Reconstructing Trees from Ship Timber Assemblages Using 3D Modelling Technology:

Three-Dimensional Tree Reconstruction Based on Archaeological Evidence.

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Submitted in partial fulfilment for the award of the degree of Doctor of Philosophy

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University of Wales Trinity Saint David

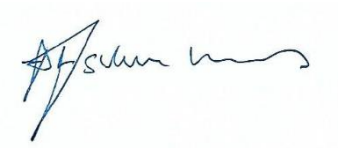
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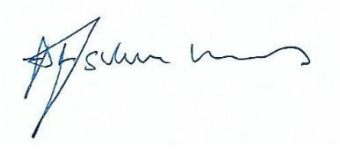
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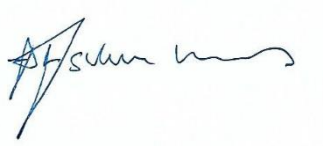
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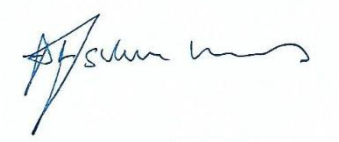
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ABSTRACT.

This thesis focuses on the development of digital methodologies to identify evidence of timber supply and selection for traditional shipbuilding through the examination of the archaeological remains of ship timbers. Traditions of archaeological ship timber recording, with particular reference to the capture of information regarding the raw material (wood) used in shipbuilding, are reviewed and developed to provide a rigorous methodology by integrating digital three-dimensional technologies increasingly employed in maritime archaeology.

This investigation led to the development of a methodology to analyse assemblages of surviving ship timbers to identify potential correlations between woodlands, shipyards and shipbuilding architecture during the Iberian Age of Discoveries. A range of digital technologies are used to allow the recording, analysis and interpretation of surviving wood features. Data is captured using a combination of a FaroArm digitiser with Rhinoceros 3D software (interpretative line data) and multi-image photogrammetry (non-interpretative cloud data) to obtain precise and accurate information.

The produced digital models reflect long-term conceptualisation and theorisation. By employing a carefully developed approach it has become possible to accurately reconstruct archaeological ship timbers' parent trees and past woodscapes based on evidence recorded from the surviving timbers within a three-dimensional environment.

Wood features such as grain, knots, tree-ring patterns and natural cracks are elevated to a new level of relevance. The digital reconstructions presented in this thesis are the result of a matured collection of tasks using several recording techniques within an approach

focusing on the importance of trees as the fundamental source material for shipbuilding – one of the most complex industries in early modern society.

Keywords: Maritime Archaeology, Digital Recording Techniques, 3D Reconstructions, Wooden Shipbuilding.

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The European Union 7th framework, Innovative Training Networks Marie Sklodowska-Curie Actions ForSEAdiscovery Project agreement PITN-GA 2013-607545[1] grant 607545 (see detailed information in http://forseadiscovery.eu/) included twelve Early-stage researchers and three Established researchers divided into three working packages (WP). These WP represented three different areas in science focus on history, maritime archaeology and wood sciences.

The ForSEAdiscovery Project aimed to:

a) *Consolidate a research line combining historical research, underwater archaeology, GIS and wood provenancing methods (dendrochronology, wood anatomy and geo/dendrochemistry)*;
b) *Increase the background and experience of trainees in the different research areas, by engaging the fellows in training courses and workshops aimed to develop their scientific, communication, and management skills*;
c) *Develop their transferable skills for future careers in academia or the private sector whilst advancing the research fields through the integration of research tools, development of reference datasets and new discoveries* (Crespo Solana et al. 2014)
d) Within the ForSEAdiscovery Project, I engage with working Package 2 (Nautical Archaeology) contributing towards to:

[1] Seventh Framework Programme of the European Union, Research Executive Agency, Networks for Initial Training (ITN), Grant agreement number 607545.

a) An inventory of key-construction features found in previously researched Spanish shipwrecks;
b) Assess and analyse excavated Spanish ship timber assemblages;
c) Select a limited number of demonstration Spanish shipwreck sites for the potential survey and dendrochronology analysis;
d) Survey and sample selected sites, carry out ring-width analysis and supply subsamples to others;

Within this established parameter, I developed my doctoral studies around the defined personal research project aiming to *develop dendro-archaeological approaches in Nautical Archaeology, with the integration of ring studies, dendrochronology and timber morphology (3D CAD) for the reconstruction of past forestry practice and exploitation* (Crespo Solana et al. 2014).

Within established parameters, an investigation held during over three years led to the main research question: How can we see trees in ship timbers? Which consisted of in the *quest* for evidence about ship timbers conversion methods, trees` morphology analysis, growth patterns and ring width studies.

The research plan involved the use of three-dimensional digital recording techniques with Faro Arm, laser scanning and computer vision photogrammetry to obtain accurate raw data from a selection of surviving sip timbers.

APPENDED DIGITAL DATA.

Appended to the thesis text was included a DVD in which can be found the digital files related to the tree reconstruction studies on the evidence recorded on a selection of:

a) Corpo Santo wreck,

b) Cais do Sodre wreck,

c) Highborn Cay wreck.

d) Emanuel Point 1 Wreck,

e) French Corvette *Bayonnaise*,

f) Bremen Kogge,

g) *VOC Batavia* wreck,

h) Belinho 1 wreck.

Each tree reconstruction study was saved in the appended DVD in multiple file formats (*3dm*, *obj*, *psz*, *sim* and 2D/3D *pdf*). Metadata and folder tree details were included to complement and to provide a user-friendly search environment.

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LIST OF ABBREVIATIONS.

CHAM – Centro de História d`Aquém e d`Além-Mar – Centre for the Humanities

CNANS – Centro Nacional de Arqueologia Náutica e Subaquática – National Centre for Nautical and Maritime Archaeology

DGPC – Direção-Geral do Património Cultural – Directorate-General for Cultural Heritage

FCSH – Faculdade de Ciências Sociais e Humanas – Faculty of Humanities and Social Sciences

IAP – Instituto de Arqueologia e Paleociencias – Institute for Archaeology and Paleoenvironmental

INA – Institute of Nautical Archaeology

PEG - Polyethene glycol.

TRS – Timber Recording Sheet

UNL – Universidade Nova de Lisboa – NOVA University of Lisbon

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NOTE ABOUT TERMINOLOGY.

The terminology employed in the undertaken research was adopted from glossaries such as the Illustrated glossary of ship and boat terms (Steffy 2011), the Iberian shipbuilding treatises *Liuro da Fabrica das Naos* (Oliveira 1580), Livro Primeiro da Architectura Naval (Lavanha 1618), Ordenanzas de 1607 (Fernandez de Navarrete 1607) and the ForSEAdiscovery Project 3D digital Glossary (Luis Filipe Monteiro Vieira de Castro et al. 2017).

The employed terminology for the analysis of wood morphology, ring width studies, tree`s growth patterns and other wood features were based on the Tree rings: basics and application of dendrochronology by Fritz Hans Schweingruber (Schweingruber 2007).

For the three-dimension, digital recording was adopted the existing terminology in the doctoral thesis Three-Dimensional Digital Recording and Modelling Methodologies for Documentation and Reconstruction of the Newport Medieval Ship by Toby Jones (Jones 2015).

During the presentation of this doctoral studies, several terms were included regarding the Rhinoceros 3D software tools. In this way, it became imperative to include an explanation about the following terms:

a) Scale – Increase or reduce a 3D digital object within mutating its shape.
b) Distance – The measurement of a space between two or more objects.
c) Extrude – To provide continuity to line drawing in one or two directions.
d) Line drawing – Data comprises two or more point to build a digital line.
e) Surface – Group of points forming a mesh.

f) Control points – Group of nonmutating points used as reference guides.

g) Object geometry – A shape produced from elements referenced in three axis - X, Y, and Z.

During the data analysis, several terms regarding the use of digital reconstruction techniques were included in the present thesis; therefore, become worth mentioning some of the most commonly adopted terms in this study:

a) Align photographs – Group of photographs having a point in common to form a 3D object using, e.g. Agisoft Photoscan/Metashape (Agisoft 2018).

b) Dense cloud – Group of points building a 3D digital shape.

c) Photogrammetry – *The art, science and technology of obtaining reliable information about physical objects and the environment through the process of recording, measuring and interpreting photographic images and patterns of electromagnetic radiant imagery and other phenomena* (Jones 1980)

d) Texturing – Is the method of wrapping and mapping pixels from a texture image to a 3D surface.

PREFACE.

Boats have been used as tools to transport people and commodities across the barriers imposed by water. Vessels assumed the uppermost relevance in the economy (Greenhill et al. 1996, 9). Their usage and complexity increased over time and became more than lifeless *floating containers* (Steffy 1994). A variety of techniques and materials were enduringly employed for their construction. Hull`s shape and its proportions mutated for a number of reasons. Shifts in technology are perhaps the most intriguing and vital moments for the study of the watercraft vessels. Partial mutations in the technology would only happen for reason of *force majeure*. Reasons that may be associated with a broader context which required the imperative need of *breaking* a pattern. These shifts in technology are considered as extremely valued for the anthropological and archaeological investigation and urge to be explored in a way to produce knowledge. Most of the maritime archaeologists would agree that shipbuilding is one of the most traditional industries and shipbuilders are long-last known as *very conservative and sceptical of changing*. Their mindset allowed archaeologists to identify patterns or disruptions in the construction of vessels[2]. Equally, the carpenters` way of managing their knowledge, permitted researchers to recognise regional adaptations of a technique/technology and eventually track back the originality/influences on their constructions.

