0.40 m high and 0.39 m wide. It had eight spike perforations. No other descriptions have been provided.

In the Fuxa wreck eight buttresses prevented the lateral movement of the mast-step (Fig. 10). They had a rectangular section and the shape of a wedge of a right-angled triangle without its tip. The highest portion was in contact with the mast step. They were all slightly different in shape and the ones mounted on the starboard side were longer than the ones to port. They were secured by unidentified metal fasteners with diameters varying between 10 mm and 20 mm. Four or five fastener holes were found on each buttress in no discernible pattern.

The reinforcement of the mast step to prevent lateral movement is a feature shared with the *Santo Antonio de Tanná*; however, it did not have buttresses, but a fish plank on each side of the mast step. In the Fuxa wreck, two riders also helped to prevent movement of the mast step, with one abaft and one afore it. They had different shapes and were apparently notched to fit the stringers and the mast step.

Oertling (2001: 236) and Castro (2008: 78) both list buttresses as the eighth trait commonly found on Iberian ships. In the examples discussed here, we can see three different solutions preventing the movement or breaking of the mast step but buttresses specifically were used in only two cases. Bigger and fewer buttresses were used in the IDM-003 than in the Fuxa wreck. References to the need for lateral supports for the mast step in 17th century Iberian vessels, with buttresses the most frequently used solution, can be found in Tomé Cano (1611), the 1618 *Ordenanza*, and Garrote (1691) (Hormaechea et al., 2018: 143–144).

Stem and sternposts

The stern assemblages of *San Diego*, *Santo Antonio de Tanná* and the Fuxa wreck were preserved and studied. Additionally, a stern assemblage was found near by the Angra B wreck site, but it has not been determined if it pertained to the same ship. The following paragraphs describe the assemblages and discuss their differences and similarities.

A short-arm stern knee with a preserved length of 2.60 m was found in a survey in the proximity of the Angra B shipwreck (Fig. 11) (Table 10). It has a maximum sided dimension of 0.18 m at the base and a minimum sided dimension of 0.10 m of the upper surface. Its molded dimension has been preserved to a height of 0.19 m at its fore end and it reaches 0.39 m aft. At 1.70 m abaft its fore end where it was attached to the sternpost, it presents an oblique rabbet for the hull planking. The horizontal section is also rabbeted to an approximate depth of 40 mm. It has a tab which apparently served to accommodate a Y frame (Bettencourt and Carvalho, 2010: 80; Bettencourt, 2011: 225).

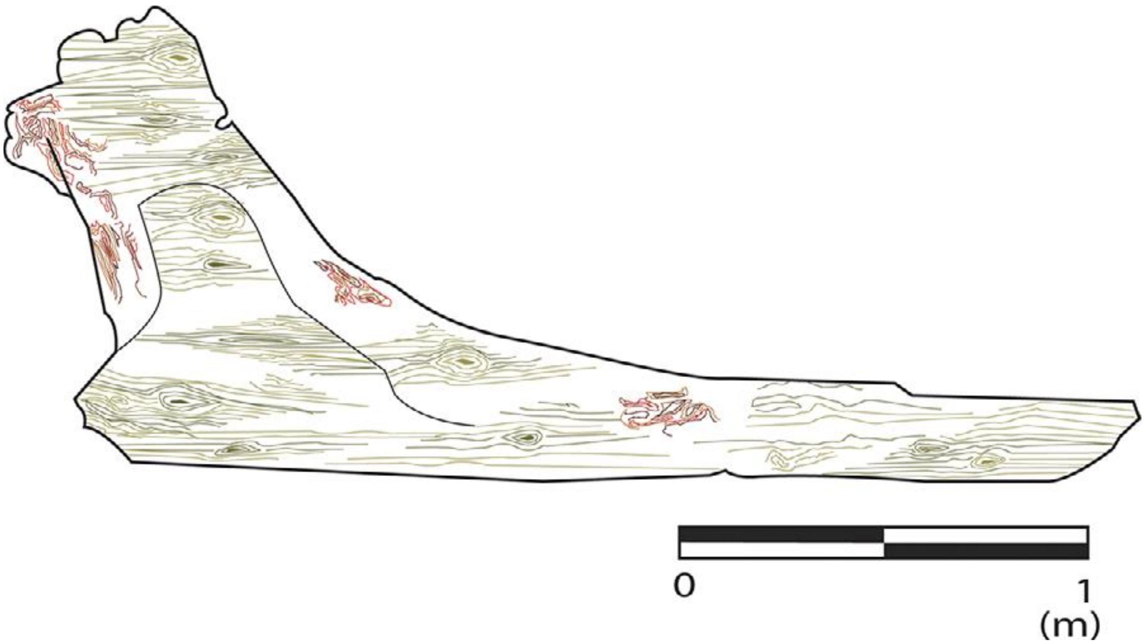

Figure 11. Stern knee found near the Angra B wreck (Laura Martínez Paris. After Bettencourt and Carvalho, 2009: 80).

Despite the short portion of sternpost that was preserved in the *San Diego*, L'Hour (1994: 147) determined that a single timber was used for the junction between the keel and the sternpost (Fig. 12). This integrated assembly offered greater streght and the Portuguese author João Baptista Lavanha mentions this in his treatise (c.1600). The preservation of the keel section that projected upwards and the lower portion of the sternpost allowed an angle of rake of the post of 60 degrees to be calculated. This measurement is the lowest angle reported among Iberian wrecks and shipbuilding treatises (L'Hour, 1994: 147).

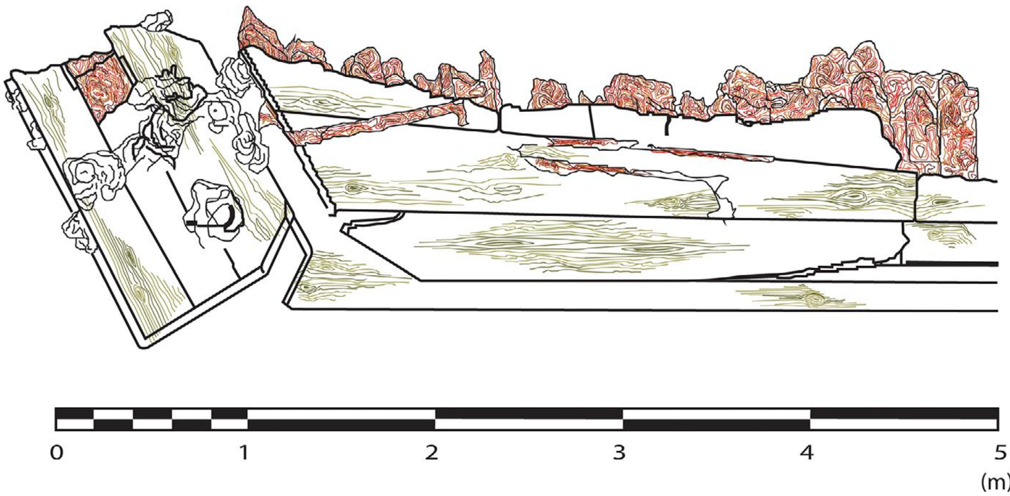

Figure 12. Reconstruction of the stern of the *San Diego.* Approximated Scale (Laura Martínez Paris. After L'Hour, 1994: 142).

The *San Esteb*an had a 65-degree angle and *San Juan* was between 65 and 70 degrees (Grenier et al., 2007). According to Garcia de Palacio (1587), the rake should be between 65 and 70 degrees. The English shipwright Mathew Baker (c.1586) suggested between 70 and 72 degrees, while Portuguese author Fernando Oliveira (c.1580) 77 and for Manoel Fernandez (1616) between 79 and 82 degrees.

The sternpost of the Fuxa wreck was found along with the false sternpost (Table 11).

Site	**Sternpost**	**Length**	**Sternpost/ False sternpost sided (cm)**	**Sternpost/ False sternpost molded (cm)**	**Stem**	**Stem sided (cm)**	**Stem molded (cm)**
Angra B	–	–	10-18	19–39	–	–	–
San Diego	60 degrees	–	–	–	–	–	–

Table 11. Sternpost and stem of published 17th century Iberian shipwrecks (after EMSD; Lopez Perez and Sanson, 1993)

Site	**Sternpost**	**Length**	**Sternpost/ False sternpost sided (cm)**	**Sternpost/ False sternpost molded (cm)**	**Stem**	**Stem sided (cm)**	**Stem molded (cm)**
Pepper wreck	–	–	–	–	–	–	–
IDM-003	–	–	–	–	–	–	–
Fuxa	70 degrees	1.30 m *1.73 m*	25 *21*	32 *23*		75?	15
Green Cabin	–	–	–	–	–	–	–
Santo Antonio de Tanná	–	–	40.1	40.1	–	–	–

Table 11 Continued. Sternpost and stem of published 17th century Iberian shipwrecks (after EMSD; Lopez Perez and Sanson, 1993)

Archaeologists studyng the Fuxa Wreck also found a deadwood knee (curva coral). The base of this timber extended 2.70 m from the keel. The edge in contact with the stern post was 1.72 m long and the knee was 0.17 m thick. Seven planks with a width of 0.50–0.70 m were fastened to it. This timber had some notches, that might have served to accommodate the Y-shaped frames (Lopez Perez and Sanson, 1992: 24; 1993: 21) (Fig. 13).

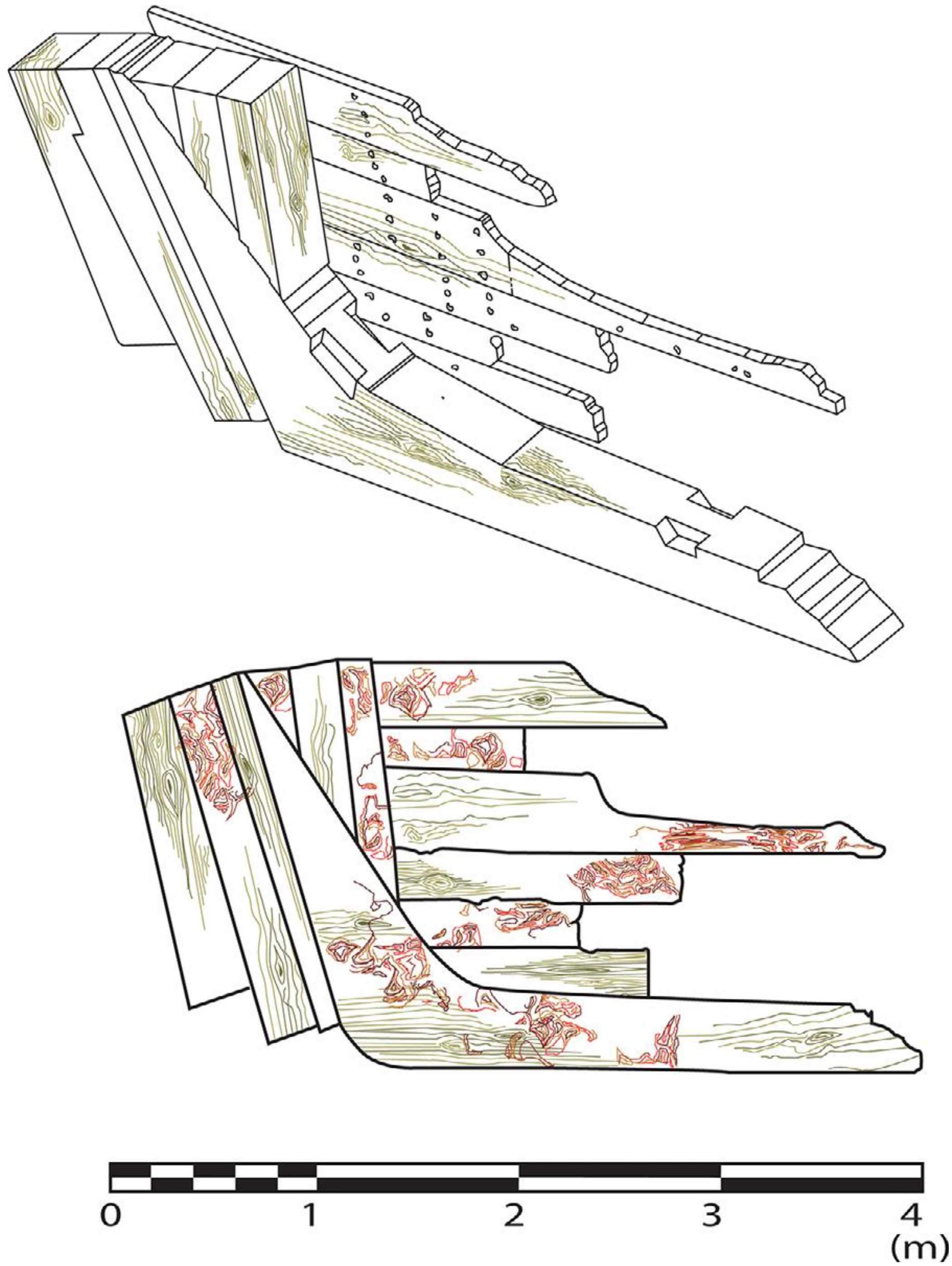

Figure 13. Reconstruction of the stern of the Fuxa wreck. Approximated Scale. (Laura Martínez Paris. After Lopez Perez and Sanson, 1993: fig. 26–27).

Archaeologists working on the Fuxa wreck also found two pieces that possibly belonged to the bow. They are shaped like a stem and false stem, but the molded dimension of 0.15 m seems too small for such structures. They had a length of 1.5 m and together had a base 0.75 m long. The exterior piece had a notch in its lower portion (Lopez Perez and Sanson, 1993: 9)

The bow of the *Santo Antonio de Tanná* was not preserved, probably due to the sinking process. The stem has not been identified among the disarticulated timbers. However, timbers identified as the lower end of the stern assemblage were partially preserved. The measurements of the stern (Table 11) were estimated by Fraga (2007: 128–129) from the photomosaic. Fraga attempted a reconstruction with two inner posts and an additional timber he discerned in the assembly (Fig. 14). What he describes as the first inner post, immediately forward of the sternpost, received the fashion pieces that were locked in place by the second inner post, which was notched for the wing transom. It is not clear whether the main sternpost was attached to the keel using a mortise-and-tenon joint reinforced with a deadwood knee or if it had a stern knee. According to Fraga's (2008) reconstruction it had both. The knee was notched to receive the Y-frames.

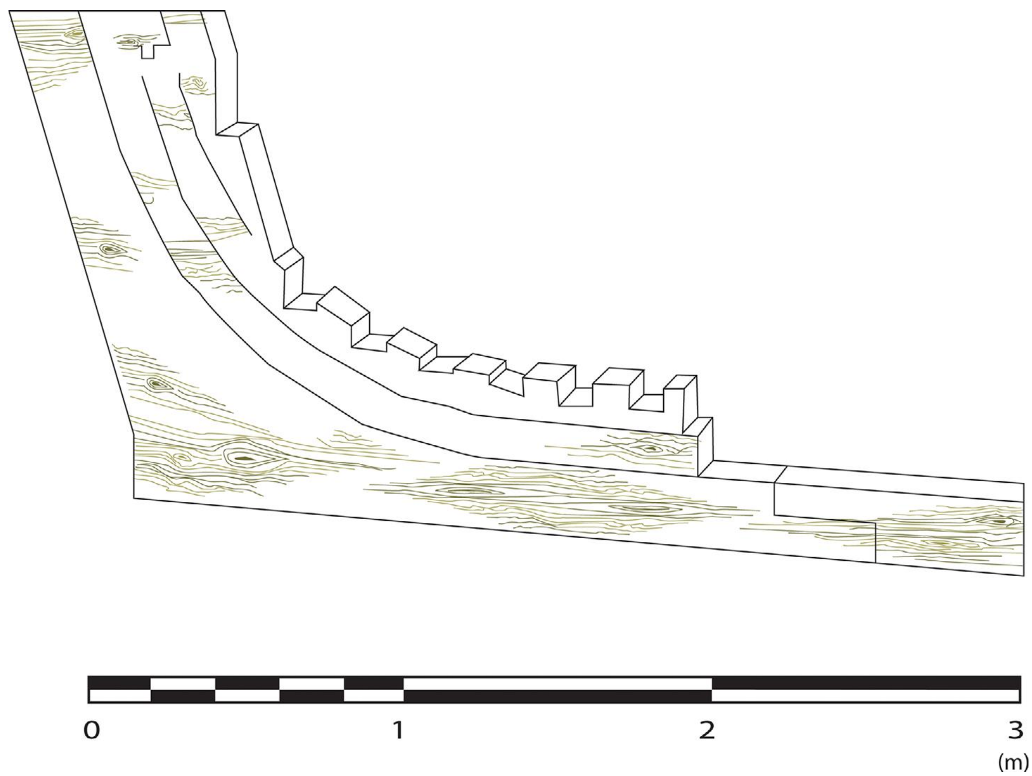

Figure 14. Reconstruction of the stern of the *Santo Antonio de Tanná.* Approximate Scale. (Laura Martínez Paris. After Fraga, 2007: Fig.79).