Under the theme of this thesis - Reconstructing trees from ship timber assemblages using 3D modelling technologies, an investigation was held in order to identify and analyse potential data about which mechanisms carpenters in the woodlands would adopt to

[2] For the purpose of the present doctoral thesis, these shifts in technology or interruptions of a pattern will be from now on referred as– trigger points.

select trees to the shipbuilding industry, which techniques did they developed to obtain the required shapes, and which processes did they develop to ensure the timber supply dedicated to the shipyards. In the course of the investigation, also became relevant to analyse the influence of forest management in the shipbuilding technology and *vice-versa* or to which extent the forest resources constraint the shipbuilding technology and which adaptations had to be made in technology to build the vessel from the available timber.

How can we see trees in ship timbers? In a broader context does not refer to the employed conversion techniques to transform wooden logs into ship timbers. It is also not referring to the solutions found in joinery to assemble the timber in a vessel`s hull, neither which techniques carpenter used to identify potential ship timbers in tree`s morphologies. Reconstruction trees from ship timbers refer to the acquisition and analysis of data recorded on the ships´ surviving timbers to identify ship timbers` parent trees to gain a better understanding of:

a) Forest management,
b) Parent trees` morphologies,
c) Forest/woodlands landscape profile,
d) Timber trade,
e) Timber transportation routes,
f) Timber conversion methods,
g) Timber assemblage techniques,
h) Timber joinery
i) also, the hull shape requirements.

Therefore, this investigation embodies the broader interconnecting activities between the woodlands and the shipyards.

In a *quest* for relevant information, questions arose from the studies held on the selected shipwrecks. Other research questions were included in this investigation regarding the knowledge transfer between shipbuilder and shipyards, the complicity between the woodland carpenters and the shipyards and, the emerging need to find answers about the abrupt interruption between shipbuilders and the woodlands during potential long last periods of timber shortage.

Within a number of publications about shipbuilding and ship timbers, maritime archaeologists mostly study the end-product of a shipyard. However, within the present investigation, a vessel starts *breathing* in the woodlands decades before its timbers have been assembled. A ship represents a world inside the world; therefore, it became imperative to develop a methodology that intrinsically embodies a method in which shipbuilding and tree´s morphologies could be analysed in a broader context.

A ship carries the legacy of generations of carpenters working in the woodlands and shipyards but also the entire sort of events which influenced the course of its history. Reconstructing trees from ship timbers assemblage will offer an innovative and integrated methodology enabling a comprehensive understanding of a ship within a broader spectre. In addition, it will provide information about the woodlands profile and their interconnectivity with the highly demanding shipbuilding industry. The approach and methodology employed in this investigation have driven into a reverse-engineering method which places the ship timbers morphologies in the centre of the investigation rather than the ship as a self-sufficient and detached instrument from the woodlands. The

surviving ship timbers contain much more information than just their dimensions, scarves and fastening. They, in fact, represent a long learning process to obtain:

a) Better efficiency forest management techniques.
b) Better efficiency in forest regeneration.
c) Better efficiency in forest protection.
d) Better compliance between trees morphologies and the predesign ship timbers.
e) Adequate timbers to employ in oceangoing vessels.
f) Reliable seasoning techniques.

The present thesis comprises five chapters, including the conclusions. Each chapter was conceptualised to provide relevant information to the following and should not be understood as independent case studies; as such each section aims to contribute to the analysis of ship timbers morphologies and a better understanding of the interconnectivity between the woodlands and the shipbuilding industry. The employed methods in each case study vary under its particularities, environment and limitations. Although, the adopted approach will remain as the pillar of the present investigation.

The first chapter is related to the *quality* of the wood employed in the shipbuilding. This section aimed to clarify the constraints imposed by the wood as raw material and how carpenters obtain suitable timber logs to convert into ship timbers. Within this chapter will also be addressed the balance found by carpenters in the shipyards between the raw material, physics and the functionality of the vessel.

The second chapter enters into an in-depth analysis of tree morphologies, their particularities and influence on the landscape and *vice-versa*. The relevance of this

section is supported in the emerging need of acknowledging information about tree`s growth patterns and shapes and their suitability for shipbuilding. Especial attention will equally be given to:

a) The identification of forest management techniques including pruning/pollarding techniques, soil improvement qualities, growth patterns and other forms of woodland management.
b) The pressure imposed by shipbuilding on the woodlands, trading routes and the limitations forced by forest regeneration extended periods.
c) A higher relevance was given the Iberian Peninsula following the aims of the ForSEAdiscovery Project theme – The shipbuilding and forest practices during the Golden Age of Discoveries.

The third chapter will be focusing on previous investigations and the techniques employed by archaeologists to extract information from surviving ship timbers. The literature review produced within the present doctoral studies was partially integrated into this chapter as a contribution to knowledge and the discussion of the central theme. Several case studies were introduced per its relevance to this investigation. Each case study is deeply related to the theme and chronological boundaries of the ForSEAdiscovery Project; therefore, within the chronological barriers ranging from the 15th-century to the 18th-century archaeological material.

The fourth chapter will be entirely dedicated to the Belinho 1 wreck and the reconstruction of the surviving ship timbers` parent trees using 3D digital techniques. This major case study will provide an integrated methodology to record and analyse ship timber within a broader spectre. The Belinho 1 case study includes the methodology,

analysis and interpretation of the archaeological evidence associated with the vessel surviving timbers.

Finally, the fifth chapter will present the achieved conclusions based on the selected case studies, skills and experience gain during the present doctoral study. Will also be present the guidelines for integrated studies aiming to investigate the archaeological evidence. In addition, a reflection about the constraints and advantages imposed by the level of conservation of the archaeological material.

Within the following chapters, several technical terms will be used to provide accurate information about the theme and particularities of the subject. Although, despite their need for singularity, are permanently in a stage of reuse, mutation, variation or linguistic fashion. Within the variety of technical terms employed in the present doctoral study, the following chapters will reinstate or establish the required definitions by the discussion and reflexion on the subject.

INTRODUCTION: FOREST RESOURCES, TREE MORPHOLOGIES AND SHIPBUILDING IN THE IBERIAN GOLDEN AGE OF DISCOVERIES.

Investigating boat or ship timber morphologies to develop digital tree reconstruction studies should be considered as essential as the study of shipbuilding technology. An integrated study should be undertaken to investigate timber assemblage techniques, conversion methods, timber morphologies, dendro dating and dendro provenance studies allowing accurate archaeological documentation of the surviving timbers. Therefore, it urges to develop a methodological approach in which ship timbers can be studied as evidence of a more comprehensive, complex social and environmental system involving forest resources and shipbuilding technology.

To obtain a clear understanding of the three major subjects (accurate recording techniques, timber`s parent trees reconstruction and woodscapes reconstruction), was essential to consider the complexity of timber morphologies and the shipbuilding architecture/technology, wood features/tree`s morphologies and assertive digital reconstruction techniques. Within these range of disciplines, the present chapter aims to identify, analyse and interpret the data extracted from surviving ship timbers in order to investigate the choices taken by shipwright and carpenters for the construction of such vessels. The approach taken to this chapter is deeply related to the theme of the ForSEAdiscovery Project (as stated in the introduction) therefore, as its boundaries settled in the Iberian shipbuilding tradition during the Golden Age of Discoveries associated chronologies.

Within this chapter tree`s morphology and its use to shipbuilding will be at the centre of the discussion by using examples mainly focus on the Portuguese Post-Medieval

shipbuilding. The option taken refers to the selection of case studies included in the present doctoral study. It has its origin on the aims of the ForSEAdiscovery Project and the associated chronologies investigated during the project`s timeframe. Thus, the study of surviving timbers associated to the Belinho 1 and Cais do Sodre wrecks along with other shipwrecks found along the coast of Portugal, will be the conducting events between chapters.

THE SHIPBUILDING INDUSTRY AND ITS IMPACT ON TREE MORPHOLOGY AND FOREST RESOURCES.

The expansionist policy of the Iberian crowns has sharply boosted the shipbuilding industry. The establishment of new shipyards, on the coastline of the Iberian Peninsula, emerged as an impose consequence by the increased maritime commercial activity (Devy-Vareta 1986, 5; Loewen et al. 2006, 100). Trees were the most wanted raw material, but their morphology and other features determined their specific usage. How trees might influence the naval technology and techniques and to which extent the *Iberian ship* (Oertling 2001) is a product of carpenters' forest management.

It became clear during this research that it is fundamental to gain a better understanding of tree`s morphology of some species in particular. In the Iberian shipbuilding, oak and pine trees were widely employed to build the oceangoing vessels of the *Carreira das Indias*. Carpenters in the Iberian shipyards had a substantial (empirical) knowledge about how trees behave, and which trees should be selected for the construction of different parts of a ship. Understanding the tree`s growth process, morphologies and the place

where they grew, was essential to obtain the *good* timber[3]. Therefore, the next paragraphs will entirely focus on the coniferous and broadleaved trees morphology and how they obtain natural or human-made shapes — followed by the analysis of the impact caused by the increased demand for wood due to the development of industries, most notably the shipbuilding.

Shipbuilding required the *noble* wood such as oak trees (*Quercus suber* and *Quercus faginea*) to the ships´ hull structure and pine trees (*Pinus sp*.) for the masts and other parts of the vessel. In Portugal since the 12th-century, shipbuilding has been supporting the maritime trade and commercial fishing, but also provided the required vessels to help in the battles. The enlargement of the territory to the South of the Iberian Peninsula during the 12th and 13th-centuries was achieved with the assistance of ships, in particular, battles occurred in the cities of Alcácer-do-Sal, Silves and Faro. Since 1312 that a permanent naval force ensures the protection of the Portuguese coastline. Later during the crown of King Fernando I, the Portuguese Navy assumed such a preponderant position on the internal and external policy that the owners of ships having over than 100 tonnes received royal privileges in 1377 (Reboredo et al. 2012, 34). The Portuguese expansionist policy increased the use of vessels which consequentially boosted the shipbuilding industry:

a) The expedition of Ceuta (1415) involved 59 galleys and 120 smaller ships.

[3] The *good* timber refers to the most wanted and adequate timber morphologies. As clearly stated in the Portuguese shipbuilding treatises (Oliveira 1580; Lavanha 1618), timbers were considered *good* for shipbuilding if the growth pattern was compliant with the desired shape and if these were short in knots, well-seasoned, had adequate length and, if the hartwood comprised the overall dimensions imposed to the required ship timber.

b) The explorations on the African coast during the reign of King D. Afonso V involving between 200 and 350 vessels.
c) To the conquest of Azamor on the Atlantic coast of Morocco (1513) King D. Manuel I, assigned a powerful naval fleet of about 500 ships. Later the conquest of Mamora (1515), also on the Atlantic coast of Morocco, was assigned a fleet of approximately 200 ships.
d) During the 16th-century, about 300 *Caravel* which would not exceed 50 tonnes were involved in the Brazilian trading routes.
e) At the end of the 16th-century, the Indian route included about 700 ships in which the *Naus* would have up to 100 tonnes. Devy-Vareta affirms that (Devy-Vareta 1986,8) the Portuguese arsenals did not have the capacity neither the wood supply required to build such numerous fleets. Therefore, oceangoing trade vessels were constructed in Indian shipyards of Goa, while smaller boats used in the Portuguese coastal trade were constructed on the estuary of the Tagus River (Gaspar 1970, 158).

By assuming the shipbuilding industry as a crucial strategic element, the Portuguese crown wanted to ensure the enduring supply of wood and progressively started a direct intervention over the private forestry. The administrative reorganisation of the forests performed until the 15th-century led to the ratification of royal decrees for the reforestation and protection of the woodlands dedicated for shipbuilding (Figure 1)*Figure 1* (Devy-Vareta 1986; Wing 2015, 15). During the first half of that century, the state promulgated an increased measure to separate the forests devoted to hunting and the woodlands dedicated for shipbuilding.

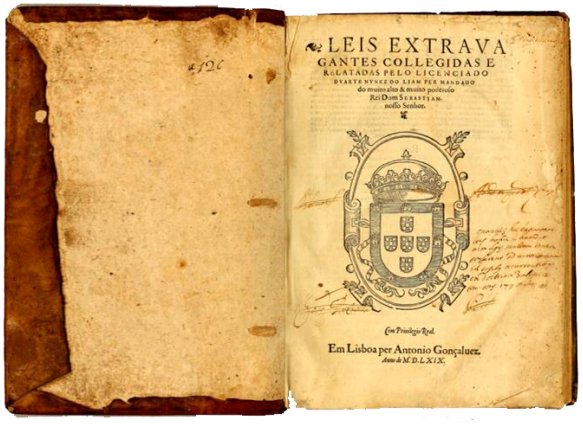


Figure 1 - Leis Extravagantes of 1569. Royal Decree for the Reforestation Forest Dedicated to Shipbuilding, Forestry Protection Policy and Prohibition imposed on the private exportation of timber.

Portugal in the early 15th-century seems to have had (in comparison to other countries in the Mediterranean) more favourable climate and geomorphology for the sustaining of the forests. Carpenters were free to cut trees *where it pleased the most*[4] as is commonly mentioned in the archives (Devy-Vareta 1986, 9). Meaning that by royal decree, carpenters could select trees to be cut down wherever they existed. The Portuguese crown was in fact, determined to ensure the continuous building of vessels for Spanish ship-owners and the supply of timber to Spain. The demand on the southern Portuguese forests had such negative impact that in 1471 a royal decree banned the export of wood and charcoal to Castille and Africa, *under the penalty of confiscation of property* (Devy-Vareta 1986, 10). This law did not have the required effect or was not even applied since the shipyards continued to build vessels for Spain with oaks (*Quercus suber*) from the mountains in Algarve (South) and pine (*Pinus sp.*) from the Baixo Mondego (Midlands).

During the 15th-century, the demands on wood have increased because of the expansionist policy and the enlargement of industries dependent on timber. Trees were being cut for a variety of purposes of everyday people´s lives. They were the raw material

[4] Original version (Portuguese): *onde mais lhes apraz*.

for building engineering, shipbuilding and other industries (Devy-Vareta 1986, 5). Per the historian, forest regeneration was extensively threatened, by the continued exploitation of the forest for industrial and business purposes and aggravated by farmers, willing to enlarge their farming areas. In several European countries, the state promulgated cutting regulations and forest code of practices. The persistent lack of timber in the Iberian countries led to the increased value of trees and putting them into a preponderant position on the European economy (timber, charcoal and firewood became profitable for landlords) (Devy-Vareta 1986; Wing 2015, 19). The term *green gold* stated by John Wing means that each tree could be used/sold in multiple industries in a variety of shapes or consumption stages (Wing 2015, 20).

The relevance of shipbuilding might not *just* be observed by the number of ships used in expeditions, but also on the impact caused by shipyards and their surrounding areas. The precinct occupied by the Portuguese Royal Shipyard *Ribeira das Naus*, in Lisbon widens in such way by 1478 that became prohibited in its vicinity, to ensure that the storage of wood would not be disturbed by the construction of houses (Devy-Vareta 1986, 10).

The circumstances in Lisbon, at the *Ribeira das Naus* were different, timber was being supplied by sea from the woodlands in Alcobaça, Leiria, Torres Vedras, Óbidos and Alcácer-do-Sal and by land from the forests of Santarém and the *coutadas*[5] do Ribatejo. In other ports of Portugal, for logistical reasons, shipyards had to be close from the supplying forests. Moreover, for technical reasons related to the shipbuilding technology, the vital timbers of the ship's framing system could hardly be found in the markets. To

[5] Portuguese word for a reserved hunting park.

obtain the most suitable timber logs, master carpenters were obliged to visit the forest to choose the required tree shapes to convert into frames, futtocks and beams (Baeta-Neves 1990; Reboredo et al. 2012, 34). Although, these forests could not supply the *good* timber within the required dimensions (a single piece) for the rigging. Therefore, the adopted solution was to import adequate trees from other countries where the tall pines such as the Nordic pine (*Pinus sylvestris*) was abundant.

Nevertheless, in some cases, this ideal combination of the supplying forests and the shipyard location could not be applied, and the geomorphology of these regions was preventing shipyards from expanding their productivity or even the construction of bigger vessels. The sedimentation of the Ria de Aveiro, the estuary of the river Lima (Viana do Castelo) and the river Ave (Vila do Conde) prevented the entry of larger *naus* to supply the required timber. The shipyards from Viana do Castelo have had severe difficulty in acquiring suitable timbers from the surrounding area for their specificities in shipbuilding (Sampaio 1979, 126; Moreira 1984, 28-29; Devy-Vareta 1986, 12).

In addition, the reorganisation of the domestic timber trade fixed the price for the supply of firewood to the urban areas. By 1456 Lisbon was in rapid expansion and increasing the demand for wood. The surrounding forests were unable to provide raw material in such haste than other areas started to be explored (Reboredo et al. 2012, 31). At the south of the Lisbon, the woodlands of Alcácer-do-Sal and Palmela were also commercialising wood with the capital. However, to boost sales on firewood and charcoal, landlords burned the forests which generated a greater discontent among the local population *for discovering*

it and then forcing them to produce charcoal destroying their honeycomb[6] (Devy-Vareta 1986, 15). The soap industry was also in need of ash which was the cause of many complaints in the areas of Torres Novas, Santarém and Abrantes. In 1450, the glass industry as one of the biggest consumers of firewood intensified their complaints about the shortage of wood: *by the considerable damage that follows in the area that labour the glass ovens to burn very often the woodlands*[7] (Devy-Vareta 1986, 16). In addition to this scenario, extensive grazing was also at the top of many complaints to the Portuguese crown (Wing 2015, 21-22). *The thin, dry soils, freed by* the cattle when moved between places *was quickly swept away* during winter by rain preventing the regeneration of the forest (Devy-Vareta 1986, 17). These factors contributed to significant and irreversible damage on the Portuguese forests.