According to Oertling (2001: 234) and Castro (2008: 9), the third trait of Iberian vessels was the use of a curved timber (*couce*/stern knee/*pie de roda*) for the junction between the keel and sternpost. Stern knees of *San Diego* and near the Angra B wreck. These timbers show close resemblance with the stern knees of the *San Juan*, the Ria Aveiro A and the *Corpo Santo*, and match the João Baptista Lavanha's specifications (c.1600) (Bettencourt and Carvalho, 2010: 80; Bettencourt, 2011: 225). The stern knee found near the Angra B shipwreck is rabbeted to receive the hull planking and it is tabbed, apparently to receive at least one of the Y-frames. This stern knee presents strong similarities with the stern assembly of the *San Diego* and both of them conform to Oertling's (2001) third trait (Table 4).

Alternatively, the Fuxa wreck and the *Santo Antonio de Tanná* had a different stern configuration, one that is closer to the versions described by Cano (1611), the *Dialogo entre un Vizcaino y un Montañés* (1635) and the 1666 *Ordenanza*. The sternpost is attached to the keel with a butt scarf and a mortise-and-tenon joint reinforced with a superimposed curved knee (*curvacoral*/deadwood knee), which received the typical Y-shaped frames (*picas*) commonly fitted in this area (Oertling, 2001: 234; Castro, 2008: 9, Hormaechea et al., 2018: 74–79). The mortise-and-tenon joint did not survive in any of the wrecks, but both had deadwood knees that were notched for the Y-frames and thus they satisfy Oertling's (2001: 236) fourth trait (Table 4).

Hormaechea et al. (2018: 74–79) asserted there was a smooth transition between the stern knees and a butt scarf with a mortise-and-tenon joint between the sternpost and the keel that in turn was reinforced with a superimposed deadwood knee. The authors explain that many solutions might have been applied with this assembly. The stern assemblages of the Fuxa wreck and *Santo Antonio de Tanná* might represent certain transitional configurations.

The archaeological examples presented here can be used to continue to build answers to questions posed by Hormaechea et al. (2018: 79), as they assert it is not known how long the system of the stern knee and the attachment of the sternpost over a mortised keel and the system of a direct junction of the sternpost to the top of the keel coexisted. They also ask how long the short-armed knee was used in Spain. *San Diego*, lost in the first decade of the 17th-century, had a recognizable stern knee and the timber found nearby the Angra B shipwreck was also a short-arm stern knee. However, the Fuxa wreck and *Santo Antonio de Tanná* had different arrangements. A more precise association and date for the short-arm stern knee found near the Angra B shipwreck, as well as revisiting the stern assemblage of

Santo Antonio de Tanná, and a more precise date for the corresponding structure in the Fuxa shipwreck, would be enormously valuable. As Hormaechea et al. (2018) have asserted, short-arm stern knees might have been abandoned in the early days of the 17th century, making the absence of this trait a potential dating parameter.

The sample of sternposts and stems is too small to allow any further comparison, but it should be noted that the angle of the sternpost on *San Diego* is sharper than one would expect based on the treatises, while the angle of the Fuxa wreck falls within the expected range.

Planking (Table 12)

Site	**Planking width (mm)**	**Planking thickness (mm)**	**Planking/Frames fastening pattern**
Angra B	260-310	50-55	nails/treenails
San Diego	300-350	65-70	nails
Pepper Wreck	–	110	nails
IDM-003	170-270	–	–
Fuxa	280-400	30-50	nails
Green Cabin	190-380	83	nails/treenails
Santo Antonio de Tanná	–	100	–

Table 12. Planking of published 17th century Iberian shipwrecks *(After EMSD)*

The dimensions of the planks vary too greatly to be considered diagnostic. However, when they are properly recorded the fastening pattern and type of fasteners provide valuable information.

In the case of Angra B, besides the average-width planking, narrower planks (0.10 m) were recorded and interpreted as potential repairs (Bettencourt, 2011: 224–225). The planking was fastened using a mix of wooden and iron fasteners. Two or three 11 mm square-section iron spikes and one 25–30 mm-diameter treenail were used to attach the planks to each frame (Bettencourt and Carvalho, 2010: 79; Bettencourt, 2011: 224).

In the excavation of *San Diego*, archaeologists did not remove the hull planking, so it has not been analyzed systematically. The planks were nailed to the frames (L'Hour, 1994: 148–149) and the samples were identified as apitong (*Dipterocarpus sp.*), probably hairy-leafed apitong or Keruing Bukit (*Dipterocarpus alatus* Roxb. or *Dipterocarpus retusus* Blume) (InsideWood, 2004; Wheeler, 2011.)

The planks of the Pepper wreck were made out of stone pine (*Pinus pinea*), as was the keel. Stone pine was commonly used by Portuguese shipbuilders of the time. Twenty-eight strakes were preserved. The planks were fastened to the frames using two square iron spikes per frame, per strake. Evidence of charring was found on the exterior of the hull (Castro, 2003: 14). All the fasteners on the Pepper wreck were made of iron.

Apparently, the external planking of IDM-003 was made of the same wood as the stringers and ceiling. Knots were reported, but never close to the edges, suggesting careful selection of timbers (Mirabal, 2013: 88).

Twenty-nine strakes were found on the Fuxa wreck. The garboards were fairly well preserved and were both 60 mm thick. The thickness of the rest of the planks ranged between 30 mm and 50 mm. The planks were fastened to each frame with three rows of square-shanked spikes of 10 mm section with a spacing of between 0.35 m and 0.45 m running perpendicular to the keel, which matches the room-and-space between the futtocks. Within each plank the vertical distance between fasteners was between 0.08 m and 0.12 m and there were three spike lines per plank. Other planks also have groups of three spike holes, but they do not show any pattern (Lopez Perez and Sanson, 1993: 13). The widths of the planks have not been reported, but based on the vertical spacing between the three rows of spikes, and allowing 20 mm from each edge, they can be calculated as between 0.28 m and 0.40 m.

Twelve strakes were found on the Green Cabin wreck, including both garboards. The planking tapered towards the bow. Stealers that fill the gaps between planks towards the ends of the vessel were also preserved. Apparently, the planks were joined with a simple butt scarf to form the strakes. The planks were fastened using 12 mm square-shanked wrought-iron spikes along the leading edge and a single treenail driven through the middle of the plank, 178 mm from the end (Moore and Muir, 1987: 192).

One conclusion regarding the planking is the fact that both Portuguese vessels, the *Nossa Senhora dos Mártires* and the *Santo Antonio de Tanná*, had significantly thicker planking than the presumed Spanish wrecks. In addition, the Fuxa wreck had surprisingly thin planking in comparison to the rest of the ships. The width of the planking varies immensely, but an average width of 0.29 m has been calculated (Table 12). Oertling (1989b) initially proposed that the garboards of Iberian Atlantic vessels were carved from extra thick planks, however Robert Grenier suggested that examples were lacking, and this trait was removed in later publications (Oertling, 2001: 236–237). From the reported garboards, the Fuxa wreck would fulfil Oertling's original suggestion, but further examples would be required to fill the data gap pointed out by Grenier. Fastening patterns seem consistent. In all cases, the planks are fastened to each frame. In the case of the Pepper wreck, they used two rows of fasteners per strake, presenting a difference with the Fuxa wreck, in which three rows have been reported. Treenails have been reported only in the cases of the Angra B shipwreck and the Green Cabin wreck, the only known examples with a combination of wooden and iron fasteners. Castro (2008: 77) asserts that the tendency in Early Modern Iberian shipbuilding outside the Basque region was towards carvel planking secured with iron fasteners rather than a combination of iron spikes and treenails as originally proposed by Oertling (2001: 234). Excluding the Angra B shipwreck and the Green Cabin wreck, which were Vizcayan-built vessels, and supporting Castro's proposal, all the remaining published wrecks share this trait. The fasteners and thickness of the external planking of IDM-003 have not been reported.

The Frames (Table 13)

Site	**Frames (No.)**	**Floors sided (mm)**	**Floors molded (mm)**	**Floor S to M ratio**	**Room-and-Space (mm)**	**1st Futtocks sided (mm)**	**1st Futtocks molded (mm)**	**Futtock S to M ratio**
Angra B	–	190	250	–	410	150-220	–	–

Table 13. Framing of published 17th century Iberian shipwrecks (After: EMSD).

Site	Frames (No.)	Floors sided (mm)	Floors molded (mm)	Floor S to M ratio	Room-and-Space (mm)	1st Futtocks sided (mm)	1st Futtocks molded (mm)	Futtock S to M ratio
San Diego	51	190	–	–	440	190	–	–
Pepper wreck	11	250	240	1.04	470	220	260	0.85
IDM-003	45	240	410	0.59	462	220	240-260	0.85-0.91
Fuxa	23	260	260	1	410	–	–	–
Green Cabin	16	191	355	0.54	426	–	–	–
Nuestra Senora de Atocha	–	240	250	0.96	508	–	–	–
Santa Margarita	–	280	220	1.27	445	–	–	–
Santo Antonio de Tanná	55	210	260	0.81	410	140	140	1
Stonewall	9	280	–	–	700	330	–	–

Table 13 Continued. Framing of published 17th century Iberian shipwrecks (After: EMSD).

The frames of the Angra B wreck were very eroded at the southern end and just two floor timbers were exposed near midships. Some first, second, and third futtocks were recognized. Floor timbers were spaced at intervals of 0.41 m and fastened to the keel with two iron spikes per floor timber. Bolts spaced approximately 1.2 m appart reinforced the joint between the keelson, the keel, and every fourth floor-timber. The two floor timbers that were observed had a rectangular limber hole over the center of the keel that was 60 mm long and 50 mm high (Bettencourt, 2011: 223). A Y- or V-frame was recorded.

San Diego had a total of 51 floor timbers and V-shaped frames. Most were in an outstanding state of preservation, except for a couple of V-shaped frames. Like the keel, the frames were made of beach calophyllum (*Calophyllum inophyllum*). The futtocks were joined laterally alternating floor timbers, first futtocks, and second futtocks. From frames M93 to M121 the first futtocks faced the stern and from 122 they faced the bow; this positioning means they were always oriented toward master frames M121 and M122. This is consistent with the specifications in Oliveira's treatise for a ship of such size. The master frames were located 0.75–0.85 m from the midpoint of the keel and their distance from the after end of this member was between 12.6 and 12.7 m. This distance is less than what Oliveira recommends in his treatise, according to whom they should be 2.96 m forward of the midpoint of the keel. The floor timbers sit directly on the false keel and were fixed with a single bolt that goes through the keelson, the frames, false keel, and keel. Some frames were not fastened or scarfed. The average spacing between floor timbers was between 0.16 and 0.19 m. The assembly between the floor timbers and futtocks was made with dovetail joints reinforced with a nail (Fig 15). Researchers did not observe any joint between the first and the second futtocks, although some assembly marks were found on the recovered V-shaped frames (L'Hour, 1994: 148–149).

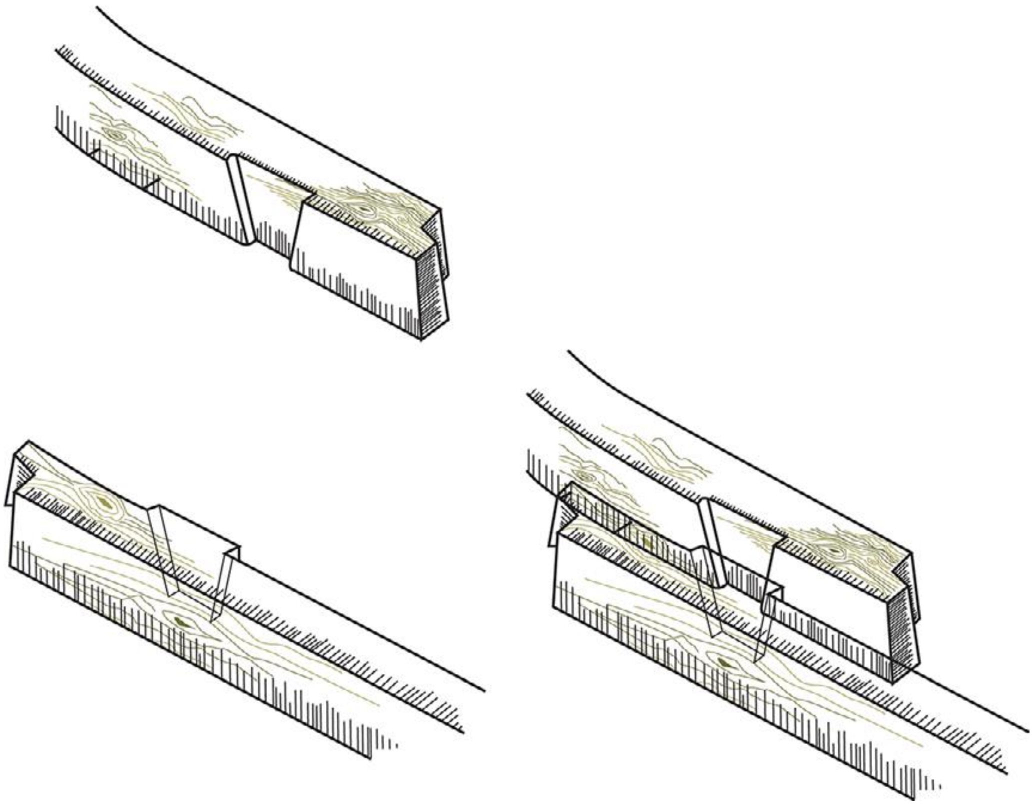

Figure 15. Dovetail joint (Laura Martínez Paris, after Oertling, 1989a: fig. 7).

The frames of the Pepper Wreck were made of cork oak (*Cuercus suber*). The floor timbers were fastened to the apron, the futtocks, and the keel with square-shanked iron spikes. Archaeologists found flush-cut treenails in the faces of three frames that have been interpreted as related to construction rather than permanent fasteners. The sided and molded dimensions of the floor-timbers measure 1 *palmo de Goa* (256 mm). The height of the floor timbers increased towards the ends of the keel. They were fastened using square-shanked iron spikes that penetrated the keel at least 0.12 m. The sided dimensions of the futtocks were slightly less than 1 *palmo de vara* (220 mm). Futtocks were fastened to the forward face of the floor timbers with three or four iron spikes inserted from the face of the floor and clenched on the futtock side. The heads and clenched portions of the nails were embedded in the wood. All of the frames were in contact with each other. As in the *San Diego* and other examples of Iberian shipbuilding, the floor-timbers and futtocks had dovetail joints. Several spike marks on the planking showed the positions of 25 frames, but not all of them were *in situ*. Construction marks on the floor timbers testified to the design process, marking the keel sides, axis, and the turn of the bilge. Roman numerals also indicated the position of the floor timbers over the keel. Other construction marks were found on frames C2 and C3, one of them showing the position of the tip of the futtock. The others seem to show the portion that was to be trimmed with an adze to generate the turn of the bilge arc. However, these were less well preserved or not as deeply incised (Castro, 2003: 12).

The Pepper Wreck had three master frames, as specified by Fernando de Oliveira for a *nau* of more than 18 *rumos* (27.72 m) of keel. According to Oliveira (1580): the total rising forward should be equal to the measure of the room-and-space, and one-and-a-half times that value aft. The total narrowing should be one- sixth of the flat of the master floor to each side. This matches fairly precisely what was found on the Pepper Wreck (Castro, 2003: 16).

The 45 floor timbers composing the central section of the starboard side of IDM-003 have been identified. The master frame, as well as the bow and stern tail frames were included among these (Table 14).

IDM-003 Frames	**Sided (mm)**	**Molded (mm)**
Master Frame	240 x 30	410
Stern Tail Frame	–	more than 500
Bow Tail Frame	–	720
Filling Frames	230 to 250	–

Table 14. IDM-003 frame dimensions. (After: Mirabal, 2013)

Just one master frame has been reported, but it was composed of three adjacent flat timbers with the same sided dimensions. Placed between the keel and the keelson, the ones on the side ended below the ceiling, but the middle one ended under the first stringer. It was 7.05 m long measured from the keelson to stringer 1. It is unknown whether it was a single timber or if it included a futtock. The center of the middle timber was 3.02 m forward of the center of the mast step mortise, which coincides almost exactly with the Portuguese measurement of 2 *rumos*.

As with the master frame, the tail frames were composed of three timbers and their sided dimensions were very close to those of the master frame. Eighteen floor timbers separated the tail frames from the master frame, and they were located at almost the same distance forward and aft the master frame. The stern tail frame was 9.21 m (6 *rumos*) abaft the master frame and the bow tail frame was 9.35 m forward of it. These measurements were taken center-to-center of the middle timbers. The distance between tail frames was 18.56 m, very close to 12 *rumos*.

The sided dimensions of the 36 filling frames were close to 1 *palmo de goa* (256 mm). The molded dimension of the floor timbers increased towards the ends, reaching its highest value at the bow tail frame, which was made out of two vertically assembled timbers. Composed floor timbers were observed from V-1 to V-13. Trapezoidal scarfs were reported on the fore face along the axis of the keel of the floor timbers V-1 to V-16. Inside the scarf there were 20-mm square-section countersunk holes for bolts that attached the floor timbers to the keel. Perforations of 30 mm diameter without countersinks were reported over floor timbers V-5, V-8, and V-42. Based on the fact that there was no countersink, it seems such perforations served to fit the at-least-1m-long bolts that attached the keelson to the keel through the floor timbers. Vertical linear marks were reported in the northern face of most floor timbers. These lines marked the position of the keelson. According to Mirabal (2013: 79) The floor timbers limber did not have holes on. The portside arms of the floor timbers were not preserved. The joints between the floor timbers and the futtocks were not observed.