According to archival research conducted by Devy-Vareta (Devy-Vareta 1986, 9), at the beginning of the 16th-century forest, resources suffered a significant reduction which led industries to a shortage of raw material[8]. Shipyards and other industries were at that time competing for each other to enlarge their occupied / working areas. The solution found to avoid a mismatch situation by the council was to limit the felling of trees to prevent strains on the surrounding forests and the reduce the building and repairs of ships. Between 1566 and 1567, timber was being imported from Galiza, Asturias and Biscaia and casks, oars and masts from Britain, Ireland and Flanders (Moreira 1984, 104). Although the *Ribeira das Naus* (Lisbon) was still securing its wood supply within the surrounding area in which the

[6] Original version (Portuguese): *.... por descobrjr çepa e que depois ha arramcam pera fazer carvam …, estragando-lhe as colmeias*.
[7] Original version (Portuguese): *... pelo grande damno que se segue na terra onde lauram fornos de vidro para se queimarem mui continuadamente as mattas ....*
[8] As an example, winemakers from the surrounding area of Viana do Castelo complained about not having enough timbers for the vineyards. Being obliged to plant trees such as oak, chestnut, walnut and willow to satisfy their requirements on wood to sustain the vineyards above the ground.

lack of trees was already reported. The Portuguese crown had difficulties in supplying the shipyards thus these intensified the timber trade with the northern European countries[9].

The discovery of the island of Madeira provided a refresh on the Portuguese timber supply. As the name suggests: Madeira – timber, the island was densely populated by trees leaving *no extent of land that was not full of magnificent trees*[10] (Marques 1944; Devy-Vareta 1986; Reboredo et al. 2012). However, the rapid colonisation of the island and the clearing of the forest associated with the increased number of settlements and shipyards soon condemned the timber supply for the continent. Same consequences were suffered by the Spanish crown, considering that the exploitation of the colonial forests in a way to meet the naval demands soon reach a dramatic shortage in wood resources (Wing 2015, 21). In fact, both countries were experiencing significant challenges due to a domestic and overseas timber shortage.

Within an attempt to solve or manage an efficient way to obtain timber without causing significant damage to the woodlands, several laws from the 12th and 13th-centuries were adopted/improved to reduce the impact over the timber resources. Despite, the strong regimentation imposed by both crowns (Portugal and Spain), the consumption of wood required substantial quantities of this resource in a variety of forms. Meaning at the same time that the difficulty in finding suitable trees to meet the increased demands imposed by the advances in technology, the slow regeneration of the forest and the importation

[9] According to Silva Marques (Marques 1944, 243) in timber coming from northern Europe increased significantly within three decades (from 1416 to 1448) timber was being transported from Danzig to Flanders and from there to Lisbon.
[10] Original version (Portuguese): *não havia palmo de terra que não estivesse cheio de grandissimas árvores*.

(having the associated costs) accelerated the decreased of the production of vessels

(Costa 1997; Reboredo et al. 2012, 34).

CHAPTER 1 – TO BE OR NOT TO BE AN IBERIAN SHIP: WOOD CHARACTERISATION OF AN IBERIAN SHIP DURING THE 15TH TO 17TH-CENTURIES.

Questions have been raised about the to be or not to be an Iberian ship (Domingues 1985; Martins 1998; Domingues 2000; Oertling 2001; Castro 2008), but what does the term mean?

Within a positivist approach and considering the conjugation made by the words Iberian and ship, answers might be found by analysing which events led to the designation of this ship type (Table 1 - *The Iberian Ship conceptual definition (Graphic by the author).*. In an effortlessly and intrinsically way, it is possible to conclude that these vessels attained the term from the raw material employed (trees harvested in the Iberian Peninsula), built following the regional tradition (regional architectural signature) and property of someone in Iberia (ownership). Although, this conjecture is rather simplistic and limited to describe an Iberian vessel.

An *Iberian Ship* is the expression taken by the scientific community (Oertling 2001; Castro 2008) to identify a multiplicity of facts which may be discipline-oriented, meaning that:

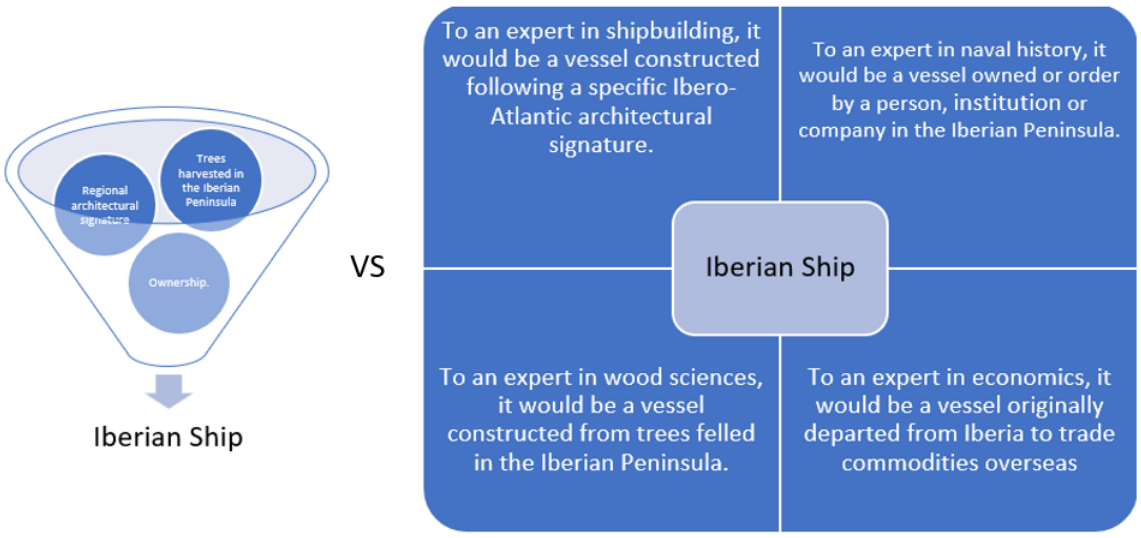


Table 1 - The Iberian Ship conceptual definition (Graphic by the author).

Under the theme of the present doctoral studies in which the tree`s morphology and its influence in the shipbuilding technology assumed the greater relevance – an Iberian ship means a vessel constructed following a specific regional architectural signature, despite, the shipyard location and the timber provenance.

In the broader term, an Iberian ship represents a combination between the above-mentioned standard concepts, in which the vessel is assumed as the end-product of a vast and complex system. Thus, the ship as a tool (Steffy 1994) to a specific purpose has benefited from substantial technological advances at the woodlands, forest management and shipbuilding technology to improve its use.

Within this conceptual discussion, a selection of case studies included in the present chapter based on the participation of the candidate in projects related to Iberian ships. Also, in the investigation performed by Oertling[11] (Oertling 2001), focusing on the

[11] Oertling`s (Oertling 2001) comparative study still considered a landmark to the investigation of this architectural signature.

particularities found in a variety of surviving Iberian shipwrecks (Table 2), to provide relevant information about this shipbuilding architectural signature.

Characteristics of 16th-century Shipwrecks Defining the Atlantic Vessel.

	RYE	SJ	PI	HCW	MRW	CW	STB	EPW	RAA	WLW	SJB	AGD	NSM	CDS	CST
1. Pre-assembled central frames, dove-tailed mortices, transverse treenails	–	Y	–	Y	Y	Y	Y[1]	Y	Y	Y	–	Y	Y[1]	Y	–
2. Planking nails: treenails per plank/frame join at midship	0:?	2:2	stern 2-3:0	–	2+:2	2:2	2:2-2	2:1	2:1	?	3:2	?	2:0	2:0	stern 2:1
3. Stempost scarphed to upper arm of keel knee	–	Y	Y	–	–	–	Y	N	Y	Y	–	?	–	–	Y
4. Single stern deadwood knee	–	Y	Y	–	–	–	Y	Y	Y	Y	–	?	–	–	Y
5. Y-timbers tabbed to deadwood	–	Y	Y	–	–	–	N	Y	N[2]	Y	N	Y	–	–	N[2]
6. Keelson notched over floor timbers	Y	Y	–	Y	–	Y	?	Y	Y	Y	–	Y	–	–	–
7. Mast step is expanded part of the keelson	Y	Y	–	Y	–	Y	?	Y	Y	Y	–	Y	–	–	–
8. Buttresses and stringers	Y	Y	–	Y	–	N	?	Y[3]	Y[4]	Y[4]	–	Y	–	Y	–
9. Ceiling and fillet planks	Y	Y	–	Y	Y	Y	Y	Y	N	Y/?	–	Y	–	Y	–
10. Rigging chain assemblies	–	Y	Y	Y	Y	–	Y	?	N	?	Y	–	N	N	–
11. Flat transom, sternpost proud of transom	–	Y	Y	–	Y	–	Y/?	N	N	Y	–	Y	–	–	N
12. Carved garboard	–	Y[5]	Y	–	–	N	N	–	N	?	–	?	N	–	Y[5]

IDENTIFICATION KEY:

– Information not available. That portion of the wreck was either not found or not preserved.
? Information was not recorded, but could be recovered at a later time.
RYE Vessel A, Rye, Sussex, England.
SJ The *San Juan*, Basque whaler at Red Bay, Labrador, Canada.
PI The *San Esteban* of the 1554 New Spain Fleet, Padre Island, Texas.
HCW The Highborn Cay wreck, Emmas Islands, Bahamas, BWI.
MRW The Molasses Reef wreck, Turks & Caicos Islands
CW The Cattewater wreck, Plymouth, England.
STB The Studland Bay wreck, Poole, England.
EPW The Emanuel Point wreck, Pensacola Bay, Fla.
RAA The Ria de Aveiro wreck, Portugal.
WLW The Western Ledge wreck, Bermuda
SJB The St. John`s Bahamas wreck, Bahamas, BWI.
AGD The Angra D`wreck, Azores.
NSM The *Nossa Senhora dos Mártires*
CDS The Cais do Sodré wreck, Lisbon, Portugal
CST The Corpo Santo wreck, Lisbon, Portugal

1 Although not dove-tailed, the floor and futtock are scarphed together and fastened transversely.
2 The San Juan possessed an unusual carved keel which was "Y"-shaped at midship and "V"-shaped at its ends (Waddell, 1980: 155 obviating the need for a garboard.
3 The mortises in this case are not dove-tailed, but square with male and female on each timber.
4 There are no tabs. The frames are iso-tailed into the deadwood.
5 In these cases the buttresses do not touch the stringers.
6 The garboard has a carved top internal edge (Francisco Alves, pers. com. 2/10/93).

Table 2- Comparative study performed by Thomas Oertling about the architectural patterns found in a selection of shipwrecks (Oertling 2001, 234).

The following paragraphs will trigger a discussion bridging the Iberian shipbuilding with wood characterisation. In addition, the aspects related to the tree`s morphologies will be taken into account to identify what extent it influenced the industry and vice-versa. Therefore, it is imperative to identify the conceptual design, the stated vessels` profile and the guidelines provided in the contemporary adopted shipbuilding treatises (Oliveira 1580; Fernandez de Navarrete 1607; Lavanha 1618). Equally, it became crucial to identify potential influences/limitations made by wood as raw material (tree`s morphologies and timber quality). Although, an inquirer made by carpenters in the shipyard had to be placed to obtain information about the possible need for adaptation/adjustment by shipbuilders to obtain suitable timber for this industry.

The shipbuilding treatises provide eloquent information about the preparation events to the construction of a vessel. These treatises often included a section that uses the term *good* timber to describe a timber perfectly suitable to employ in shipbuilding, meaning adequate dimensions (length, width and height), well-seasoned, absent in knots and compliant with the desirable curvatures and shape. Although, in an attempt to establish a

symbiotic relationship between these treatises (archival) and the archaeological remains (material culture) of the Iberian vessels, it is not clear, yet, the linear relation between both *worlds* – the world of *must-do* and the world *has done*. Thus, from the authors of the treatises, the archaeologist may obtain information about how ships should be conceived/constructed and from the surviving remains, obtain information about the real ships (Steffy 1994). Associated with these *worlds* are the constraints imposed by the available timber, its supply mechanisms and the tree`s morphologies. Assuming the pressure made by a contract agreement to build a vessel within the imposed schedule, shipbuilders had to employ a variety of timber logs to fulfil the contract. This means obtaining the timber from elsewhere in a substantial quantity and quality, not always respecting both requirements (Sampaio 1979; Moreira 1984; Devy-Vareta 1986).

The following case studies will address the specificities of the Iberian shipbuilding architectural signature and the required wood features. The selected case studies were analysed based on the published information. No relevance has been given to the associated artefacts neither to the conjectures assumed about the wrecking event. Therefore, the ship timbers will be at the highest focus in the present chapter. Limitations were found during the analysis performed on the selection of surviving remains, namely due to a lack or deficit of information published about timber morphologies and wood studies performed on these shipwrecks. Thus, chapter 1 aims to contribute to a better understanding of the ship timbers employed in the Iberian shipbuilding and the impact on wood resources applied to this industry from the 15th to the 18th-century.

THE CORPO SANTO WRECK.

In 1996 the remains of a wooden ship dating from the 14th-century were discovered during the excavation of a ventilation hole associated to the construction of the Lisbon metro station Praça do Corpo Santo at the Lisbon City Centre. The archaeologists Francisco Alves, Eric Reith and Paulo Rodrigues (Alves, Rieth, et al. 2001) responsible for the investigation of the Corpo Santo wreck recorded the surviving timbers found at about 4 m below the present ground level. The surviving remains consisted of a collection of ten individual timbers having a correlation made by the scarfs and fastening. From the longitudinal timbers only remained the stern with the heel and coral. From the transversal timber, three Y-frames and the from the longitudinal timbers only five planks (two from the port side and three from the starboard. The surviving timber assemblages had 180 cm in length, 160 cm height and 60 cm width (Figure 2 - Photograph was taken during the first archaeological assessment *on the remains of the Corpo Santo Wreck (photograph by an unknown author).*. The remains of the vessel and associated artefacts[12] were hidden on the stratigraphy mainly composed by sand, corresponding to the former level of the Tagus river in the 15th-century.



Figure 2 - Photograph was taken during the first archaeological assessment on the remains of the Corpo Santo Wreck (photograph by an unknown author).

[12] The set of artefacts included a leather shoe and ceramics dated from between the 15th to the 16th-century.

The recording and analysis performed on the face of the timbers were limited by the massive concrete ventilation wall which cut the vessel by at about two-thirds of its length. As the archaeologists were not allowed to excavate in the adjacent area of the wall due to health & safety reasons, a broader investigation focus on the vessel was delayed until further notice.

During the investigation held on the surviving remains of this vessel, archaeologists established a correlation between the timbers and the Portuguese treatises (Oliveira 1580; Lavanha 1618). A greater focus was given to the features identified at the stern, which are impressively similar to the illustration of the sternpost in the *Liuro da Fabrica das Naos* (Oliveira 1580, 82, 99).

The remarkably well-preserved fragment of the sternpost has 140 cm in length, 125 cm height and 78° angle concerning the horizontal axis. Meaning that these timbers were shaped following the recommendations found in the treatises, suggesting the adoption of 77° to 78° angles. Although, *no correlation can be made between the angles of the sternpost and the date*s which led to the assumption that dating the vessel based on the treatises would be inconclusive (Alves et al. 2001, 410). The team of archaeologists established potential chronology to this vessel based on a comparative study between the characteristics recorded on the Corpo Santo wreck with the data collected from the *Ria de Aveiro A,* Highborn Cay and the Sand Diego wrecks. This exercise allowed to assume a potential dating to which the stratigraphy and the treatises allowed to include the Corpo Santo wreck in the 14th to the 15th-centuries.

Radiocarbon analysis performed (Figure 3 - Radiocarbon dating report on the Corpo Santo Wreck *timber sample.*, on the samples collected from the vessel[13] revealed to be insufficiently accurate. The results yield from a planking sample a date of 620 ± 40 years BP, as described in the following summary: In calibrating the date obtained using the curve of Stuiver and Person (Radiocarbon, 1993, 35.1, p. 1-23) intersections were achieved in 1315, 1347 and 1390 cal AD and the following intervals: for 1 sigma: 1302-1401 cal AD; for 2 sigma: 1292-1412 cal AD2 (Alves et al. 2001, 405).



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CERTIFICADO DE DATAÇÃO PELO RADIOCARBONO

Amostra enviada para análise por:

Dr. Francisco Alves
Cento Operacional de Arqueologia Subaquática
IPPAR
Palácio Nacional da Ajuda
1300 LISBOA

Resultado:

Ref. do Laboratório	Ref. da amostra	Tipo	$\delta^{13}C$ (‰)	Idade (anos BP)	Data calibrada
Sac-1361	Barco Corpo Santo	Madeira	-24,07	620±40	*

Comentários:

*Ao calibrar a data obtida fazendo uso da curva de STUIVER e PEARSON ("Radiocarbon", 1993, 35(1) pp. 1-23) obtêm-se as intersecções em 1315, 1347 e 1390 cal AD e os seguintes intervalos:

para 1 sigma: 1302-1401 cal AD;
para 2 sigma: 1292-1412 cal AD.

A. Monge Soares
(Laboratório de Isótopos Ambientais)

NOTAS: BP (Before Present) refere-se ao ano de 1950 (ano zero) e aplica-se às datas convencionais de radiocarbono.
cal BC e cal AD referem-se a datas calibradas por dendrocronologia.
Em todas as publicações onde se mencione a idade desta amostra deverá citar-se a referência Sac-xxxx .
O intervalo de confiança associado à data corresponde aos erros estatísticos e de outro tipo cometidos na medição da radioactividade do Carbono-14 da amostra efectuada por este Laboratório.
Esta data irá ser enviada para publicação na revista RADIOCARBON.

Figure 3 - Radiocarbon dating report on the Corpo Santo Wreck timber sample.

Further investigation focus on wood anatomy was taken into consideration. The wood analysis performed by Wim van Leeuwarden and Ana Paula Fernanda Queiroz (Figure 4 -

[13] The remains of the Corpo Santo ship are stored in the Portuguese Heritage Agency (DGPC) and still due to conservation.

Wood anatomy studies performed on the Corpo Santo Wreck (Alves, Rieth, et al. 2001).) from the Centro de Investigação em Paeloecologia Humana e Arqueociências from the Instituto Português de Arqueologia yields the following results.

a) The heel was made of *Quercus suber.*

b) The stern knee built from *Quercus rotundifolia.*

c) The Y-frames no. 1 and no. 3 from *Quercus suber*

d) The Y-frame no. 2 of *Quercus pyrenaica*.

e) The planking and treenails were made of *Quercus suber*.