Sixty first futtocks, associated with second and third futtocks, were reported for IDM 003. The molded dimension of the first futtocks was close to 1 *palmo de goa*. The length was variable, but most of them started inboard of the ceiling planking and extend to the lower face of the first deck clamp or its waterway, where they were attached to the second futtocks. Only Ft1-14, Ft1-20, and Ft1-22 surpassed this height and ended in the closest stringer. Some futtocks were composed of more than one timber and joined with a slanted scarf. First futtocks were connected to the third futtock with a second futtock made out of a single timber. The upper faces of the futtocks forward the stern tail frame and immediately below the orlop deck, were marked with consecutive Roman numerals from 0 to XV, the last given to the master frame. According to Mirabal (2013: 83) the use of 0 did not become popular among Portuguese shipbuilders until the 17th century. Ft1-25 was marked with an Arabic 12, as well as with the Roman number XII. Given that when the futtocks were in position the marks were upside down, they were likely made before the vessel was assembled.

Two frame assemblages were described for IDM-003. In frame 1, the first futtock was 5.30 m long and it was placed in between floor-timbers V-1 and V-2. It ended under the first deck clamp. The third futtock was thicker than the first (0.30 m molded) and 3.95 m long and continued in the direction of the first futtock. It was connected from below to another piece with what Mirabal (2013: 85) called a ‘slanted scarf’. Apparently, this piece was the fifth futtock. The second futtock started under the first stringer and ended under the waterway of the second deck. Its forward face connected laterally to the first and third futtock. The keelson was made out of two laterally-joined timbers for a total length of 4.84 m. The first piece was 4.35 m long and the second was 2.35 m long and had a lateral scarf. It acted as a filling arm between two futtocks. The fourth futtock followed the second, showing an alternating pattern, in which futtocks of even numbers follow each other, as well as futtocks of odd numbers. Wedge-shaped wood pieces filled the gaps between futtock 1 and 2, as well between futtock 3 and 4. No dovetail joints were reported, but the frames had notches to receive the stringers. Filling frames were reported between the third and fourth futtock of each frame and also between the third futtock of one frame and the fourth futtock of the next. The number of filling frames increased towards the bow and the stern from the second deck upwards.

Archaeologists found 17 floor timbers on the Fuxa wreck. Number 74–158 seemed to be the master frame, as it was located underneath the mast-step and was the widest. It was 0.26 m molded and 0.24 m sided. It was mounted atop the false keel and fastened with treenails. The floor timbers under the mast step, where the bilge pump was located, had two limber holes and the rest had just one. The floor timbers were fitted to the futtocks with dovetails and fastened with treenails (mistakenly reported as '30 cm in diameter', but most likely 30 mm). A treenail supported each side of the dovetail (two per dovetail and four per floor timber). The distance between treenails was not standard. The dovetail mortise was carved in the floor timbers to a depth of between 10 and 20 mm and, there was a corresponding protruding tenon on the futtocks. The depth of the dovetail joint corresponds with 1 *dedo* (18 mm), as dictated by Lavanha (1610) (Hormaechea et al., 2018: 101). The widest section of the dovetail faced the interior of the vessel, as has been observed on other

Iberian vessels such as the Pepper wreck. This might have made any replacement process easier. All the recorded floors had the dovetails facing the stern. The size of the dovetails was not consistent, other than in their depth. Floor timber 92–196 was an exception, as it had four dovetails instead of two. Archaeologists observed engraved arrows on the frames, probably indicating the position of the futtock. All the frames of the Fuxa wreck were made of downy oak or pubescent oak (*Quercus pubescens*). Near floor timber 64, they found a piece that filled a gap between frames that was apparently made by mistakenly during the construction process (Lopez Perez and Sanson, 1992: 22–24).

In the Fuxa wreck, structures identified as *orcas, piques, or horquillas*, were apparently one V-shaped frame and one rider, as one was placed on top of the 'false keel' and the other one was below this timber. The V-shaped frame had no bolt hole and apparently there was a mistake in how it was fastened to the 'false keel'. The rider had two holes; one over stringer 31 and another 0.15 m distant (Lopez Perez and Sanson, 1992: 21). This rider might have been added after the vessel was constructed. Beacause bilge water ran over the ceiling, the riders had limber holes (Hormaechea et al., 2018: 65) and this is the case of the Fuxa wreck (Lopez Perez and Sanson, 1992: 21).

In the case of the Green Cabin wreck, 16 frame stations were preserved, including fragments of the first futtocks. The master frame was located 6.4 m abaft the forward end of the keel. This was the case for *San Diego* as well, from the main frame (No.12 in the Green Cabin wreck) the futtocks 1 through 11 of the forward section faced the bow and futtocks 13 through 16 abaft the main frame were erected facing the stern. The position of the midships frame was determined based on it having fragments of futtocks attached to both sides. The room and space varied between frame stations, so the listed number is an average, as is the sided dimension of the floor-timbers. The joints between floor timbers and first futtocks were probably made with dovetails described by Moore and Muir (1987: 192) as ‘shear joints’, which they assert was the same method used in the upper hulls of *Santa Margarita* and *Nuestra Señora de Atocha*.

Fifty-five frames can be recognized in the site plan of the *Santo Antonio de Tanná*, each one made up of a floor timber and at least two futtocks. The average sided dimension of the floor timbers was calculated by Fraga (2007: 132) as between 0.20 and 0.21 m, while previous studies on the frames carried out by Jordan (2001: 305) gave an estimated average sided dimension of 0.23 m and an average molded dimension of 0.26 m. The measurements in Fraga have been approximated to the units of *polegada* and *palmo de Goa* used in the Portuguese shipyards of the time and they show a fair degree of consistency. Fraga asserts that the ship originally had around 81 frame stations. The futtocks have a square section of 0.14 m but based on his analysis Fraga has suggested sided dimensions of 0.15 m for both the first and the second futtocks. He has also asserted that floor timbers likely tapered towards the heads to match the first futtocks and that the second futtock also tapered to 0.12 m molded. Dovetail joints have not been reported but might be present under the ceiling.

A feature shared by all wrecks is a number of pre-assembled central frames, which in conjunction with the dovetail joints between the futtocks and floor timbers, is the first Iberian trait recognized by Oertling (2001: 235). Dovetail joints were also reported in all the cases where the joints were accessible. However, the fasteners used to secure these joints varied between the published wrecks. According to Hormaechea et al. (2018: 64), joints between floor timbers and futtocks were fastened with three riveted bolts, but this is not the case in any of the wrecks described here.

Again, according to Hormaechea et al., two countersinks were made on the faces of floor timbers to attach them to the keel with two oblique spikes that did not interfere with the bolts that later fastened the keelson, the floor-timbers and the keel (Hormaechea et al., 2018: 65). This feature has also not been observed in any of the wrecks described here, but flush-cut treenails on the faces of the frames of the Pepper wreck have been interpreted as fulfilling this function in the construction process.

Hormaechea et al. (2018: 101–104) have rigorously traced the use of different variations of dovetail joints with different types of fasteners in 16th and 17th century Iberian vessels based on both the archaeological record and shipbuilding treatises. Dovetail joints are first mentioned by Lavanha (1610) and remained the only accepted way to join the floor timbers and futtocks in 1688 when Gaztañeta published his *Arte de Fabricar Reales*. Based on Tomé Cano's (1611) treatise, the authors explained that this type of joint reinforced the bottom of the vessels to avoid the 'spewing' of the caulking when the ships dried or were caulked.

Following Oliveira and the available examples, the number of main frames can be used to determine the length range of the keel: if the keel was 19.71–23.65 m long, it required have had two main frames, as in the case of the *San Diego*. If the keel exceeded that length, the vessel required three master frames, as in the Pepper wreck. Judging by the sided dimensions of the three timbers composing the master frame, rather than a single master frame, IDM-003 had more likely three master frames, as its keel was about the same size as that of the Pepper wreck.

In the reported cases, the face to which the futtocks were attached to the floor timbers changed fore and aft of the master frame or master frames. This was surely the case of the

San Diego and the Green Cabin wreck, and very likely that of IDM-003 and *Santo Antonio de Tanná*. In the Pepper wreck, the surviving futtocks were fastened to the forward face of the floors, as opposed to the Fuxa wreck in which the surviving futtocks were attached to the aft face of the floors, probably because the areas of futtocks that survived in these wrecks were forward of the master frame and abaft the master frame respectively. This arrangement has been confirmed by Hormaechea et al. (2018: 104) for Early Modern Iberian vessels as they explain the three ways in which the futtocks could be attached to the floor timbers abaft and aft the master frame in relation to bow and stern. Although not exclusively Iberian, this arrangement should be considered a twelfth trait that should be added to the cluster proposed by Oertling (2001) and Castro (2008).

The sided dimensions of the floor timbers also seem fairly consistent in vessels of similar keel length, ranging from 0.19 m in three cases: *San Diego*, the Angra B shipwreck, and the Green Cabin wreck; to 0.28 m in the cases of the Stonewall wreck and the *Santa Margarita*. A mean value of 0.24 m is seen in both IDM-003 and *Nuestra Señora de Atocha*. Curiously none of the sided dimensions of the frames closely match the measuring units used at the time, the *palmo* (0.21 m), *palmo de goa* (0.26 m), or the *palmo de vara* (0.22 m) (Castro, 2008: 69).

Other coincidences can also be found in the room-and-space measurements, as in the cases of *San Diego* and *Santa Margarita* with 0.44 m and 0.445 m respectively, or the Angra B shipwreck, *Santo Antonio de Tanná* and the Fuxa wreck with 0.41 m. Measurements for the first group perfectly match 2 *palmos de vara* and measurements for the second group slightly exceed 2 *palmos*. The Pepper wreck and IDM- 003 had the same sided and molded dimensions of the frames and a narrow room and space, but care must be taken when considering the similarity of these two vessels, as most of the reconstruction of IDM-003 were based on Castro's calculations for the Pepper Wreck, using exactly the same measurements.

Ceiling (Table 15)

Site	**Length (m)**	**Width (mm)**	**Thickness (mm)**
Angra B	–	260-300	50-60
IDM-003	–	150-300	100
Fuxa	0.30–4	100-400	–
Santo Antonio de Tanná	–	–	20-50

Table 15. Ceiling of published 17th century Iberian shipwrecks. (After Lopez Perez and Sanson, 1992; Fraga, 2007; Mirabal, 2013)

As was the case with the planking, the ceiling varies considerably and is not very diagnostic. No report regarding the ceiling has been made for *San Diego* and the Green Cabin wreck and no ceiling planking was found on *Nossa Senhora dos Martires*. The ceiling planking of the Angra B shipwreck was fastened using iron nails and wooden treenails. The ceiling was notched to receive the Y- or V-frames (Bettencourt, 2011: 224). The length of the ceiling planks has not been reported. In the case of IDM-003, the entire section of ceiling planking on the flat midships of the starboard side was preserved, encompassing 65 strakes. Rectangular holes (0.10 x 0.20 m) to support the bulkheads were reported in the external strakes, with a fairly regular (1.8–2 m) spacing between them. The strakes were nailed to floor timbers and first futtocks with 0.02 m square-section iron spikes in countersunk holes with a diameter of 60 mm. The strakes were connected longitudinally with 'slanted scarfs' (Mirabal, 2013: 87).

A total of 41 ceiling planks were found on the Fuxa wreck. There was considerable variation in length and width. The thicknesses were not reported (Lopez Perez and Sanson, 1992: 27). The ceiling of the *San Antonio the Tanná* was preserved up to the height of the hanging knees of the main deck. The scarfs presented considerable variation. The planks were secured with nails and treenails. No obvious pattern was noted (Fraga, 2007: 138).

The ceiling of the wrecks varies immensely and there does not seem to be common features in this regard. According to Oertling (2001) ceiling usually extends just over the floor timbers and the last strakes are notched to receive the filler planks inserted between futtocks to seal the lower bilge. This arrangement has been confirmed and described in detail by Hormaechea et al. (2018: 111) and coincides with the arrangement found in the Angra B shipwreck. A similar arrangement was also reported for IDM-003. In the case of the *Santo Antonio de Tanná*, the ceiling went up to the height of the hanging knees.

Stringers and clamps (Table 16)

Site	**Stringers length (m)**	**Stringers sided (cm)**	**Stringers molded (cm)**	**Clamps sided (cm)**	**Clamps molded (cm)**	**Ceiling thickness (cm)**
Angra B	–	21	13	–	–	–
San Diego	14.2	25-30	4.5-8	31-35	14.5	–
Pepper wreck	–	–	–	–	–	–
IDM-003	–	–	–	–	–	–
Fuxa	–	–	–	12-19	20-24	–
Green Cabin	–	–	–	–	–	–
Santo Antonio de Tanná	–	20-25	12	–	–	2-5

Table 16. Stringers and clamps of published 17th century Iberian shipwrecks (After: EMSD).

Stringers and clamps reinforced the longitudinal structure of the vessels. Such timbers have been reported for the Angra B, the *San Diego*, IDM 003, the Fuxa wreck and *Santo Antonio de Tanná*. They were not preserved in the Pepper wreck and none of them were reported for the Green Cabin wreck.

In the Angra B shipwreck, two stringers per side reinforced the structure, running over the junction between the floor-timber and the first futtocks. Both stringers had a longitudinal bevel in their upper surface. Treenails and iron concretions testify that a combination of wooden and metal fasteners was used in the junction between the stringers and the frames. At least one of the stringers was notched to receive the frames (Bettencourt, 2011: 224).

Five stringers were found on *San Diego*, three on the port side and two on the starboard side. The two timbers closest to the keelson were different from the remaining three stringers and probably acted as footwales. They were made out of the same wood as the keelson (*Terminalia Sp.*). The stringers were made out of a different wood type (*Dypterocarpus CF Gradiflorus*). The fact that the stringers were made out of a different wood type from the footwales was probably a deliberate choice by the shipwright. The wood used for the stringers was a very hard type which was difficult to work. Stringers and footwales were nailed to the frames with two rows of nails. The footwales were as large as the stringers and notched to fit the frames (L'Hour, 1994: 146–147). In *Nossa Senhora dos Martires*, the nail holes on the frames do not clearly indicate the runs of the stringers.

The orlop deck and the second deck clamps and waterways of the starboard side of IDM-003 were all preserved, and this allowed the height between decks to be measured. The ship had at least three decks. The distance between them was 2.4 m (Mirabal, 2013: 89). Neither a description nor the measurements of the clamps and stringers were reported.

Five stringers were found on the Fuxa wreck. The spacing between stringers 155 and 159 is 0.25–0.30 m. The spacing between stringers 73 and 79 is 0.18–0.23 m. The stringer tagged as 31 is 0.23 m from the keelson in the bow and 0.54 m in the stern. Irregular notches were noted on all the stringers. Observing the metal concretions, it has been suggested that the stringers were bolted to the frames using 20 mm-diameter bolts, but only the concretions and holes remain. According to the report, the stringers mounted closer to the keelson were scarfed. Judging by the drawing, the scarfs were flat horizontal. The stringers of the Fuxa wreck were made of *Quercus pubescens* (Lopez Perez and Sanson, 1992: 15–16).

Seven stringers on the port side and two on the starboard side have been found on the *Santo Antonio de Tanná*. The first three stringers were placed closely together at the headline of the floor timbers and the turn of the bilge. Stringers 4 and 5 were added at the mid height of the hold. The fourth stringer was exactly at an intermediate distance between the third and the fifth stringer, 2.16 m from the top of the keel to its upper corner. Two additional stringers served as bases for the hanging knees at the top height of the hold. One of the stringers in four pieces was preserved to a length of 29.2 m. Of its four components, the longest started at the stern and measured 19.10 m. The second section was 5.35 m, the third 2.65 m, and the fourth was incomplete, but had a length of 2.10 m. Most stringers have diagonal scarfs, but the second on the port side had a butt scarf, a stealer, and ended forward in a flat scarf. Stringer number 6 also had a flat scarf. All the stringers were fastened to the frames using two spikes per frame (Fraga, 2007: 139).

Hormaechea et al. (2018: 105–106) reported that Early Modern Iberian vessels had two bottom stringers per side. The first two ran at the height of the foot of the futtocks and the second at the height of the head of the floor timbers. *Santo Antonio de Tanná* fulfilled this trait (Fraga, 2007: 138). It is not clear whether the position of the stringers in regard to the frames described by Hormaechea et al. was the case in the rest of the vessels described here as publications tend to record the position of the stringers in relation to each other and not to the foot or head of floor-timbers and futtocks.

Whether this could be considered another a trait to be added to Oertling's (2001) and Castro's (2008) cluster requires further archaeological support and remains a question for the future. Still the ninth trait is visible in all the reported cases, as the stringers were notched to receive the frames, as observed by Hormaechea et al. (2018: 105) in their research on the 1618 *Ordenanza*. This feature was reported for the Angra B wreck, *San Diego*, and the Fuxa wreck. Hormaechea et al. (2018: 105) added that the heads of the futtocks might have had a small groove to accommodate the notched stringers, but this has not been reported yet in the archaeological record of Early Modern Iberian vessels. Future archaeological timber recording should pay close attention to the location of the stringers in relation to the foot of futtocks and heads of the frames, as well as to the potential presence of grooves on the floor timbers to accommodate the notched stringers. In other regards the recorded stringers and clamps varied considerably among the wrecks.

Another visible coincidence is that in the cases of the *Santo Antonio de Tanná* and the *San Diego*, the stringers were fastened to the frames using two spikes.

Lead sheathing and caulking

Sheathing with different materials was a common practice against biofouling, which increased resistance and diminished hydrodynamics. Caulking was indispensable to make the plank seams watertight. Among the 17th century Iberian shipwrecks that have been published, lead sheathing has been reported just in the cases of IDM-003 and the Green Cabin wreck. Moore and Muir (1987: 193–194) also report that the *Santa Margarita* was lead sheathed. Caulking materials were sampled in the *San Diego*, the Pepper wreck and IDM 003. The interesting caulking method used in the Pepper wreck was recorded in detail by Castro (2003: 69).

The Angra B shipwreck was at least partially lead sheathed, but the dimensions of the sheets has not been reported. The caulking of the *San Diego* was sampled. Although the results have not been published, the researchers think it might have had a plant origin and according to Castro's EMSD, it had coconut fibrs. In the case of the Pepper wreck, a twisted lead strip was pushed into the seams of the strakes and covered with two layers of oakum pressed against it from the exterior. The seams were finally covered with another lead strip nailed through the seams or on both sides of it using iron tacks with circular heads. In some cases, an additional layer of oakum was inserted prior to the twisted lead (Castro, 2003: 14).

In the scarfs of IDM-003's keelson a filling caulking with tar or pitch helped to fix the joints (Mirabal, 2013: 69). Lead caulking was also observed between the strakes (Mirabal, 2013: 89).

Remains of lead sheathing have been found on the *Santa Margarita*, IDM-003, and the Green Cabin wreck. An underlayer of canvas was placed between the lead sheathing and the wood in the Green Cabin wreck and the *Santa Margarita* as attested by weave impressions left on the planking (Moore and Muir, 1987: 193). This practice has also been observed by me on the *San Felipe*, intentionally sunk in 1741 off Bochachica, Cartagena de Indias, Colombia, which is as yet unpublished. The lead of the Green Cabin wreck was attached using iron tacks or nails.

No traces of lead sheathing were found on the Fuxa wreck, but a lead patch was noted on strake 215 and apparently the stem was also covered (Lopez Perez and Sanson, 1992: 15). No information on the caulking method was provided in the report.

No details on sheathing or caulking have been reported on *Santo Antonio de Tanná*.

Moore and Muir (1987: 193–194) suggest that lead sheathing was a common feature of European vessels, but not among those built in America. No consistent caulking method has been observed on 17th-century Iberian shipwrecks, but IDM-003, the Green Cabin wreck, and the *Santa Margarita* had lead sheathing. A layer of canvas underneath the sheathing was reported in the last two cases. The lead sheathing of the *San Martin* and the *Santa Margarita* has been described as being identical by Moore and Muir (1987: 193–194).

Ballast

Ballast was required to adjust the buoyancy and balance of the vessels. Some of it was fixed (or permanent) and some was added or removed depending on the amount of cargo. Ballast is ubiquitous in shipwrecks and it is a common way to detect them. The ballast of the Angra B shipwreck included limestone, quartzite, and flint. A consolidate permanent containing sand, lime, and gravel was found between the frames (Crisman, 1999: 255–262).

Near the stern, the first futtocks of the V-shaped frames of the *San Diego* were covered in mortar. Apparently, this mortar was intended to give the stern more weight or to protect the wood from insects. According to a documentary source of the 17th century, this was a common practice among shipbuilders in the Philippines (L'Hour, 1994: 148).

In the case of the Pepper wreck, it was difficult to recognize the ballast as the riverbed where it rested is composed of cables pebbles with diameters between 0.08– 0.12 m (Castro, 2003: 14). On the other hand, the ballast that has been found in *Santa Margarita*, *Atocha*, and the Green Cabin wreck has been described primarily as fine and composed of sand, lime, gravel, and pebbles. According to Moore and Muir (1987: 193), this combination created a sort of concrete once in contact with the water coming from leaking seams. In IDM-003 a hard concretion of ballast stones and remains of iron was reported over the stern tail frame (Mirabal, 2013: 76). According to L'Hour's (1994: 148) research on the *San Diego*, it is possible that rather than solidifying when in contact with the leaking seams, this combination might have been deliberately poured mortar. Crisman (1999: 255–262) also interpreted this material as primary ballast in the case of the Angra B shipwreck, in which it was found covered by the ceiling.

Hormaechea et al. (2018: 104, 109) have explained that the *Ordenanza* of 1618 ordered the spaces between floor timbers and futtocks to be filled with lime mortar and that between 1630 and 1640, Lopez Guitián insisted on the use of mortar for this purpose. This technique is confirmed in the cases of the Angra B wreck, *San Diego*, Green Cabin wreck, *Atocha*, *Santa Margarita*, and IDM-003, and thus it should be regarded as the 13th common trait of Early Modern Iberian vessels (Table 4).

According to Castro (2008: 63) 'data suggests that a distinctive shipbuilding tradition existed on the Iberian Peninsula', as the vessels shared conceptual designs and features. This observation should have been especially true in the 17th century, as there was already a growing interest among shipbuilders around the world in spreading their legacy and standardizing the ideal measurements and proportions through treatises. The first Spanish treatise was the *Itinerario de navegacion* (Escalante 1575), but Garcia de Palacio's (1587) *Instruccion nautica para navegar* was the first to be published. Portuguese shipwrights were no less prolific. Most scholars agree that Father Fernando Oliveira's (1507–c.1581) *Ars nautica* manuscript was written around 1570 (Lopes de Mendonça, 1898; Barker, 1992; Rieth, 1998). The anonymous *Livro náutico* was being written around the same time (Rahn Phillips, 2000: 7–8). Further treatises were produced in the Iberian domains across the following century (Table 3), up to 1712, Gaztañeta finished his *Proporción de las medidas arregladas a la construcción de un bajel de guerra de setenta codos de quilla*, which introduced the ship of the line to the Iberian world.

In the case of Spain, official attempts were made by the Crown to standardize vessels. The measurements agreed upon between notable naval officers and private shipbuilders were meant to be applied to all newly built vessels, including merchantmen, so that the Crown could maintain a significant reserve of potential war vessels in private hands (Rahn Phillips, 1993: 234). The results of the technical discussions held in Spain were published as legal documents called *Ordenanzas*. Different scantlings were issued in 1607, 1613, and 1618, with subsequent modifications in 1666 and 1679 (Casabán, 2014). The *Ordenanzas* were one of the earliest official attempts to standardize naval and merchant vessels, predating the English Naval Establishment by almost one century.

Similar standardization processes could be expected for the structural timbers. The evidence laid out in Table 4 supports the argument that, as shipwrights were conservative communities, changes in ship construction occurred at a very slow rate. A cluster of successful structural solutions to the strains of ocean sailing remained in use from the late 15th century until the end of the 17th century. When the timbers have been preserved, the trait cluster is consistent despite the year of construction, purpose, geographic location of the shipyard, or size of the vessels (Table 3).

However, there were some changes, such as the transition between the stern knees and a butt scarf with a mortise-and-tenon joint between the sternpost and the keel, that in turn was reinforced with a superimposed deadwood knee (Hormaechea et al., 2018: 74–79). Here we have described some transitional stern configurations that support the suggestion that short-arm stern knees might have been abandoned after the first decade of the 17th century.

Despite the constraints of the small sample size, two additional traits were discerned in the archaeological record that could be added to the cluster proposed by Oertling (2001) and complemented by Castro (2008) and Hormaechea et al. (2018: 64–65). The face of the floor-timbers to which the futtocks are attached changes fore and aft of the master frame. Futtocks aft of the master frame face the stern and futtocks forward face the bow. A primary ballast of mortar composed of lime and gravel was deliberately poured into the spaces between the frames.

The sample of 17th-century Iberian shipwrecks is too small to constitute a solid confirmation of these hypotheses surrounding shared features, but many trait coincidences have been found among the studied wrecks. However, further scientific research, publication, and preservation enforcement are required. More evidence is required to elucidate both regional specificities and the rhythm at which the changes in diagnostic traits occurred in 17th-century Iberian shipbuilding (Loureiro, 2012).

Efforts are being made to construct a standard for the publication of wooden hulls, including the minimum features that should be recorded in every case and the order in which they should be presented. The current lack of standard protocols, makes the task of identifying the similarities and differences very hard and time consuming (Castro et al., 2018). Not even a fairly consistent set of images of the timbers can be provided with this article, as some of the publications are very poor in terms of illustrations. However, the biggest hazard is not the lack of standardization in published material for each site but rather the looting and salvage that shipwrecks of this period have been subjected, which rarely results in either field record or scholarly publication.

Hormaechea et al. (2018: 64–65) have carried out laudable research to add further traits to the cluster proposed by Oertling (2001) and Castro (2008) for Early Modern Iberian shipbuilding. Close attention must be payed to the features that they report and have not yet been recorded in the archaeological record. Archaeological confirmation of other traits proposed by Hormaechea et al. (2018: 64–65) might arise from the analysis of shipwrecks found to be preserved above the waterline.

The pending decisions of the Colombian Government on the future of the outstandingly well-preserved *San Jose* galleon. This vessel was built in Guipúzcoa, Spain in 1698 following the specifications of Garrote and Gaztañeta, and was lost near to Cartagena de Indias in 1708. The *San Jose* excavation can create a paramount corpus of significant information on the subject, or might represent a giant step backwards in terms of the preservation of the archaeological record left by 17th- century Iberian ships. In this regard, it must be kept in mind that no ethical, scientific archaeological research is compatible with financing the excavation by the sale of materials proceeding from the context. This practice contradicts the concepts of integrity and context, as it inevitably ends up in the dispersion of the collection in private hands.

CHAPTER VI

RECONSTRUCTION OF SEVENTEETH CENTURY IBERIAN RIGGING

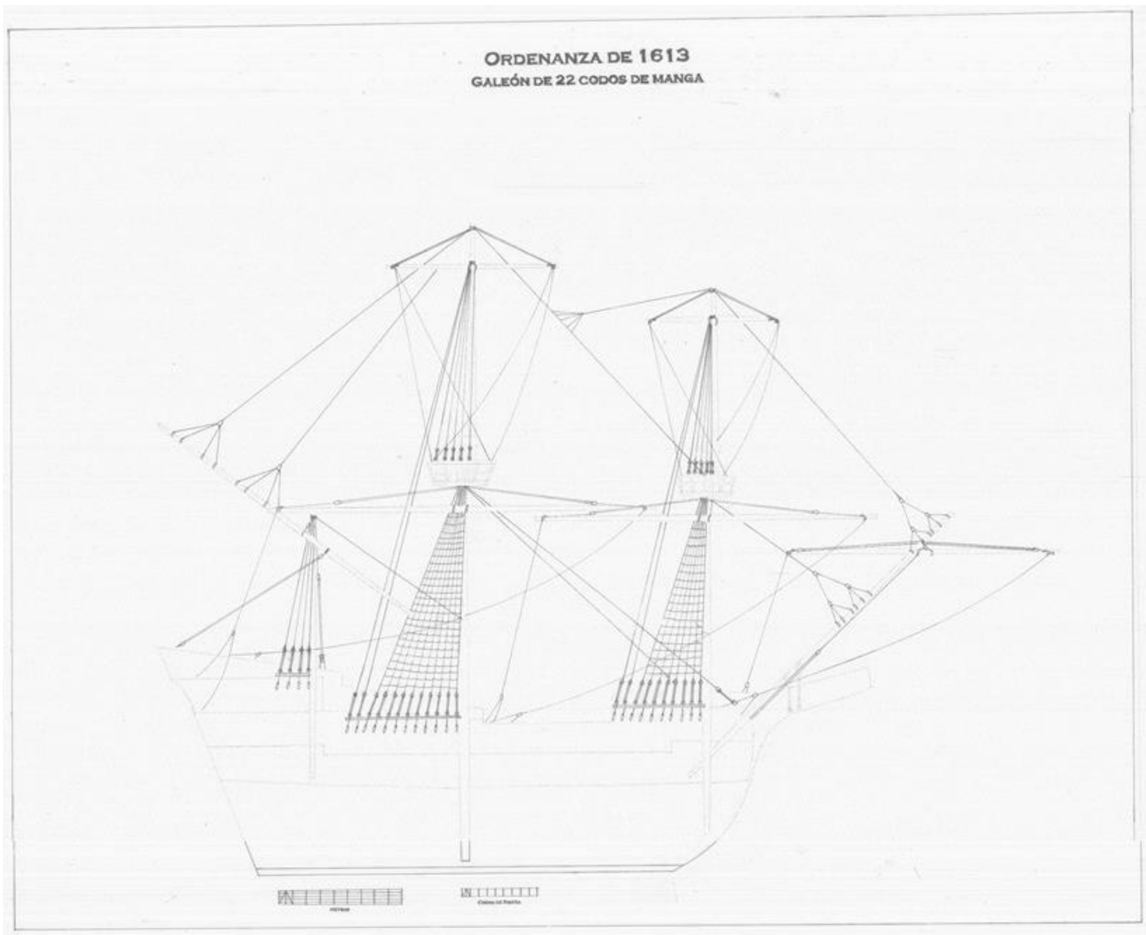

Fig 16. Rigging reconstruction of a galleon of 22 *codos* of beam following the *Ordenanza* of 1613 (Hull from Hormaechae et al. 2018)

This chapter presents the rigging reconstruction of a galleon of 22 *codos* (12.65 m) of beam and 1073.33 *toneladas* of tonnage, based in the *Ordenanza* of 1613. As explained earlier, the *Ordenanzas* were official documents regulating shipbuilding, equivalent to the later English Establishments. The contents of this chapter are based on the author's research in different shipbuilding treatises and other documentary and iconographic sources, most of them compiled, transcribed and published by Hormaechea *et al.* (2018), Castro *et al.* (2018), and Castro (2018). Throughout the chapter, the spar plan, mast placement, construction process and materials of the masts and yards, the Flemish fish mast (*chapuz*), the trestle-trees and cross-trees, the fid, the mast cap, the doubling and, finally, the standing and running rigging are discussed.

Spar Plan

Large Iberian vessels of the early 17th century had a bowsprit, and three masts, the fore, main and mizzen. In the 16th century they often stepped a fourth mast at the stern, the bonaventure. Hormaechea *et al.* 's (2018: 220) research on ocean-going Iberian Atlantic vessels suggests that by the beginning of the 17th century the bonaventure mast, and its outrigger or spreader which projected from the stern were already obsolete. However, the outrigger might still have been useful as a spreader for the lateen sail on the mizzen mast. The spreader is still present in Portuguese iconographical sources, including one example seen in the artwork of Domingo Sanches (1618) and a painting of the *Igreja dos Francesinhos* (1620) (Castro *et al.* 2018: 50 - 52). In the case of Spain, the latest paintings showing an outrigger, among the consulted sources, is exhibited in the *Sala de Batallas del Escorial* (1590) (Castro 2018: 31-32). Spreaders are not mentioned in the Spanish 1613 and 1618 *Ordenanzas*. This might mean that the spreader disappeared earlier in Spanish ships than it did in the Portuguese vessels, with a a *terminus ante quem* of 1590 on the Spanish naval paintings. No the 17th century Portuguese or Spanish references consulted show a bonaventure. However, it appears in a model kept at the *Museo Naval de Madrid* representing a vessel ca. 1593, but apparently this model was made in 1845 (Castro 2018:33), so it is not a contemporary source or the vessel it represents is inaccurately dated.

Curiously, the same model has also a spritsail topmast with its yard. A small mast stepped at the outboard end of the bowsprit, the spritsail topmast is very rare in Iberian Iconography of the late 16th and early 17th centuries and they are not mentioned in the 1613 and 1618 *Ordenanzas*. Notwithstanding, Carla Rahn Phillips (1991) published an engraving dating to 1611 that is preserved at the *Archivo Histórico Provincial de Guipúzcoa*, which displays this feature. Hormaechea *et al.* (2018: Vol 2. 207) also quote a Portuguese secondary source, which asserts the spritsail topsail first appeared around 1600. Finally, Anderson (1974: xi) dates the topmast between 1600 and 1720 and asserts they were present on large Dutch men-of-war by 1613. Although the evidence shown by Rahn Phillips is earlier than the Dutch example cited by Anderson, it seems reasonable to think that the spritsail topsail was a Dutch influence in the Iberian rigging of the 17th century, as many other characteristics, such as the Flemish fish mast (*chapuz a la flamenca*), which will be covered later in this chapter.