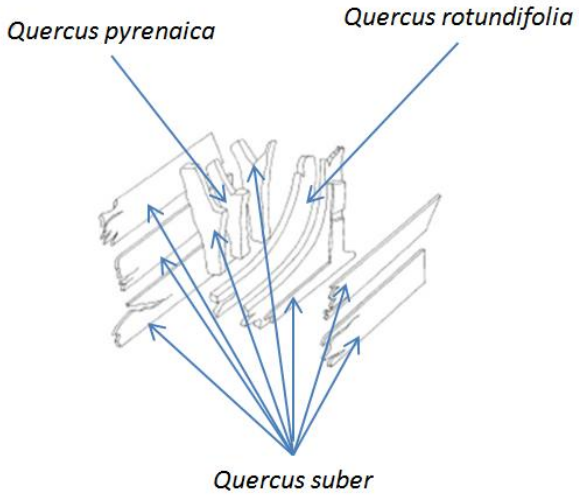


Figure 4 - Wood anatomy studies performed on the Corpo Santo Wreck (Alves, Rieth, et al. 2001).

Meaning that, based on the wood anatomy analysis performed on the samples collected from the Corpo Santo wreck, the employed trees/timber to build the vessel are in line with the suggested tree species stated in the Portuguese treatises (Oliveira 1580; Lavanha 1618) - *Quercus suber* to the framing system and *Pinus sp.* to the planking.

Drawings produced from the ship timbers (Alves et al. 2001, 408, 409, 413) included a variety of features recorded from the ship timbers` face. These included the original and damaged edges and other details, the timbers cross-sections, treenail location and nail

angles. The above-published illustration (Alves, Rieth, et al. 2001) represents the *exploded* position of each timber in comparison with the entire collection of surviving timbers Figure 4 - Wood anatomy studies performed on the Corpo Santo Wreck (Alves, Rieth, et al. 2001).. Although, has it may be observed the produced drawings do not include the surviving wood features still enclosed on each ship timber face. Thus, the preformed record (Figure 5 - Corpo Santo wreck: surviving timber assemblage (Alves, *Rieth, et al. 2001).* does not allow to obtain data about potential information referring to the tree`s growth pattern and branches position and pith growth direction (Figure 5 - Corpo Santo wreck: surviving timber assemblage (Alves, *Rieth, et al. 2001).*. Therefore, under the developed approach, the published drawings present absence in information to the performing of tree reconstruction studies.

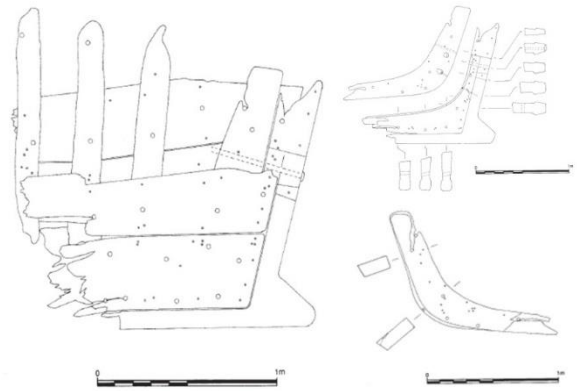


Figure 5 - Corpo Santo wreck: surviving timber assemblage (Alves, Rieth, et al. 2001).

The investigation held on the remains of this vessel did not include the quest for answers about:

a) Timber provenance neither ring-width studies to obtain accurate dating from tree´s felling dates.
b) Tree´s morphologies, to identify relevant data about the use of suitable tree shapes to obtain *good* timber for the construction of the vessel.

c) Drawings produced to illustrate the ship timber surfaces did not include aspects from tree´s morphologies.

The process of dating the vessel was performed through a tentative trial of methods. In which the stratigraphic analysis was followed first by a comparative study between the archaeological evidence and the shipbuilding treatises, and then by dating the Corpo Santo Wreck based on a single Radiocarbon analysis (single sample). This analysis allowed to date the vessel from the 14th-century but ranging more than 70 years since that tree felling date.

In completion of the analysis performed on the published data about the Corpo Santo Wreck, it was possible to identify relevant information to the theme of the present doctoral studies. Such published data has evidenced more considerable attention given to the ship´s architectural signature rather than the wood features. Nevertheless, and despite the initially assumed dating of the vessel, archaeologists also integrated wood analyses to clarify their hypothesis. The integration of wood anatomy analysis to identify the tree species employed in the construction of the vessel and the Radiocarbon dating (of a single sample), allowed to establish a correlation between the archaeological evidence and the contemporary documentation. Although further investigation focusing on the surviving timber would provide some information if:

a) Radiocarbon dating included a sample from each surviving timber.
b) Employed wood morphologies studies to identify the conformity between the tree´s growth pattern and the ship timbers shape.

After identifying those gaps in knowledge, a study conducted within the present thesis presented important information which may be used as an add-on to the previous publications/documentation focusing the investigation of the remains of the Corpo Santo Wreck.

In the completion of the analysis performed on wood morphology:

a) The surviving timbers were shaped from relatively fast-growing young trees.
b) Y-frames and the stern knee presented less than 30 annual rings on average.
c) Timber morphology compliant with the predesigned ship timber shape.
d) A low number of knots observed on the timber surfaces.

The analysis performed focusing on timber conversion:

a) Timber logs were converted by tangential cut.
b) Timber conversion by sawing.
c) Use of adequate tree morphologies to obtain the desirable ship timbers (the pith flowed along with the entire timber and avoided its interruption).
d) The Y-frames were obtained from trees having adequate angles in correlation to the hull shape.
e) The stern knee was obtained from a trunk having an adequate branch in size and angle.

The analysis performed on the timber logs (overall evidence):

a) It became evident that the construction of the vessel designated by Corpo Santo can be characterised as an Iberian ship (Oertling 2001) in its overall features. This

theory is based on the previous investigations and corroborated by the analysis performed on the surviving timber within the present doctoral studies.

b) Thus, the anatomy, morphologies and wood requirements and the ship´s architectural signature are entirely compliant with the recommendations and the suggestions stated in the Portuguese treatises.

c) The development of a digital recording of the selected timbers (stern knee and sternpost/heel) allowed obtaining a clear understanding of the tree morphologies (Figure 6) employed and the hypothesis of a certain level of forest management dedicated to the shipbuilding industry. In fact, to obtain the compliant tree shapes with the predesigned ship timber, carpenters had to perform a careful tree selection in a period of the significantly increased level of ship construction would also need to have an adequate amount of timber logs pre-shaped.

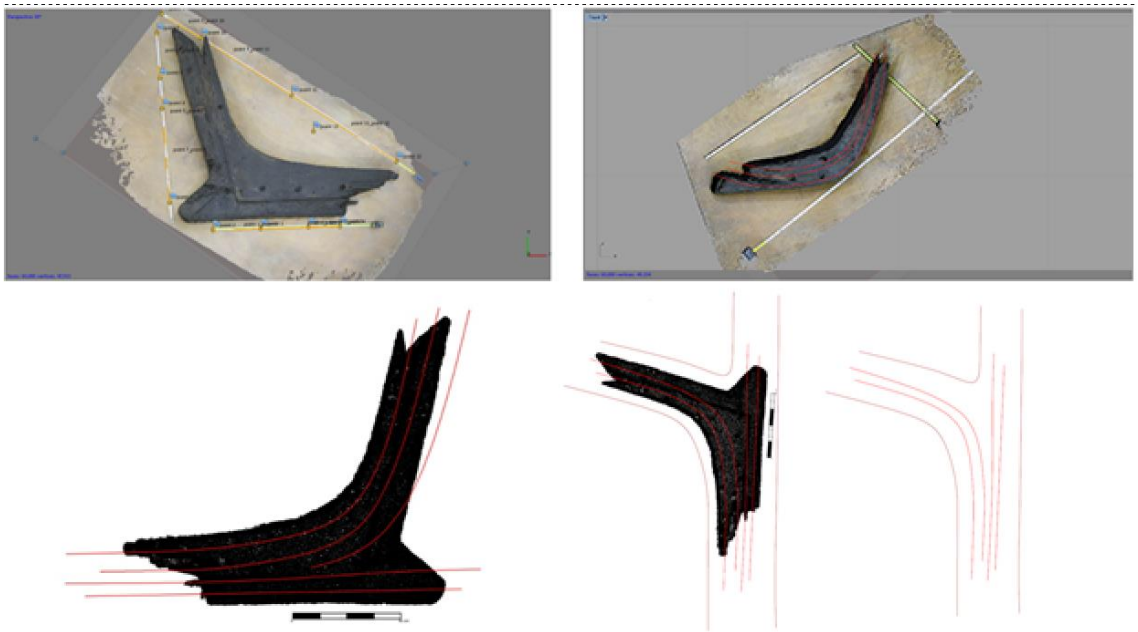


Figure 6 - Wood morphology analysis performed by Adolfo Miguel Martins under the theme of the present doctoral studies.

The above results were achieved during the wood morphology analysis performed on the selected timbers (sternpost and stern knee) from the Corpo Santo Wreck. This integrated the following tasks:

a) Selection of the surviving timber which would provide relevant information about the tree`s morphologies employed in the construction of the vessel.
b) Digital recording and documentation of the selected timbers by taking sequence photographs to cover each angle of the surface of the timber.
c) The use of Agisoft Photoscan/Metashape software to build the 3D digital model of each selected timber.
d) Calibration of each 3D model in Photoscan/Metashape by employing a series of point and measurements to obtain a 1/1 digital scaled model.
e) Exported the *obj* file produced with Agisoft Photoscan to the Rhinoceros 3D software to identify timber`s growth patterns and other wood features to obtain a hypothesis of each timber parent tree.
f) Export the end product model to a *jpg* file in a way to observe wood details and features to include its representation in this chapter.