According to the *Ordenanzas* of 1613 and 1618, the main and fore masts had topmasts to support the fore and main topsails and their yards. This is consistent with the most common pattern in both Spanish and Portuguese iconographic sources of the period. Neither the mizzen top sail nor the fore and main top gallants are mentioned in the regulations and they have not been observed in the Iberian paintings of the period, with the exception of the Portuguese representation in *Roteiro do Mar Roxo* of João de Castro (Castro *et al.*2018: 24), preserved at the *Universidad de Coimbra*, dating as far back as 1540-1541. Hormaechea *et al.* (2018: Vol2 - 220) show evidence that top gallant sails did not become widespread until mid-17th century, when their use became prevalent on the masts of big ships.

In the 17th century, masts of Iberian vessels were reduced in comparison to the previous century. According to primary documentary sources, Hormaechea *et al.* (2018: 208) suggest this was done, following the Flemish fashion. The masts might have been reduced to increase stability.

Construction Process and Proportions

Escalante (1575: 43) asserted, masts should be made of a single tree, but the *Ordenanzas* show evidence that by 1613 the masts did not have the same thickness throughout their length. The thickest portion was at the height of the mast partners at the upper deck level. By the first quarter of the 17th century, there were already coefficients to calculate the proportions of the masts and yards, as well as algorithms governing their shape. The most common methods were known as building by the *quinto* (fifth) or by the *tercio* (third). When mast making by these methods the mast measurements were based on the thickest part of the mast. In the case of the *quinto*, the head and heel of the mast measured three fifths 3/5 the thickness occurring at the mast partner (*fogonadura del puente*). In the case of the *tercio*, the head and foot were supposed to be 2/3 the thickness of the mast at the partners. The yards were built using proportions based on the center of the yard at the slings.

When building by the fifth, yard arms tapered to 2/5 (instead of 3/5 which was the case of the masts) of the full thickness at the center. These coefficients varied depending on the vessel's size and Hormaechea *et al.* (2018: 204) asserted that by the third quarter of the century Jacinto Antonio Echeverry (1673) referred doing it by the seventh and the ninth.

When building the masts, the first step was to make a square-sectioned timber out of the log. Later the algorithms known as *bruscas* and *mesalunas* were used to generate a set of grooves (*chazos*) of different depths marking the diameter that the mast should have at each point. The four edges of the square timber were trimmed down with an adze, resulting in an octagonal mast. Further trimming of the angles yielded timbers with sixteen or even thirty-two faces. The angles were planned down yielding a circular-sectioned mast or yard as the final product (Hormaechea *et al.* 2018: 203-2014). Two different *bruscas* were used, as the mast was not divided in two equal lengths. The length below deck was considerably shorter. According to Escalante (1575: 43), one third of the mast remained inside the hull below the partners and the remaining two thirds projected from the deck upwards. *Bruscas* and other related algorithms are explained by Sarsfield (1984) and Castro (2007) and summarized in the second chapter of this dissertation. Their explanations refer to the rising and narrowing of the hulls, however the algorithms apply consistently to the diminishing in thickness of masts and yards.

Sometimes the yards were made of two pieces, each measuring ¾ the total length and overlapping 2/3. The wooldings that bound together the two halves of the yards were made with used ropes, as they did not stretch as much as new ones (Hormaechea *et al.* 2018: 205).

Cristobal de Barros (1581), Plantations Superintendent of the Crown during the reign of Felipe II (1556-1598), asserts the most appreciated wood for building the masts and yards was the Baltic pine, also known as Prussian pine (Hormaechea *et al.* 2018:108). Notwithstanding, Escalante (1575:38) opined six years earlier that the best wood for mast making was the Flemish pine called *prusa*, adding that the top masts should be made out of a lighter wood. Norwegian pine was also appreciated among riggers. However these pines were in high demand and by the end of the 16th century they were scarce and they became very expensive, Spanish oak was sometimes used as a substitute, increasing the ideal thickness of the masts. The added weight aloft resulted in stability issues (Hormaechea *et al.* 2018: 200).

The following tables (17 to 23), present the proportions of the spars in Spanish and Portuguese treatises and other primary sources of the late 16th and the 17th century.

Source	**Foremast Length**	**Foremast Thickness**
Presidente Visitador 1560 (Hormaechea *et al.* 2018: 97)	1 keel + ½ beam = 2.45 x beam	
Escalante 1575 (Escalante, 1575: 43)	Two thirds protrude and one third remains inside	
García de Palacio 1587 (Hormaechea *et al.* 2018:210)	= keel	
Tome Cano 1611 (1611: fol. 24)	Mainmast - 1 *codo*	Circumference of the mainmast - 1/5
Ordenanza 1613 (Art. 75)	Mainmast - 4 *codos*	Circumference of the mainmast - 1/6
Antonio de Urquiola 1614 (Hormaechea *et al.* 2018: 193)	1x keel – 1 *codo* (at least)	

Table 17. Proportions of the foremast according to different treatises and primary sources.

Source	Foremast Length	Foremast Thickness
Francisco Díaz Pimienta 1645 (Hormaechea *et al.* 2018: 254)	Mainmast - 6 *codos*	
1668 Fernando de Ezquerra (Hormaechea *et al.* 2018: 289)	Mainmast - 3 *codos*	Circumference mainmast - 1/2 *palmo*

Table 17 Continued. Proportions of the foremast according to different treatises and primary sources.

Source	Mainmast Length	Mainmast Thickness
Presidente Visitador 1560 (Hormaechea *et al.* 2018: 97)	1 keel + 1 beam	
Escalante 1575 (Escalante, 1575: 43)	3 x depth in hold	
García de Palacio 1578 (Hormaechea *et al.* 2018: 210)	1 keel + 1 fore rake of the stem	
Tome Cano 1611 (1611: 24)	2 ½ x beam	Circumference = 1/5 x beam. (If 12 *codos* of beam or less. When more than 15 *codos* of beam, the proportion must be reduced.)
Ordenanza 1613 (Art. 73 y 74)	1 x keel (from heel to trestletrees)	Circumference in *palmos de vara* = ½ beam in *codos*
Antonio de Urquiola 1614 (Hormaechea *et al.* 2018: 193)	1 x keel + 5 *codos* (From the heel to the mast cap)	

Table 18. Proportions of the mainmast according to different treatises and primary sources

Source	Mainmast Length	Mainmast Thickness
Ordenanza 1618 (Art.72-73)	1 x keel + 2 *codos*[2]	Circumference in *palmos de vara* = ½ beam in *codos*
Diálogo entre un Vizcaíno y un Montañés 1632 (Hormaechea *et al.* 2018: 212)	2 2/3 x beam (The length is 41.7 x the diameter)	Circumference = 1/5 x beam
Francisco Díaz Pimienta 1645 (Hormaechea *et al.* 2018: 254)	2,6 x beam	
Fernando de Ezquerra 1668 (Hormaechea *et al.* 2018: 289)	2 x beam + 1 depth at the height of the gun deck	Diameter: 9 *palmos*

Table 18 Continued. Proportions of the mainmast according to different treatises and primary sources.

Source	Mizzenmast Length	Mizzenmast Thickness
Garcia de Palacio 1578 (Hormaechea *et al.* 2018: 221)	= bowsprit	
Ordenanza 1613 (Art. 79).	Main topmast + 3 *codos*	= Main topmast

Table 19. Proportions of the mizzenmast according to different treatises and primary sources.

[2] The difference of 2 *codos* in the size of the mainmast in the *Ordenanzas* of 1613 and 1618, can be explained by the fact that that the vessels of 1618 have the same beam as the ones of 1613, but have shorter keels and overall lengths. Based in this Hormaechea *et al.* (2018: 2012) confirmed that although the mast size is expressed in relation to the keel, the actual measurement determining the proportion of the masts is the beam. They also explain that the length of the mainmast in relation to the beam diminishes when the overall-length increases. They further explain that as the beam increases, the ratio length/diameter of the mast diminishes.

Source	Bowsprit Length	Bowsprit Thickness
Garcia de Palacio 1578	4/5 x foremast	
Ordenanza 1613 (Art.76)	Foremast - 2 *codos* (45 degrees in respect to the main deck, where his mast-step is located)	Thickness: ½ palmo less than the foremast (Art.75)

Table 20. Proportions of the bowsprit according to different treatises and primary sources.

Source	Topmast Length	Topmast Thickness
Escalante (1575: 43)	1/3 x corresponding lower mast	
Gracia de Palacio 1578 (Hormaechea *et al.* 2018: 180)	Main: 1 ½ x beam Fore: Main-topmast - 1/5	
Cano (1611: 24)	½ Lower mast	1/5 the lower mast head
Ordenanza 1613 (Art. 77)	Main: 1 ½ x beam (From mast fid to trestletrees) Fore: main-topmast – 1/5	Main: lower mast head - 1 *pulgada* Fore: foremast head - 1 *pulgada*
Ordenanza 1618	Main: 1 2/3 x beam Fore: main-topmast – 1/5	lower mast head - 1 *pulgada* Fore: foremast head - 1 *pulgada*
1668 Fernando de Ezquerra (Hormaechea *et al.* 2018: 289)	2/3 mainmast	2/3 and 2 *puntos*

Table 21. Proportions of the topmast according to different treatises and primary sources.

Source	Foreyard Length	Foreyard Thickness
Presidente Visitador 1560 (Hormaechea *et al.* 2018: 97)	1 keel	
Escalante (1575: 43)	Main yard - 1/3	
García de Palacio 1587 (Hormaechea 2018: 210)	Main yard - 1/3	
Cano (1611: f.24)		= Mast head

Table 22. Proportions of the foreyard according to different treatises and primary sources.

Source	Foreyard Length	Foreyard Thickness
Ordenanza 1613 (Art. 80 - 81).	2 x beam	Mainmast head – 1 *pulgada*
1668 Fernando de Ezquerra (Hormaechea *et al.* 2018: 289)	2 x beam	

Table 22 Continued. Proportions of the foreyard according to different treatises and primary sources.

Source	Mainyard Length	Mainyard Thickness
Presidente Visitador 1560 (Hormaechea *et al.* 2018: 97)	1 x keel + ½ beam	
Escalante (1575: 43)	2 x beam	
García de Palacio 1587 (Hormaechea 2018: 210)	2 1/3 x beam	
Cano (1611: f.24)[3]	Mainmast – 5%	= Mast head
Ordenanza 1613 (Art. 80 - 81).	2 ¼ x beam	= foremast - 1 *pulgada*
1668 Fernando de Ezquerra (Hormaechea *et al.* 2018: 289)	2 ¼ x beam	

Table 23. Proportions of mainyard according to different treatises and primary sources.

Tables (24 to 35) show the metric measurements calculated for the reconstruction of the galleon of 22 *codos* of beam, based in the *Ordenanza* of 1613. According to Castro (Pers. Com.) there is evidence for the use of Spanish measurements in Portugal by the beginning

[3] This measurements varied in the case of warships, Cano (1611: f 24 v) explains that the mainyard must be 2 ¼ times the beam to allow better close-hauling and he adds that the length subtracted from the yard, must be added to the mast.

of 17th century. However, Hormaechea (Pers. Com.) asserts there is no evidence for the use of Portuguese measurements in Spain. Notwithstanding, the *Ordenanzas* used the *palmo de vara* (22 cm), which according to Castro (Castro 2008: 69) is a Portuguese measurement. Casaban (Pers. Com.), as Hormaechea, asserts the *palmo* referred in the *Ordenanzas*, is the Spanish *palmo* (20.9 cm). Notwithstanding, when certain reconstructed spars are drawn the Portuguese *palmo de vara* seems more plausible and it is reasonable to think there were Portuguese shipwrights involved in the formulation of the *Ordenanzas* were written. By 1613, Portugal had been ruled by Spanish crown for over 30 years and the flow of shipwrights across Europe by the 17th century was already considerable, as shown by the architectural evidence of the 1628 Swedish warship *Vasa*, where archaeologists found shipwrights employed both Dutch and Swedish rulers (Cederlund: 1985).

Source	**Mainmast Length**	**Mainmast Thickness**
Ordenanza 1613 (Art. 73 y 74). Proportion	1 x keel	Circumference in *palmos de vara* = ½ x beam in *codos*
Measurement	31 m	Diameter: 73 cm using Spanish *palmos* Diameter: 77 cm using Portuguese *palmos de vara* Heel and head: 43.8 cm (palmo) or 46.2 cm (p. de vara)

Table 24. Mainmast proportions and metric measurements of a galleon of 22 *codos* of beam and 1073.33 *toneladas* according to the *Ordenanza* of 1613.

Source	Foremast Length	Foremast Thickness
Ordenanza 1613 (Art. 75) Proportions	4 *codos less* than the main mast	Circumference: mainmast - 1/6
Measurement	28.7 m	Diameter: 60.8 cm (*palmos*) Diameter: 64.1 cm (*p. de vara*) Heel and head: 36.5 cm (palmos): 38.46 cm (*p. de vara*)

Table 25. Foremast proportions and metric measurements of a galleon of 22 *codos* of beam and 1073.33 *toneladas* according to the *Ordenanza* of 1613.

Source	Mainyard Length	Mainyard Thickness
Ordenanza 1613 (Art. 80) Proportions	2 ¼ x beam	Diameter = head of the mainmast
Measurement	28.46 m	60.8 at the sling, 24.2 cm at the arms (*palmos*) 64.1 at the sling, 25.6 cm at the arms (*p. de vara*)

Table 26. Mainyard proportions and metric measurements of a galleon of 22 *codos* of beam and 1073.33 *toneladas* according to the *Ordenanza* of 1613.

Source	Foreyard Length	Foreyard Thickness
Ordenanza 1613(Art. 81) Proportions	2 x beam	Diameter = head of the foremast – 1 *pulgada*
Measurement	25.3 m	58.5 cm at the sling, 23.4 at the arms (*palmo*) 61.8 at the sling, 24.7 at the arms (*p. de vara*)

Table 27. Foreyard proportions and metric measurements of a galleon of 22 *codos* of beam and 1073.33 *toneladas* according to the *Ordenanza* of 1613.

Source	Main Topmast Length	Main Topmast Thickness
Ordenanza 1613 (Art. 77) Proportions	1 ½ x beam	Lower mast head - 1 *pulgada*
Measurements	18.9 m	41.5 cm (*palmos*) 43.9 cm (*p. de vara*)

Table 28. Main topmast proportions and metric measurements of a galleon of 22 *codos* of beam and 1073.33 *toneladas* according to the *Ordenanza* of 1613.

Source	Mizzenmast Length	Mizzenmast Thickness
Ordenanza 1613 (Art.79) Proportions	main topmast + 3 *codos*	= main topmast
Measurements	19.1 m	34.2 cm

Table 29. Mizzenmast proportions and metric measurements of a galleon of 22 *codos* of beam and 1073.33 *toneladas* according to the *Ordenanza* of 1613.

Source	Fore Topmast Length	Fore Topmast Thickness
Ordenanza 1613 (Art. 77) Proportions	Main topmast – 1/5	Head of the foremast - 1 *pulgada*
Measurements	15.12 m	34.2 cm (*palmos*) 36.16 (*p. de vara*)

Table 30. Fore topmast proportions and metric measurements of a galleon of 22 *codos* of beam and 1073.33 *toneladas* according to the *Ordenanzas* of 1613.

Source	Bowsprit Length	Bowsprit Thickness
Ordenanza 1613 (Art. 77) Proportions	Foremast - 2 *codos*	Foremast - ½ *palmo*
Measurement	27.5 m	57.9 (*palmos)* 61.2 (*p. de vara*)

Table 31. Bowsprit proportions and metric measurements of a galleon of 22 *codos* of beam and 1073.33 *toneladas* according to the *Ordenanza* of 1613.

Source	Spritsail Yard Length	Spritsail Yard Thickness
Ordenanza 1613 (Art.82) Proportions	Forecourse yard - 1/5	No information
Measurement	20.24 m	

Table 32. Spritsail yard proportions and metric measurements of a galleon of 22 *codos* of beam and 1073.33 *toneladas* according to the *Ordenanza* of 1613.

Source	Mizzenyard Length	Mizzenyard Thickness
Ordenanza 1613 (Art.85) Proportions	= Foreyard	No information
Measurement	25.3 m	

Table 33. Mizzenyard proportions and metric measurements of a galleon of 22 *codos* of beam and 1073.33 *toneladas* according to the *Ordenanzas* of 1613.

Source	Main Topsail Yard Length	Main Topsail Yard Thickness
Ordenanza 1613 (Art.85) Proportions	= Beam	= main topmast head
Measurement	12.6 m	24.9 cm (*palmo*) 26.34 (*p. de vara*)

Table 34. Main topsail yard proportions and metric measurements of a galleon of 22 *codos* of beam and 1073.33 *toneladas* according to the *Ordenanza* of 1613.

Source	Fore Topsail Yard Length	Fore Topsail Yard Thickness
Ordenanza 1613 (Art.84) Proportions	= Topsail yard - 1/5	No information
Measurement	10.12 m	

Table 35. Fore topsail yard proportions and metric measurements of a galleon of 22 *codos* of beam and 1073.33 *toneladas* according to the *Ordenanza* of 1613.

Flemish Fish Mast (*chapuz)*

In the 17th century there were no cheeks in the joint between the lower masts and the top masts of Iberian vessels. Instead, they used a fish mast arrangement, using timbers shaped like tiles to surround the upper portion of the lower mast. These timbers, composed the Flemish fashion *chapuz*, which was made out of oak, mahogany or walnut. The fishes were joined to the mast with a dovetail inside and wooldings in the outside. The *Ordenanza* of 1607 (f. 291) mentions the *chapuz* covered 8 *codos* of the mast, but López Guitián (1630) asserted it covered half of the mast (Hormaechea *et al.* 2018: 2014-2015). Instead of the later jeers, wheels called sheaves fitted into the mast. By 1607 the sheaves were placed below the mast top, but after 1613, they became part of the *chapuz* and were placed above the point of attachment of the shrouds, above the trestletrees and crosstrees. Hormaechea *et al.* (2018:215) suggest the wheels were displaced up to avoid weakening the fish arrangement in the area that was subject to the tension caused by the shroud attachments.

Trestle-trees and Cross-trees

According to Anderson (1955:14-15), the trestle-trees were as long, or slightly longer, as the mast head, their molded dimension was 1/13 of their length and their sided dimension was between 7/8 and 9/10 of their depth. Quoting secondary sources, the same author asserts they were three tenths of the beam of large ships and 1/4 of the beam of smaller vessels. The crosstrees tended to be shorter. Both, crosstrees and trestletrees tapered towards the ends, the middle quarters retained their full molded dimension which sloped off gently toward the ends, which lost to half their thickness. This was done either with strait edges or with the arc of a circumference. It has to be kept in mind that Anderson (1925, 1927, 1974) wrote for a model builder audience and that most of his research is thus based on models. Given the lack of other sources and the scarcity of iconography to inform on many aspects of 17th century rigging, his books become a valuable source when a careful scrutiny of his statements is conducted.

Fid, Mast Cap and Doubling

The top mast fid was made of iron and was inserted through a slot cut trough the heel of that mast over the trestletrees to support it (Hormaechea *et al.* 2018: 219). Anderson (1955: 24) asserts its location was variable as well as the lower portion of the topmast heel that projected bellow the trestle-trees. He calculates this portion should not be less than twice or more than three times the thickness of the topmast at the cap. The *Ordenanza* of 1607 (fol. 293) specifies that the mast caps must be made of iron, but their dimensions are not specified. According to Anderson (1955: 21) in the case of English ships, the mast caps were half the size of the mastheads or less, the width was 6/11 of the length and the depth 3/7 of the width. Once this is sketched, it seems however sturdier than it should be, but this cannot be checked with iconography as this piece is always obscured by the crow's-nests and the topmast shrouds.

None of the *Ordenanzas* specify the measurement of the doubling, but according to Anderson (1955: 24) the square section of the topmast heel covered the upper quarter of the lower mast's head. According to French sources of the late 17th century consulted by Gauthier-Berube (Pers Com.), the doubling was 1/9 of the topmast length. Castro (2005:115) calculated the doubling as being 1/12 of the lower mast, based on Fernandez (1616). This would correspond to 1/7 of the length of the main topmast.

Crow's nests

According to the *Ordenanza* of 1613 (Art.88-89) the crow's nest was almost 1/3 of the beam in diameter. The height of the crow's nest shown in the reconstruction of the galleon of the 22 *codos* of beam following the *Ordenanza* of 1613 seems excessive, but it is as tall as it should be based in iconographic sources of the period. According to Anderson (1955: Fig. 10 – 11) their shape changed around 1650, when they lowered the forward upper rail. However, this same arrangement is also present in a 16th century Portuguese painting of the *Livro de Praga* (1568) (Castro *et al.* 2018: 35). A painting of the *Sala de Batallas del Escorial* (1590) (Castro 2018: 31-32) and a representation of the Battle of Lepanto painted by Andriesvan Eertvelt (c.1622) (Castro 2018: 40) shows men standing on the crow's nest with the upper rail reaching the height of their chests. Another Spanish crow's-nest of considerable height is shown in the fragment of an artwork, published by Hormaechea *et al.* (2018: Fig. 17.15/Fig. 21.8) and maintained at the *Museo Naval de Madrid,* that probably represents the battle at Figuerola, Spain in 1622. In the case of Portuguese ships, a votive sculpture of the *Igreja de Sagres* (1600) and a representation of the *Nau Santa Cruz* (c.1620) kept at the *Museu de Marinha* also show incredible heights in this construction (Castro *et al.* 2018: 54). However, earlier and later representations show much lower crow's nests until the mounting of swivel guns in the mast tops, as this was coupled with a considerable increase of their height (Grieco Pers. comm.). The aforementioned painting published by Hormaechea *et al*.(2018), as well as the representation of the Battle of Lepanto show that the spaces between the rails of the crow's nests were covered with a surrounding piece of red cloth or more likely leather which might well have served to protect sailors from arrows.

Standing Rigging

Channels or chain wales were thick horizontal planks attached above the upper wale or located at the height of the main deck, which were structurally reinforced with vertical timbers attached to the hull. These provided a sort of table, which is actually their name in Spanish (*mesa de guarnición*). Channels secured the shroud attachments at the dead eyes and extended them outboard from the sides of the vessel to provide a better lead angle for supporting the lower masts. The *Ordenanza* of 1613 (Art.45), states that cannels were to be made in the Portuguese fashion, but no further explanation is provided. Based in the measurements given by Gaztañeta's treatise, Hormaechea *et al.* (2018: 165) have calculated the length of the foremast channels plate at seventeen percent of the overall length of the vessel, the main mast channels at nineteen percent, and the mizzen mast corresponding piece was nine percent.

By the second quarter of the 17th century, full chain links were being produced for chain plates and were the type that riggers preferred. Garcia de Palacio (1587: Chapter 1) asserts there were supposed to be twelve dead eyes attached to the main mast channel with four to five chain links each. This is not consistent with the iconography, which shows that the number of shrouds was reduced in the 17th century in relation to the previous era, but it never shows more than ten, eight being a very consistent number in 17th century paintings. Palacio asserted that each chain link should measure one *palmo* (20.9 cm), but an example of a late 16th century dead eye attachment preserved at the *Museo Naval de Madrid* presents only two 36 cm long chain links, a dead eye clamp which is 18 cm wide by 25 cm long, and the corresponding bolt to fasten the chain to its plate, which is 41 cm long (Hormaechea *et al.* 2018: Fig. 16.10, page 163). According to Diego Lopez de Guitán (1630-40), the chain links were supposed to be two *codos* long and were intended to be reinforced at the center (Hormaechea *et al.* 2018: 235). If one considers that by the time of Garcia de Palacio, riggers used between four and five (104 cm) links of one *palmo* each, two chain links of *2 codos* (115 cm), would have made a slightly longer attachment. The chain links were embedded in the edge of the chain plate, which was probably notched for them, and a reinforcing strap was nailed to the outboard edges of this protruding plank.

The dead eyes themselves were sort of pear-shaped by the beginning of the century, instead of the round ones that were used from the late 17th century onward. Daniel Mark Brown posted a picture of a dead eye on ResearchGate (https://www.researchgate.net/figure/One-of-Harriss-deadeyes-very-reminiscent-of-a-Vasa-deadeye-ca-1610-1640-Photo-by_fig5_292144862) that presents this pear shape and is dated between 1610 and 1640. The dead eyes of *Vasa* (1628) also have also this same shape (https://www.flickr.com/photos/koosakkedis/4497977558/).

The Lines

The circumference of the section of rope was named *mena* and it was measured using a strip of parchment rolled up in a reel named the *pulgadera* in accordance with the measuring unit *pulgada* (2.32 cm) in which it was graduated. Hormaechea *et al.* (2018: 228) have calculated the *mena* of different components of the rigging, in relation to the main stay, which based in their research had 1/5 the circumference perimeter of the main mast at the height of the mast partner, which as noted before was the thickest point. The *mena* varied depending on the quality of the rope and it decreased once the cordage was installed and under tension. Hormaechea *et al.* (2018: 229) assert that when lines constructed from low quality hemp were used the *mena* was increased up to 50% when compared to lines made from higher quality materials.

The standing rigging was tarred to extend the logevity of the rope and the best tar came in holm oak barrels from the port of Vyborg, (on the Gulf of Finland) as it was as clean and clear as oil. However, for Spaniards it was less expensive to use the darker local product boiled in Tarifa, Catalunya that was good or even better than the one from the Baltik, although it was not as clean (Hormaechea *et al.* 2018: 229).

The optimal raw material for ropes was the good crops of hemp harvested in Calatayud and other regions of Aragón (Escalante, 1575: 38), but rope were also imported by Flemish merchants from Russia, Germany, Holland and nearby Baltic areas (Hormaechea *et al.* 2018: 224). The quality of the rope was carefully observed, to the point that some authors have suggested that in Italy there was a quality control procedure for naval ropes as early as 1588 (Martin 1978: 45, 1979:35). Based on the rigging *Ordenanza* written by the *Universidad de Mareantes* (1620), Hormaechea *et al.* (2018: 225) proposed that quality control of rope was implemented and regulated in Spain by the first quarter of the 17th century. It seems there was corruption in the Iberian realms and the hemp was sometimes mixed with lower quality fibers to increase the sellers profits. Five different qualities of ropes were recognized by the time. From the lowest to the highest quality they were named: *estopa, chorrón, canal, medio cerro* and *cerro*. (Hormaechea *et al.* 2018: 224).

Some lines that might seem strange in the rigging reconstruction of the galleon are the lifts of the mizzen yard that extended to the main topmast head, but this can be seen in a painting Viso del Marquez (c.1590) (Castro 2018: 25) in the Battle of Lepanto quoted above and also in the *Recuperación de San Martin* (c. 1633) of Juan de la Corte (Castro 2018: 42). In the case of Portuguese representations, it is present in the Leiden View of Lisbon (1550) (Castro *et al.* 2018: 27), as well as in one of the paintings of the *Igreja dos Francesinhos* (1620) (Castro *et al.* 2018: 53). This arrangement is also confirmed by Anderson (1974: Fig.33). Foot ropes, stirrups and horses are not mentioned in Spanish sources until 1691, when Garrote (1691: Chapter 18) takes them into account in his treatise.

Running Rigging

Most of the rigging in my reconstruction is based on the most consistent lines shown in Portuguese and Spanish iconography, but some of the components appear to be attached in counterintuitive places. This is the case of the braces of the topmast yards, as they attach directly to the crow's-nest. Such a short angle would not allow much movement to the yards. Even though this feature can be clearly observed in the ship images of Viso del Marquez (c. 1590) (Castro 2018: 26), in a painting of the *Sala de Batallas del Escorial* (c.1590) (Castro 2018:31), in the *Recuperación de San Martin* (c.1633) (Castro 2018: 41), and in the *Recuperación de San Cristobal* painted by Felix Castello (c.1634), just to mention some of the sources. The only Portuguese case where it was found, was the *Memória das Armadas* of 1566 (Castro *et al.* 2018: 33). Unfortunately, the running rigging of the mizzen is commonly covered by the lateen sail in most iconographical sources, so its sheets (Anderson 1974: Fig. 240) and halyard (Anderson 1974: Fig.110) were based on Anderson's drawings.

Throughout this chapter the author has attempted to provide a comprehensive description of the rigging of Iberian vessels of the 17th century, but there is still a lot of research left to do, especially in regard to the aspects that cannot be observed in iconographic sources. In our current state of knowledge, the subject seems very static, but a more dynamic picture would probably arise from further chronological comparative analysis of the sources. We have shown that Portuguese and Spanish vessels had much in common, but there were some differences between them and certain features were adopted or abandoned earlier in one country than in the other. The only Portuguese treatise consulted (Cano 1611) seems to show that Portuguese vessels had longer masts and yards in respect to Spanish vessels of the same period. Finally, the Flemish influence on Iberian rigging of the 17th century must be highlighted.

CHAPTER VII

CONCLUSIONS

Naval architecture was integral to the Scientific Revolution which resulted from the recovery of ancient knowledge and discoveries in astronomy, mathematics, and physics and other fields of knowledge that exerted a direct influence upon ship design. The inventions of calculating devices and measuring aids, and the transition from synthetic geometry to analytical geometry played an important role in the development of Iberian shipbuilding and design that has not been full well-acknowledged so far. I have shown coefficients and algorithms were applied in ship design or naval architecture since at least the fifteenth century and that by the 17th century, Iberian naval architecture achieved a high degree of accuracy in shape prediction.

By the second half of 17th century ships exclusively designed for war were being built by the French, Dutch, and English, while the Habsburg Crown kept building dual purpose vessels that served to carry and protect cargoes across the oceans. These Iberian galleons mirror the rise of capitalism aiming to increase the profit of merchants, satisfying the global demand for goods and diminishing the cost of labor by reducing crew size. Iron fasteners, a characteristic shared by all Iberian shipwrecks analyzed here, had the advantage of permitting the employment of unskilled workers in the shipyards. However, they corroded faster, making the life span of the vessels shorter, yielding to a period of mass production.

Many naval historians and maritime archaeologists have argued that Spain was experiencing a period of technological and scientific backwardness. However, its vessels successfully sailed and defended the trade routes and colonies well into the eighteenth century, as they resulted from deep scientific discussions among prominent naval architects and officers and were built by shipwrights holding the profound experience and the weight of a very long tradition.

The application of analytical geometry should have encompassed a transition to rationalist among shipbuilders and designers. However, empiricism was philosophically strongly rooted and experience remained the most valuable base for shipbuilding and design. Innovation was too high a risk in lives and goods to be accepted lightly.

Coefficients and algorithms were known to naval treatise writers, but they were not well understood by master shipbuilders, who only applied them by using molds and gauges (*graminhos* in Portuguese, *gálibos* in Spanish), divorcing shipbuilding and naval architecture at this very early stage. The morphological structure and geometrical proportions made the body shapes of ships explicit before they were built. For the previous reasons, Iberian naval architecture of the 17th century should be regarded as an incipient science, although it did not reach its full potential until the following centuries.

In chapter I explained how useful it is to analyze Iberian shipbuilding and design in light of the philosophical thought of the Scientific Revolution in which they occurred. I cannot prove that Descartes actually influenced the thought of Iberian naval architects. However, his early work contains multiple elements that help us to understand Iberian ship design of the 17th century in its intellectual context, which encompassed the tension between algebra and geometry and the tension between rationalism and empiricism that was the *zeitgeist* of this century. A potential topic of research would be whether the Kantian synthesis of empiricism and rationalism influenced later developments on ship theory that later on resulted in the institutionalization of naval architecture.

In Chapter II, I discussed how deep changes in the conception of ship's structures, as well as innovations in their structural components, arrangements and connections were required for the adoption of skeleton-based construction. However, this method allowed the determination the shape of the ships before they were built. We showed there was preconception of ship shapes expressed in *ad hoc* coordinate systems, multiple algorithms and coefficients. This new method required as well profound changes in the minds of the people. Despite the attachment to empiricism, the three-to-one and the ace, two three rules, combined with the half moon, the infinite stick, incremental triangles, and the sword's tail testify to the transition from a purely empirical approach to a more rational shipbuilding mentality. This knowledge was apparently exclusive of ship designers or naval architects; however, it was materialized in molds for the use of shipbuilders.

Chapter III presented the origin, development, and changing functions of galleons. I showed that galleons were not a unified type before the mid-16th century and that even in the same location, the term was used to designate vessels of different characteristics, sizes, and functions. Evidence suggested that galleons originated in Italian territories, adopting some qualities of galleys and incorporating features of whalers, before they were replaced by the *navíos.* Galleons were multipurpose vessels that performed as merchant and military vessels. As I have shown, power struggles and the need to maintain military power, both inherent to colonialism; in conjunction with the phylosphical tought of the period, framed the shipbuiding practices of this period and determined which designs were likely and ulikely to occur. The shape of hulls does not appear to change significantly along the century. A pending complementary analysis of iconography would help to clarify the development of the freeboard and upper works, as well as to complement the rigging reconstruction we present in Chapter VI.

New information might also arise from the quantitative research being conducted by the author, Andrés Succolotto and Patricia Schwindinger which contrastis the ideal and real measurements with the reconstructions of shipwrecks from the archaeological record and the ships described in documentary sources. This has the potential to result in a dating procedure using multivariable analysis.

Following previous assertions of Rieth (1998), Castro (2008) and Oertling (2005, 2008), in Chapter IV showed that in the published Iberian shipwrecks a distinctive shipbuilding tradition can be inferred. Attempts towards standardization and the publication of rules and treatises make this hypothesis even more likely in the 17th century than in previous centuries. Standardization processes are also visible in structural timbers, keeping in mind a consistent cluster of successful structural solutions to the strains of sailing remained in use independently from the year of construction, the purpose, geographic location of construction and size of the vessels. Further research might clarify regional specificities and the rhythm at which changes occurred as proposed by Loureiro (2012). I proved that there was scientific interest in 17th century Iberian shipbuilding in standardizing the most desirable shapes and components, as attested by the cluster of traits found on Iberian shipwrecks and the coincidences in the sided to molded ratios of structural timbers. Two additional traits were discerned in the archaeological record that could be added to the cluster proposed by Oertling (2001) and complemented by Castro (2008) and Hormaechea et al.