On the completion of this study, it possible to assume that: the sternpost and stern knee associated with the Corpo Santo Wreck were shaped from a relatively young tree, having a significant absence of knots and a compliant shape with the predesigned ship timber shape. The tree trunk from which the sternpost was shaped had at about 42 cm diameter on the lower surviving area and about 29 cm diameter at the upper area. Although, concerning the other surviving ship timber wood morphologies, it was not possible to establish a correlation between the other surviving timber. Nevertheless, each timber

possesses an adequate shape and dimension required to the construction of the ship`s hull, evidencing that the criteria were already applied.

THE CAIS DO SODRÉ WRECK.

In 1995, during the building of a new line of the Lisbon Metro, the remains of a vessel were exposed (Castro et al. 2002, 4). The surviving remains of the hull had 24m in length but missing both ends (stern and stem) (Figure 7 - Cais do Sodré Wreck site plan (Castro et *al. 2002, 6).*. After the cleaning process, a complete set of timber drawings were produced at a 1/10 scale. This task was performed in three stages:

a) Drawings from the ceiling planks.
b) Drawings from the framing system.
c) Drawings from the planking inner surface.

The full set of timbers were then wrapped and delivered to the Portuguese Heritage Agency. Although, due to a variety of reasons, the remains of the vessel were left to dry and decay until a new team restarted the investigation (Castro et al. 2002, 4).

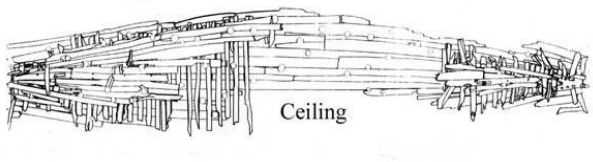


Figure 7 - Cais do Sodré Wreck site plan (Castro et al. 2002, 6).

During the following field seasons (2001 and 2002) and investigation coordinated by the archaeologist Paulo Rodrigues in collaboration with the Texas A&M University, recorded of the complete collection of timbers at a scale 1/1 and 1/10. A total of 23 timbers from the aft and 14 timbers from the forward in which much of them had construction marks and numerals.

The employed methodology comprehended the recording of four faces (outboard, inboard, aft and forward faces) of each frame at a 1/1 scale over plastic sheet at an orthogonal projection (Castro et al. 2002, 19). Secondly, the team performed the conversion from the 1/1 scale drawing into 1/10 scale using pencil and graph paper. The 1/1 scale drawings were placed on top of a grid with 1x1 cm squares and transferred the lines to the graph paper to obtain better accuracy. Finally, the 1/10 scale drawings were inked, scanned and finished on a computer with a graphics software (Castro et al. 2002, 19). The drawings were performed in high detail having the original edges, damaged edges, treenail and nail location and angles, tool and intentional marks and wood features including pith location. Relevant information might be extracted from these drawings even after more than one decade after fieldwork. In fact, the employed methodology might be considered innovative in the Portuguese maritime archaeology. The drawings illustrate information about the timber as part of a structure (vessel) and at the same time, showing the recorded wooden features. A few exceptions might be made regarding a possible reconstruction of the trees from the Cais do Sodré wreck timbers. Drawings from the frames 82, 83, 84, 87, 89, 91, 95, 96 and 144 do not show evidence of the pith location but yet have other relevant information[14]. After cross-checking the produced drawings with the timbers, the end-product of each timber include a *printout* version having the four faces represented in a four-view figure (Figure 8 - Example of a produced drawing from floor timber (*frame 100) (Castro et al. 2002, 49).*

[14] This represented gaps regarding essential features to be observed in order to reconstruct the trees from ship timbers. Meaning that 9 from 37 timbers are not possible to be subject of tree reconstruction.

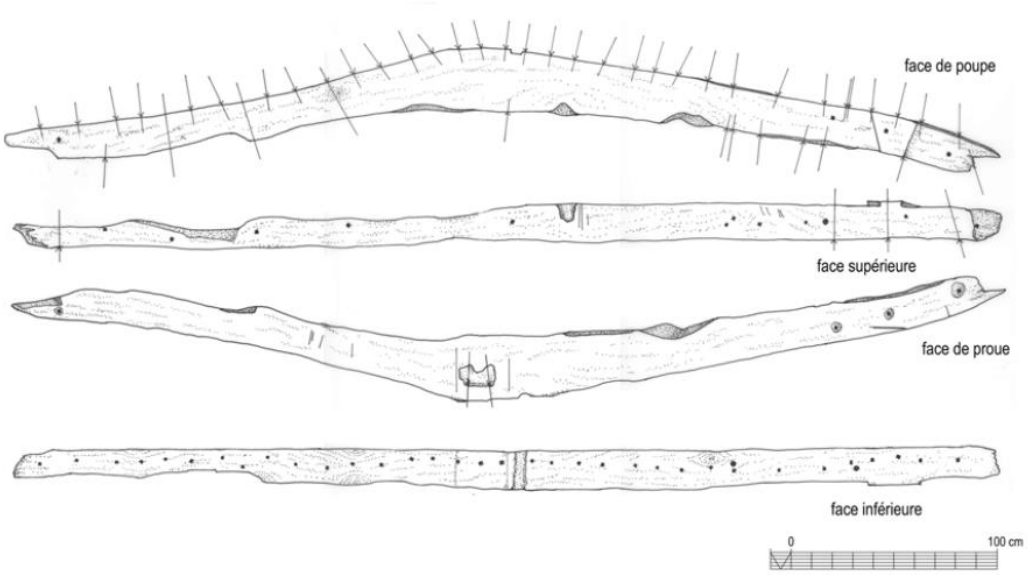


Figure 8 - Example of a produced drawing from floor timber (frame 100) (Castro et al. 2002, 49).

Although, following the publications and despite the high detailed produced drawings during the *In situ* recording of the Cais do Sodre Wreck and later within the 2001 and 2002 filed seasons, much of the information related to the wood features and wood characterisation was not included in the investigation. Those aspects were only referred and published later in 2011 in which a thorough examination and dating were performed (Castro & Yamafune 2010). The two samples taken in 1995 integrated the sampling of another two from 2010 providing a dating to the vessel built from trees felled in the mid-to-late 15th-century. The study also comprised wood anatomy analysis concluding that the vessel was mainly built from:

a) *Quercus Faginea* (Portuguese oak) to the planking, keel, keelson, apron, stringers, buttress, orlop beam and stanchion.
b) *Quercus robur* (Common oak) to the breast-hook.
c) *Pinus pinea* (Stone pine) to the planking (only on strake no. 4 and no. 5).

The Cais Sodre ship built following the Iberian architectural signature (Oertling 2001; Castro & Yamafune 2010) presents a similar carpenter´s choice to the selection of tree species. As observed in the Corpo Santo Wreck, shipbuilders employed timber obtained from a landscape populated by relatively young trees having compliant shapes to the predesigned ship timbers (Figure 9). This may be observed in the collection of drawings produced from the individual surviving timber (field seasons 2001 and 2002) (Castro et al. 2002, 25-63).

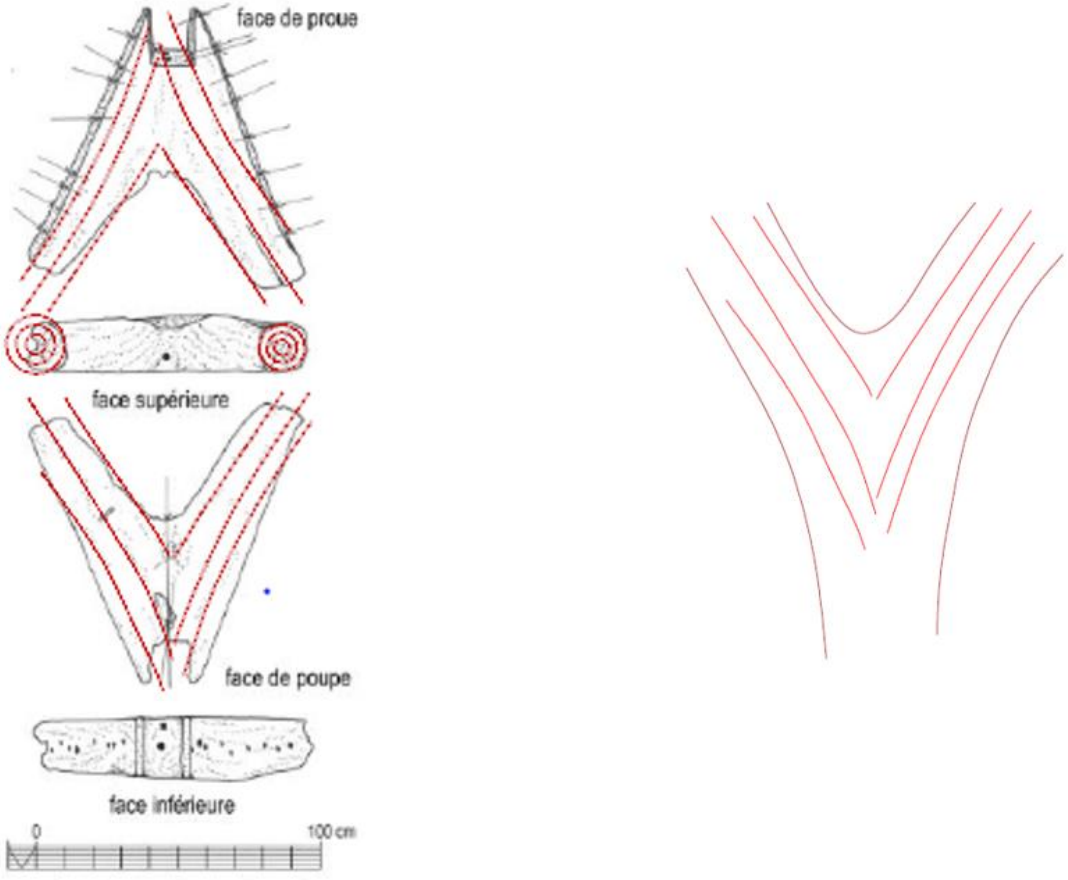


Figure 9 - The use of produced drawings for performing wood characterisation studies. Y-frame 154 (Castro et al. 2002, 61) (sketch by the author).