(2018: 64–65). The face of the floor timbers to which the futtocks are fastened changes forward and aft of the master frame, and a primary ballast composed of lime and gravel (mortar) was poured in the bilge.

Chapter VI provided a description of the rigging of Iberian vessels of the early 17th century, but there are still many aspects that cannot be observed in iconographic sources. Chronological comparative analysis of a wider collection of maritime images should help us abandon the most likely mistaken idea of an unchanging rigging resulting from the present state of knowledge. I showed that Portuguese and Spanish vessels had much in common, despite the minor differences and the divergent rhythms at which certain components were adopted or abandoned.

My hypotheses were that:

1. If there was a scientific interest in 17th-century Iberian shipbuilding to standardize the most desirable shapes and if it was successful:

- There should be a cluster of traits that all Iberian vessels share

The idea of a cluster of traits shared by Atlantic ships\ was originally developed by Oertling (1989b, 2001), discussed by Rieth (1998), and furthered by Castro (2008). I have built upon this hypothesis throughout the dissertation with the final results displayed in Table. 5, which indicate that most of the 13 proposed traits are shared by all published vessels. Further work toward uncovering and recording buried features might show even more similarities. The adjustment of vessels to certain traits will remian unknown in cases when the structures are not preserved. This hypothesis can be catalogued as possitively tested.

- There should be coincidences in the sided to molded ratios of the vessels and their structural timbers

In this case, I have not found as much coincidences as I expected. However,

- There is a coincidence in the length to bean ratios (3.32) of the *Santo Antonio de Tanná* and *San Diego*. *Nuestra Señora de Atocha*'s length to beam ratio (3.36) also falls within a very close value

- There is a coincidence in the keel to length ratios (1.42) of the Pepper wreck and IDM-003

- There is a coincidence in the keel to beam ratio of IDM-003 and the Fuxa wreck

- In the cases of the Green Cabin wreck (2.65) and the *Nuestra Señora de Atocha* (2.63), the keel to beam ratios fall within very close values

- There is a coincidence in the sided to molded ratios (0.83) of the keels of the *San Diego* and the Pepper wreck

- There is an overlap in the ranges of the length to sided ratios of the keelsons of *San Diego* (70–87.50) and *Santo Antonio de Tanná* (87.29-107.85)

- There is an overlap in the ranges of the length to sided ratios of the keels on the Fuxa (8.51-13.68) and Green Cabin wrecks (13.47-19.30)

- There is a coincidence in the sided to molded ratio (0.85) of the futtocks of the Pepper wreck and IDM- 003

- The sided to molded ratios of the floor timbers of IDM-003 (0.59) and the Green Cabin wreck (0.54) fall within close values

- There is a coincidence in the sided to molded ratios (1.6) of the stringers of Angra B and *Santo Antonio de Tanná*

Missing information due to partial excavation, missing or not recorded features and non-preserved structural timbers (or their full dimensions) is likely one of the causes why I did not find more coincidences in the ratios, but the available information still confirms that this hypothesis was positively tested.

2. If ship design was strongly influenced by mathematics, but still attached to empiricism from a philosophical perspective:

- Shipbuilding treatises should show a mixture of references to geometry and experience as the main sources of knowledge for proficient shipbuilders and designers

As I have shown, whole molding was known at least since mid-15th century. It was based on the coefficients of three-to-one and one-two-three, along with the algorithms of the half-moon, infinite stick, incremental triangle and sword's tail. The lengths of the spars were expressed in coefficients as well and their shapes were foreseen using these same algorithms. This shows that ship shapes could be foreseen before the vessels were actually built, despite the fact that improvements were still dependent on the master's experience.

Although algebraical notation of curves was not adopted yet among ship designers, as early as 1570 and 1587, Oliveira and Palacio respectively implemented coordinate systems *ad hoc* for ship design. Intrestingly, these systems predate the cartesian coordinate system (Fig. 1).

In 1575, Escalante affirmed shipwrights must be well versed in geometry. Tome Cano asserted in 1611 that shipbuilders must be arithmeticians. However, as late as 1673, Jacinto Echeverri asserted the most suitable proportions of a vessel were achieved by the power of experience. For these reasons, I can assert this hypothesis was positively tested.

The final conclusion is that further efforts towards scientific research and protection of the legacy of the severely affected naval heritage of this period is required, if we want to fully assemble the historical puzzle about these intriguing machines, the people who built and operated them, and the goods, ideas, and people they transported around the whole world for the first time..

REFERENCES

Anderson, R.C., 1925, Italian Naval Architecture about 1445. *The Mariner's Mirror,* **11**. 2, 135-163.

Anderson, R.C., 1927, *The Rigging of Ships: in the Days of the Spritsail Topmast, 1600-1720*. Marine Research Society, Salem, MA.

Anderson, R.C., l955, *Seventeeth-Century Rigging. Handbook for Model Makers*. Percival Marshall.

Anderson, R.C., 1974, *Seventeeth-Century Rigging. Handbook for Model Makers*. Model and Allied Publications LTD. Hertfordshire, England.

Apestegui, C., 1998, La arquitectura naval entre 1660 y 1754. Aproximación a los aspectos tecnológicos y su reflejo en la construcción en Guipúzcoa. *Itsas Memoria: Revista de Estudios Marítimos del País Vasco* **2**, 237-66.

Apestegui, C., 2001, Arquitectura y construcción navales en la España Atlántica, el siglo XVII y primera mitad del XVIII. Una nueva sistematización, in F. Alves (ed.), *Proceedings, International Symposium on Archaeology of Medieval and Modern Ships of Iberian-Atlantic Tradition : hull remains, manuscripts, and ethnographic sources : a comparative approach*, 163-212. Instituto Portugues de Arqueologia, Lisbon, Portugal.

Barker, R., 1992, *Fernando Oliveira: The English episode,1545-47.* Academia de Marinha, Lisbon, Portugal.

Barkham Huxley, M., 1998, Las pequeñas embarcaciones costeras vascas en el siglo XVI: notas de investigación y documentos de archivo sobre el «galeón», la «chalupa» y la «pinaza». *Itsas Memoria: Revista de Estudios Marítimos del País Vasco* **2**, 201-222.

Baroncini, R., 2002, Zorzi Trombetta e il complesso di piffari e tromboni della Serenissima: Per un storia "qualitativa" della musica strumentale del XV secolo. *Studi Musicali*, 31, 57-87.

Basch, L., 1972, Ancient Wrecks and the Archaeology of Ships. *International Journal of Nautical Aracheology* **1**.1, 1–58.

Bellabarba, S., 1993, The Ancient Methods of Designing Hulls. *The Mariner's Mirror* **79**. 2, 274–92.

Bellabarba, S., 1996, The Origins of the Ancient Methods of Designing Hulls a Hypothes. *The Mariner's Mirror*, 82:3, 259-268

Bettencourt, J., 2011, Angra B e Angra F (Terceira, Açores): Dois Navios Ibéricos Modernos para a Navegação Oceânica, in A.T. de Matos and J.P. Oliveira e Costa (eds.), *A Herança do Infante*. 217–235. Câmara Municipal de Lagos, CEPCEP e CHAM, Lisbon, Portugal.

Bettencourt, J. and Carvalho, P., 2010, Arqueologia marítima na baía de Angra (Angra do Heroísmo, Terceira): enquadramento e resultados preliminares do projecto PIAS. *Arqueologia Moderna e Contemporânea* **1**, 69–91.

Bloesch, P., 2017, Letter to Dr. Filipe Castro on the rising and narrowing of Cais do Sodré. Unpublished Material.

Bloesch, P., 1983, Mediterranean Whole Moulding. *The Mariner's Mirror* **69**.3, 305–306.

Borrero L., R., 2020, Archaeology of 17th-Century Iberian Shipwrecks: Reassessment and comparison of excavated, recorded, and published hull remains. *International Journal of Nautical Archaeology*, **49**.1, 155-178.

Bos, H.J.M., 1981, On the Representation of Curves in Descartes' *Géométrie. Archive for History of Exact Sciences*, **24**.4, 295-338

Bourger, P., 1746, *Traite de Navire.* l'Académie Royale des Sciences, ci-devant Hydrographe du Roy au Port du Croisic, & au Havre de Grace, Paris.

Cafarus, Imperiale Di Sant'Angelo, Marco, Cesare Carlo Stefano and Luigi Tommaso Belgrano., 1890, *Annali Genovesi Di Caffaro E De'suoi Continuatori Dal MXCIX Al MCCXCIII*. Sordo Muti, Genoa, Italy.

Casaban, J. L., 2014, The Reconstruction of a Seventeenth-Century Spanish Galleon. In C. Dagneau and K. Gauvin (eds.), *Underwater Archaeology Proceedings*, 267-275. Society for Historical Archaeology, Québec, Canada.

Casado Soto, J.L., 1988, *Los barcos españoles del siglo XVI y la Gran Armada de 1588*. San Martin, Madrid, Spain.

Casado Soto, J. L., 1998, Aproximación a la tipología naval cantábrica en la primera mitad del siglo XVI. *Itsas Memoria: Revista de Estudios Marítimos del País Vasco* **2**, 169-191.

Casado Soto, J. L., 2006, Barcos para la guerra: soporte de la monarquía hispánica. *Cuadernos de Historia Moderna* **5**, 15-53.

Castro, F., 2003, The Pepper Wreck, an Early 17th-century Portuguese Indiaman at the Mouth of the Tagus River, Portugal. *International Journal of Nautical Archaeology* **32**.1: 6-23.

Castro, F., 2005, *The Pepper Wreck*. Texas A&M University Press, College Station, Texas.

Castro, F., 2005, Rigging the Pepper Wreck. Part I—Masts and Yards. *International Journal of Nautical Archaeology* **34**.1, 110–122

Castro, F., 2007, Rising and Narrowing: 16th-Century Geometric Algorithms used to Design the Bottom of Ships in Portugal. *International Journal of Nautical Archaeology* **36**.1, 148–154

Castro, F., 2008, In Search of Unique Iberian Ship Design Concepts. *Historical Archaeology* **42**.2, 63-87.

Castro, F., 2009,"Rigging the Pepper Wreck. Part 2-Sails.*" International Journal of Nautical Archaeology* **38**. 1, 105-15.

Castro, F., 2018, *Spanish Merchantmen Iconography. Report 31. Draft 01*. ShipLab, Texas A&M University.

Castro, F., C. Bending, Berube, M., Borrero, R., Budsberg, N., Dostal, C., Monteiro, A., Smith, C., Torres, R., and Yamafune, K., 2018, Recording, Publishing, and Reconstructing Wooden Shipwrecks. *Journal of Maritime Archaeology*, **13**.1, 55–66.

Castro, F., and Fonseca N., 2006 Sailing the Pepper Wreck: A Proposed Methodology for Understanding an Early 17th-Century Portuguese Indiaman.*" International Journal of Nautical Archaeology* **35**.1, 97-103.

Castro, F. and Gomes-Dias D., 2015, Moulds, *Graminhos* and Ribbands: a pilot study of the construction of *saveiros* in Valença and the Baía de Todos os Santos area, Brazil. *International Journal of Nautical Archaeology* **44.** 2, 410–422.

Castro, F., Monteiro, A. and Bendig, C., 2018, *Portuguese Merchantmen Iconography. Report 29*. ShipLab, Texas A&M University.

Cano, T., 1611 (1964), *Arte de fabricar, fortificar y aparejar naos.* Transcription of Enrique Marcos Dorta. Ed Instituto de Estudios Canarios, La Laguna, Canary Islands.

Cederlund, C. O., 2006. *Vassa. The archaeology of a swedisch warship of 1628*. Stockholm National Maritime Museums of Sweden.

Contente, F., 2004, *Os Navios do Mar Oceano. Teoria e empiria na arquitectura naval portuguesa dos séculos XVI e XVII*. Centro de Historia da Universidad de Lisboa, Lisbon, Portugal.

Corominas, J., 1987, *Diccionario etimológico de la lengua castellana*. Gráficas Cóndor, Madrid, Spain.

Crisman, K., 1999, Angra B: Delat-sheated wreck at Porto novo. (Angra do heroísmo, Terceira island, Azores, Portugal). *Revista Portuguesa de Arqueología* **2**.1, 255-262.

Damianidis, K. A., 1998, Methods used to control the form of vessels in the greek traditional boatyards, in : E. Rieth (ed.), *Concevoir et construire les navires*, 217-244, Paris.

De Barros, C., 1581, (March 19th) Informe de Cristóbal de Barros desde Santander de 19 de marzo de 1581 sobre cómo han de ser los galeones y cómo eran los de Pero Menéndez de Avilés. MNM, Colección Navarrete, Tomo XXII, doc. 76, *Reales cédulas expedidas por el Rey a Cristóbal de Barros y siete pareceres*... fols. 292–296. (T). In: Hormaechea, C., Rivera, I. and Derqui, M., 2018, *Los barcos oceánicos del Atlántico ibérico en los siglos XVI y XVII*. Barcelona, Spain.105 -108.

Deleuze, G., 1993, *The Fold: Leibniz and the Baroque*, University of Minnesota Press, Minneapolis.

Dennis, D., 1997, Rene Descartes' Curve-Drawing Devices: Experiments in the Relations Between Mechanical Motion and Symbolic Language. *Mathematics Magazine* **70**.3, 163-174.

Descartes, R., 1998a, *The world and other writngs*. Cambridge Unversity Press, Cambridge.

Descartes, R., 1998b, *Discourse on method and meditations on first philosophy*. Hackett Publishing Company, Indianapolis and Cambridge.

Dethlefsen, E. S., Davison E. and Lynn Buchman, D., 1977, The Stonewall wreck. Interim report on a 17th century Spanish vessel wrecked off Bermuda. *International Journal of Nautical Archaeology* **6**.4, 315-329.

DeWitt, R., 2010, *World Views. An Introduction to the History and Philosophy of Science*.

Willey-Blackwell, UK.

De Urquiola, A., 1614, Parecer de Antonio de Urquiola sobre la fábrica de galeones. MNM, Colección Navarrete, T XXIV Doc. 15 - folios 67 a 71. In: Hormaechea, C., Rivera, I. and Derqui, M., 2018, *Los barcos oceánicos del Atlántico ibérico en los siglos XVI y XVII*. Barcelona, Spain. 191-195.

Díaz Pimienta, F., 1645, Medidas y fortificaciones que al general Francisco Díaz Pimienta le parece deben tener los galeones que el capitán Agustín de Baraona se obliga a fabricar y entregar en el puerto de Cartagena de Indias a quien S.M. mandare. MNM, Colección. Vargas Ponce, Tomo 3A, Doc. 102, fol. 371–376. (T). In: Fernández Duro, C. *Disquisiciones náuticas*, vol. VI, 223.

Domski, M., 2007, *The God of matter, the God of geometry: The connection between Descartes (apostrofe) math and metaphysics*. In: http://philsci-archive.pitt.edu/3592/, consulted on March 31, 2021.

Echeverri, J. A., 1673, Discurso incompleto y anónimo sobre la construcción naval. Museo Naval de Madrid. In: Hormaechea, C., Rivera, I. and Derqui, M., 2018, *Los barcos oceánicos del Atlántico ibérico en los siglos XVI y XVII*. Barcelona, Spain. 295-299.

Elliot, J., 1961, The Decline of Spain. *Past and Present* **20,** 52-75.

Escalante de Mendoza, J., 1575 (1985), *Itinerario de Navegación de los Mares y Tierras Occidentales.* Museo Naval de Madrid, Madrid, Spain.

Ezquerra, F., 1668, Carta de Fernando Ezquerra a Francisco de Lezo para enviarle la memoria de las nuevas reglas que deben aplicarse en la fábrica de galeones para la Carrera — 1668. MNM, Col. Vargas Ponce, T. 3B, doc. 13, fol. 59—61. In: Hormaechea, C., Rivera, I. and Derqui, M., 2018, *Los barcos oceánicos del Atlántico ibérico en los siglos XVI y XVII*. Barcelona, Spain. 289-290.

Fernández Duro, C., 1881, *Disquisiciones náuticas*. Imprenta, Estereotipia y Galvanoplastia de Arbau y CA, Madrid.

Fernández Duro, C., 1895, *De algunas obras desconocidad de cosmografía y de navegación, y singularmente de la que escribió Alfonso de Chaves a principios del siglo XVI.*: Imprenta de la Revista de Navegación y Comercio, Madrid.

Ferreiro, L. D., 2007, *Ships and Science: The Birth of Naval Architecture in the Scientific Revolution, 1600-1800*. MIT Press, Cambridge, Massachusetts.

Fraga, T. M., 2007, *Santo Antonio de Tanná*: Story and Reconstruction. Master's Thesis, Department of Anthropology, Texas A&M University.

Fraga, T. M., 2008, Santo António de Tanná: Story, Excavation and Reconstruction, in: F. Castro and K. Custer, (eds), *Edge of Empire*. *Proceedings of the Symposium held at the 2006 Society for Historical Archaeology Annual Meeting*, 201-215. Portugal.

Galilei, G., 1629 (1697), *Dialogue Concerning the Two Chief World Systems—Ptolemaic & Copernican.* University of California Press, Berkeley and Los Angeles.

García de Palacio, D., 1587 (1993), *Instrucción Náutica para el buen uso y regimiento de las naves*. Museo Naval de Madrid, Madrid, Spain.

García, C. and Monteiro, P., 1998, Angra D: A shipwreck from Angra Bay, Azores, in *Proceedings of the International Symposium 'Archaeology of Medieval and Modern Ships of Iberian-Atlantic Tradition'*. 431–447. IPA/CNANS, Lisbon, Portugal.

Garrote, F., 1691 (2008), Recopilación para la Nueva Fábrica de Baxeles Españoles, por Francisco Garrote. BNM. Centro Marítimo y Naval Castro Méndez Nüñez, Madrid, Spain.

Gaztañeta, J.A., 1688 (1992), *Arte de Fabricar Reales.* Editorial Lunwerg, Barcelona, Spain.

Gaztañeta, J.A., 1712, *Proporción de las medidas arregladas a la construcción de un bajel de guerra de setenta codos de quilla*. In: Hormaechea, C., Rivera, I. and Derqui, M., 2018, *Los barcos oceánicos del Atlántico ibérico en los siglos XVI y XVII*. Barcelona, Spain. 313-324.

Gracia, J.J.E., 1993, Hispanic Philosophy: Its beginning and golden age. *The review of metaphysics.* **46.**3, 475-502.

Goddio, F.,1994, An Account of Adventure, Deceit and Intrigue - *San Diego*. *National Geographic*. **186**.1, 35-57.

Grenier, R., Stevens, W., and Bernier, M. A., 2007, *The underwater archaeology of Red Bay: Basque shipbuilding and whaling in the 16th century*. Parks Canada, Ottawa.

Haring, C. H., 1918, *Trade and navigation between Spain and the Indies in the time of the Hapsburgs.* Harvard University Press, Cambridge.

Harpster, M. 1996. Possible Effects of Historic Trends and Events on the Shell-First Construction Technique in the Classical Mediterranean. Fourth Annual Conference for New Researchers in Maritime History Proceedings.

Hernández L., V., 2002, La Geometría Analítica de Descartes y Fermat: ¿Y Apolonio?. *Apuntes de Historia de las Matemáticas* **1**. 1, 32-45.

Hormaechea, C., Rivera, I. and Derqui, M., 2018, *Los barcos oceánicos del Atlántico ibérico en los siglos XVI y XVII*. Barcelona, Spain.

Hormaechea, C., 2017. Las Proporciones en la Construcción Naval del Siglo XVI. In: https://www.academia.edu/34448277/Las_proporciones_en_la_construcci%C3%B3n_naval_del_siglo_XVI_-_2_-_09_-_2017.pdf, consulted on March 3rd, 2018.

Hubregtse, M., 2017 Concrete curves: architectural curvilinearity, Descartes' Géométrie, Leibniz's calculus and Eero Saarinen's TWA terminal, *Journal of Mathematics and the Arts* **11**.4, 223-239.

InsideWood. 2004. In: http://insidewood.lib.ncsu.edu/search, consulted on February 25th, 2020.

Jones, M.W., 2009, Ancient Greek and Roman architects(apostrofe) approach to curvature-The Corinthians Capital, Entasis and Amphitheaters, in : Nowaki, H. and W. Lefevre (eds.), *Creating Shape in Civil and Naval Atchitecture*. 93-118. Leiden, Boston.

Jones, M. L., 20016. Calculating devices and computers, in: Lightman, B. (ed.), *Blackwell Companionto the History of Science*. 472-487. John Wiley & Sons, Chichester, UK.

Jordan, B., 2001, Wrecked Ships and Ruined Empires: an Interpretation of the *Santo Antonio de Tanná*´s Hull Remains Using Archaeological and Historical Data, in: F. Alves, (ed.), *Trabalhos de Arqueologia 18 - Proceedings International Symposium on Archaeological of Medieval and Modern Ships of Iberian-Atlantic Tradition*. 301-16. Lisbon, Portugal.

Klein, F., Hedrick, E.R. and Noble C.A., 1948, *Elementary Mathematics from an Advanced Standpoint/Geometry*. Dover, New York.

Kuhn, T., 1996. *The Structure of Scientific Revolutions*. University of Chicago Press, Chicago and London.

Lane, F., 1934, Venetian Naval Architecture about 1550, *The Mariner's Mirror*, **20**.1, 24-49.

L'Hour, M., 1994, *Le* San Diego*: Un Trésor sous la Mer*. Association Française de Actions Artistiques, Paris, France.

L'Hour, M., 1998, À l'aube de la construction navale espagnole en Asie: le *San Diego* (1600). *Arqueonautica*. **14**, 237-241.

Lindemann, F. A., 1933, The place of mathematics in the interpretation of the Universe. *Philosophy,* **8**, 29, 14-39.

Lopes de Mendoça, H., 1989, *O padre Fernando Oliveira e a sua obra nautica*. Typographia da Academia real das sciencias, Lisbon, Portugal.

Lopez Perez, A. and Sanson, C. A., 1992, *La Nao* Nuestra Senora del Rosario*, Naufragio para la Historia.* Departamento de Arqueologia, Carisub, Cuba.

Lopez Perez, A. and Sanson, C. A., 1993, *La Nao* Nuestra Senora del Rosario*, Estudio de su estructura*. Departamento. Arqueologia, Carisub, Cuba.

Losee, J., 1981, *Introducción histórica a la filosofía de la ciencia.* Alianza Editorial, Madrid, Spain.

Loureiro, V., 2012, Signatures architecturales vs. Spécificités régionales au sein de la tradition de construction navale ibéro-atlantique. *e-Phaïstos Revue d'histoire des techniques*, 27–38.

Lucena, M., 1996, La flota de Indias. *Cuadernos de Historia* **16**: 3-31.

Martin,C., 1978, *La Trinidad Valencera* A Spanish Armada Wreck. *Archaeology* **31**.1, 38-47.

Martin, C., 1979, *La Trinidad Valencera*: an Armada invasion transport lost off Donegal. Interim site report, 1971-76. *The International Journal of Nautical Archacologv and Underwater Exploration* **8**.1, 113-38.

Martin, C., 2001, De-particularizing the particular: approaches to the investigation of well-documented post-medieval shipwrecks. *World Archaeology* **32**(3): 383-399

Martínez, J. L., 1983, *Pasajeros de Indias*. Alianza Editorial, Madrid, Spain.

Meide, C., 2002, A Plague of Ships: Spanish Ships and Shipbuilding in the Atlantic Colonies, Sixteenth and Seventeenth Centuries. Department of Anthropology, College of William and Mary, Williamsburg, VA.

Mirabal, A., 2013, The Excavation of the *Nossa Senhora da Consolacao (1608)*. Arqueonautas Worldwide SA., Funchal, Portugal.

Misa, T., 2004, *Leonardo to the Internet: Technology and Culture from the Renaissance to the Present*. The Johns Hopkins University Press, Baltimore and London.

Moore, D. and Muir, B. 1987, Archaeology of the *San Martin*, in: *Seafarers*. The Atlantic Alliance for Maritime Heritage Conservation, Key West, FL.

Navarro, J. 2005, Los Elementos de Euclides en castellano. Centro Virtual de Divulgación de las Matemáticas. In: http://vps280516.ovh.net/divulgamat15/index.php?option=com_content&view=article&id=10674&directory=67&limitstart=10, consulted on February 25th, 2019

Nieto, M., 2013, *Las máquinas del imperio y el reino de Dios: Reflexioes sobre ciencia, tecnología y religión en el mundo atlántico del siglo xvi*. Universidad de los Andes, Bogotá, Colombia.

Nowaki, H., 2007, *Shape Creation Knowledge in Civil and Naval Architecture*, in: Nowaki, H. and W. Lefevre (eds.), *Creating Shape in Civil and Naval* Architecture, 7-41. Max Planck Institute for the History of Science. Berlin, Germany.

Odriozola, L., 1998, La construcción naval en Gipuzkoa. Siglos XVI-XVIII. *Itsas Memoria: Revista de Estudios Marítimos del País Vasco* **2**: 93-146.

Oertling, T.J., 1989a, The Highborn Cay wreck: The 1986 field season, *International Journal of Nautical Archaeology*, **18.** 3, 244-253.

Oertling, T. J., 1989b, The Few Remaining Clues. In: J. Barto Arnold, (ed*)*, *Underwater Archaeology Proceedings for The Society for Historical Archaeology Conference*. 100–103. Society for Historical Archaeology, Baltimore MD.

Oertling, T. J., 2001, The Concept of the Atlantic Vessel, in F. Alves, (ed.), *Proceedings: International Symposium on Archaeology of Medieval and Modern Ships of Iberian-Atlantic Tradition*, 233-241, Lisbon, Portugal.

Oertling, T. J., 2005, Characteristics of Fifteenth- and Sixteenth-Century Iberian Ships, in F. M. Hocker and C. A. Ward, (eds.), *The Philosophy of Shipbuilding*, 129–136. Texas A&M University Press, College Station, TX.

Oliveira, F., 1578, *Liuro da fabrica das naos*. Biblioteca Nacional de Portugal, Lisbon.

Piercy, R.C.M., 1977, Mombasa wreck excavation, Preliminary report, 1977., *International Journal of Nautical Archaeology,* **6**. 4, 331-347.

Piercy, R.C.M., 1978, Mombasa wreck excavation, Second preliminary report, 1978., *International Journal of Nautical Archaeology* **7**.4, 301-319.

Piercy, R.C.M., 1979, Mombasa wreck excavation, Third preliminary report, 1979., *International Journal of Nautical Archaeology* **8**.4, 303-309.

Piercy, R.C.M., 1981, Mombasa wreck excavation, Fourth preliminary report, 1980., *International Journal of Nautical Archaeology* **10**. 2, 109-118.

Pissarra, José Virgilio, 2016. O galeão português e o desenvolvimento das marinhas oceânicas 1518-1550. Doctoral Dissertation, Faculdade de Letras, Departamento de História, University of Lisbon.

Pomey, P., 2009, On the Use of Design in Ancient Mediterranean Ship Construction, in: Nowaki, H. and W. Lefevre (eds.), *Creating Shape in Civil and Naval Atchitecture*, 49-65. Leiden, Boston.

Pomey, P., Kahanov, Y. and Rieth E., 2012, Transition from Shell to Skeleton in Ancient Mediterranean Ship-Construction: analysis, problems, and future research. *International Journal of Nautical Archaeology* **41**.2.: 235–314.

Rahn-Phillips, C.,1991, *Seis galeones para el Rey de España.* Alianza Editorial, Madrid, Spain.

Rahn Phillips, C., 1993, The Evolution of Spanish Ship Design from the Fifteenth to the Eighteenth Century. *The American Neptune* **53**.4: 229-238.

Rahn Phillips, C., 2000, Manuel Fernandes and his 1616 "*Livro de Traças de Carpintaria*". *The American Neptune* **60**.1: 7-29.

Rahn-Phillips, C. 2007, *The Treasures of the San José. Death at Sea in the War of Spanish Succession*. The John Hopkins University Press, Baltimore, MD.

Real Cancillería de los Reyes de Castilla. Registro del Sello de Corte., 1493, Al corregidor de Almería que desembargue las mercaderías tomadas de un galeón, que son de Agustín Italiano y de Martín Centurión, mercaderes genoveses estantes en Málaga. Archivo General de Simancas. ES.47161.AGS/2.2.27.5//RGS,LEG,149305,100. Simancas, Spain.

Rieth, E., 1998, Construction navale à Franc-Bord en Méditerranée et Atlantique (XIVe–XVIIe siècle) et "Signatures Archictecturales" Une Première Approche Archéologique, in: E. Rieth, (ed), *Méditerranée antique. Pêche, navigation, commerce.* 177–188. Comité des Travaux Historiques et Scientifiques, Paris, France.

Russell, B., 1897, *An Essay on the Foundations of Geometry*. Cambridge University Press, Cambridge.

Samorano, R., 1576, *Los seis libros primeros de la geometría de Euclides*. Biblioteca Virtual Andalucia. In: http://www.bibliotecavirtualdeandalucia.es/catalogo/consulta/registro.cmd?id=6060, consulted on April 27th, 2019

Samorano, R., 1586 (2012), *Compendio del Arte de Navegar*. Vicent Garcia Editores, Valencia, Spain.

Samorano, R., 1585, *Repertorio y Cronologia de la Razon de los Tiempos*. In: https://archive.org/stream/cronologiayrepo00zamogoog/cronologiayrepo00zamogoog_djvu.txt, consulted on April 27th, 2019.

Sarsfield, J. P., 1984, Mediterranean Whole Moulding. *The Mariner's Mirror* **70**.1: 86–8.

Sarsfield, 1984, Notes: Mediterranean Whole moulding. *The Mariner's Mirror* **70**.1, 86–8.

Sarsfield, 1991, Master Frame and Ribbands, in R. Reinder and P.Kees (eds.),*Carvel construction technique: skeleton-first, shell-first: Fifth International Symposium on Boat and Ship Archaeology*, Amsterdam. Oxford.

Schuster, J. A., 1980, Descartes' mathesis universalis: 1618–1628, in S.W. Gaukroger (ed.), *Descartes: Philosophy, mathematics and physics*. 41–96. Harvester Press, Brighton.

Smarcevski, L., 1996, A alma do saveiro. Odebrecht, Salvador.

Serrano Mangas, F., 1992, *Función y evolución del galeón en la Carrera De Indias*. Editorial MAPFRE, Madrid, Spain.

Serrano Mangas, F., 1998, Realidad, ensayos y condicionamientos de la industria de construcción naval vasca durante el siglo XVII en la Carrera de Indias. *Itsas Memoria: Revista de Estudios Marítimos del País Vasco* **2**: 223-36.

Smith, J. T., 2011, *Methods of Geometry*. Wiley, New York.

Sosson, J. P., 1962, Un compte inedit de construccion de galeres a Narbonne (1318-1320). *Bulletin de l'Institut historique belge de Rome*, **34** : 57-318.

Steffy, J. R., 1994, *Wooden Shipbuilding and the Interpretation of Shipwrecks*. Texas A&M University Press, College Station, TX.

Steffy, J. R., 1995, Ancient scantlings: the projection and control of ancient hull shapes, in: T. Harry, (ed.), *Tropis III, Proceedings of the 3rd international symposium on ship construction in antiquity*, 417–428, Athens, Greece.

Trigger, B., 2009. History of Archaeological Thought. Cambridge University Press, New York, NY.

1632 (1998) - *Diálogo entre un Vizcaíno y un Montañés*. Transcription of María Isabel Vicente Maroto, Universidad de Salamanca, Salamanca, Spain.

Usher, A. P., 1932 Spanish Ships and Shipping in the 16th and 17th Centuries. *Facts and Factors in Economic History*. Atheneum House, Boston, MA.

Veturi, N., 1489. *Ragioni Antique*

Wallerstein, I., 1980, *The capitalist world-economy*. Cambridge University Press, New York and London.

Wheeler, E.A., 2011, InsideWood - a web resource for hardwood anatomy. *IAWA Journal*, **32**.2, 199-211.

ca. 1580 – 1590, Livro náutico ou meio prático de construção de navios e galés antigas. Biblioteca Nacional de Portugal. In: http://purl.pt/13907/4/cod-2257/cod-2257_item4/cod-2257_PDF/cod-2257_PDF_24-C-R0150/cod-2257_0000_capa-capa_t24-C-R0150.pdf, consulted on April 27, 2019.

ca. 1560, De los papeles y relaciones de visita que recogió el presidente siendo visitador. AGI - PATRONATO, 260, N.2, R. 41. In: Hormaechea, C., Rivera, I. and Derqui, M., 2018, *Los barcos oceánicos del Atlántico ibérico en los siglos XVI y XVII*. Barcelona, Spain. 105 -108.

1607, Real Ordenanza para la fábrica de navíos – 1607. MNM, Colección Navarrete, tomo XXIII, doc. 47, fol. 288 y sig. In: Hormaechea, C., Rivera, I. and Derqui, M., 2018, *Los barcos oceánicos del Atlántico ibérico en los siglos XVI y XVII*. Barcelona, Spain.146-156.

1613, Real Ordenanza para la fábrica de navíos de 6 de julio de 1613. AGI, Indiferente, 2595. (T). In: Hormaechea, C., Rivera, I. and Derqui, M., 2018, *Los barcos oceánicos del Atlántico ibérico en los siglos XVI y XVII*. Barcelona, Spain. 167-185.

1618, Real Ordenanza para la fábrica de navíos – 1607. MNM, Colección Navarrete, tomo XXIII, doc. 47, fol. 288 y sig. In: Hormaechea, C., Rivera, I. and Derqui, M., 2018, *Los barcos oceánicos del Atlántico ibérico en los siglos XVI y XVII*. Barcelona, Spain.196-215.