The above-included exercise allowed to identify the timber 154 parent tree morphology. In this case, it is notorious the use of a compliant tree to obtain the dimension, angle and shape required to the ship timber, which would (assumedly) only fit in the position of the remaining structural timbers. As may be observed in the drawing above, the portside top-

end of the Y-frame comprises an entire collection of tree rings in its complete perimeter. It is indicating the employ of a tree fully compatible with the required angle. On the other hand, carpenters had to sacrifice a small-sided section of the branch on the starboard side top-end to obtain the desired width of the Y-frame. On the forward face of the same Y-frame, it is also visible a small knot in the junction between the branches eventually related to a dead branch or a small branch (the drawing does not sufficiently specify the nature of the branch). Based on the information published, but laking on a direct visual assessment on the surviving timber 154 faces, it is possible to assume that its parent tree grew in a managed dedicated forest to the shipbuilding industry. Moreover, the anatomy of the surviving timbers is mainly associated to the Portuguese oak (*Quercus faginea*) which is a Western Iberia autochthonous tree species, which directly associates the Cais do Sodre Wreck to an Iberian shipbuilding tradition using local timber supply.

THE HIGHBORN CAY WRECK.

In the mid-1960s, the remains of an Iberian vessel sank off the Bahamian island of Highborn Cay were subject to a salvaged operation. In 1983, archaeologists investigated the surviving ship`s structure and artefacts. Despite the damaged caused by salvaging, a significant section of the ship`s hull was still time encapsulated under the ballast. The first academic documentation was published in 1985 by Roger C. Smith, Donald H. Keith and Denise Lakey (Smith et al. 1985), reporting the discovery of a vessel from the 16th-century resting at a depth of 7-8 meters. This paper described the location of the surviving remains of the vessel covered by a large amount of ballast in a mound shape, surrounded by corals in a sandy seabed.

In the following year (1986) a team from the Institute of Nautical Archaeology (INA) conducted fieldwork to a more in-depth investigation on the surviving timbers. The initial task involved surveying *the immediate area of the shipwreck*[15] (Oertling 1989, 245). Followed by an accurate record of the preselected hull sections[16] of the vessel. The strategy included the deploy of a 2 m² grid to allow an accurate record of the preselected working areas. The ballast stones were removed by hand and the sand using a dredge. To the record of the ship`s timbers, archaeologists employed a recording technique consisting of hand-drawn sketches, measurements[17] (Table 3), photographs and films.

Length	*c.* 19 m		
Beam	5·0–5·7 m		
	Sided	Moulded	Length
Keel	15–16·5 cm	21 cm	12·60 m estimated
Scarph table			0·30 m
Sternpost	—	21 cm	1·49 m preserved
Keelson	16–21 cm	17 cm	8·15 m preserved
Mast step	40 cm	25 cm	1·95 m revealed
			2·25 m estimated
Mortise	15·0–17·0 cm wide		
	13·5–15·5 cm deep		
	65 cm long		
Buttresses			0·646 m (av.)
Inboard end	13·5 cm	21·9 cm	
Outboard end	11·8 cm	16·0 cm	
Floor frames (av.)			
Aft	15·7 cm	—	—
Midship	16·5 cm	17·6 cm	2·35 m
Forward	14·0 cm	24·0 cm	—
Centre to centre spacing = 40 cm av. except the frames just forward and aft of the midship frame, which are spaced 30 cm.			
Outer planking	8–25 cm wide, *c.* 6 cm thick		
Ceiling planking	12–31 cm wide, *c.* 3 cm thick		

Table 3 - A record of the measurements taken on the Highborn Cay shipwreck`s timber (Oertling 1989a, 246).

The recording and analysis of the preselected excavation areas (Figure 10 - Highborn Cay site map (Oertling 1989a, 248).yield the following results:

[15] According to Oertling (Oertling 1989a, 245) no relevant anomalies were detected.
[16] The team from INA selected a number of areas which would potentially provide a better identification of the ship`s architectural signature, therefore, only uncovered areas corresponding to the mast step, master. frame, the forward of the keel when it joins with the stem post and the frame curvatures.
[17] Measurements were taken from all the most relevant timbers in order to allows a comparative study with other vessels of the 16th-century.

a) At the aft part fragments of the keel, five frame fragments and two frame positions were uncovered:
    a. Under the frames was the stern part of the keelson has a regular mortise for the mast step and a few ceiling planks.
    b. Under the frames, several hull planks were still preserved.
    c. The keel was deteriorated.
b) At the forward part, the stem post and the keel were still connected by the vertical scarf:
    a. A few strakes of planking from the portside underlay two-floor timbers and one futtock.
    b. The keelson comprises an expanded/enlarged area to accommodate the mast step.

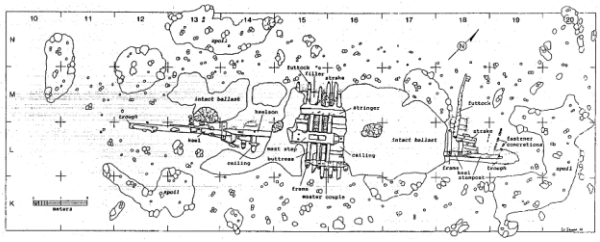


Figure 10 - Highborn Cay site map (Oertling 1989a, 248).

During the recording process were taken 15 wood samples from the *principal* timbers from which 13 revealed to be shaped from white oak (*Quercus sp*) and two from the pump well of willows *(Salicaceae)* and cedars *(Cupressaceae)* (Oertling 1989a, 251).

In completion of the studies performed by Oertling from the excavation undertaken in Highborn Cay, it was assumed that the vessel holds relevant information about the Iberian shipbuilding. For the first time, a shipwreck with these features and from the 16th-century was found in the Caribbean. The measurements allowed to estimate the length of

the ship and it is considered one of the oldest known Iberian ships. The study of its remains added relevant information to the study of ships design and construction methods from the 16th-century.

Nevertheless, and despite the wood analysis performed revealing the existence of ship timbers shaped from *Quercus sp*, genus *Salix* and coniferous trees, the dating of the vessel was in greater practice, fundament in the evidence found regarding its construction technology and ballast analysis.

Moreover, in 2017, the *Converging Worlds Project* joined a team directed by Nicholas Budsberg (Texas A&M University) conducted an investigation[18] in which:

a) The entire collection of ballast stones was removed.
b) A complete record of the surviving timbers was performed.
c) The record of individual timbers and artefacts.
d) The reburial of the timbers and artefacts took place at an adjacent area to the wreck zone.

Within the above-mentioned tasks, a selection of surviving timbers was subject to wood morphology analysis. The selection of those timbers was dependent on the available dates to such investigation. Therefore, a relatively fast visual analysis on the timber surface was performed immediately after the removal of the ballast stones in a way to identify the potential (timber) candidates to the study.

[18] From this investigation funded by the National Geographic Society under the relevant information will be published within the following year, therefore, due to copyright responsibilities cannot be included in the present doctoral studies.

Some of the observed timbers (at that moment) were still attached to others by the scarves and fastening and some under the ceiling planks. The task of selecting potential candidates revealed to be rather complex since most of the timber faces were in connection, not allowing clear observation of relevant data. Nevertheless, a collection of photographs was taken from each timber face which constitutes an essential digital record from joinery techniques and shipbuilding technology. In terms of the employed trees to build the vessel, relevant information was recorded from those timbers from which a floor timber (Figure 11) and a fragment of the keel (Figure 12) were subject to a 3D digital recording and analysis.

The observation of the floor timber no. T0817 allowed to perform wood morphology analysis based on data collected by handwriting and digital recording (Figure 11 - *Digital representation of the floor timber no. T0817 using Rhinoceros 3D and Agisoft Photoscan software (photogrammetry and drawings by the author).* of each visible timber face sections. The results obtained from this analysis allowed to identify:

a) A correlation of its morphology with other ship timbers associated with the Iberian shipwrecks.
b) Consistency in the use of compliant tree shapes to obtain the predesigned ship timbers, suggesting that the trees employed in the construction of the vessel had a suitable growth pattern to the shipbuilding technology requirements.

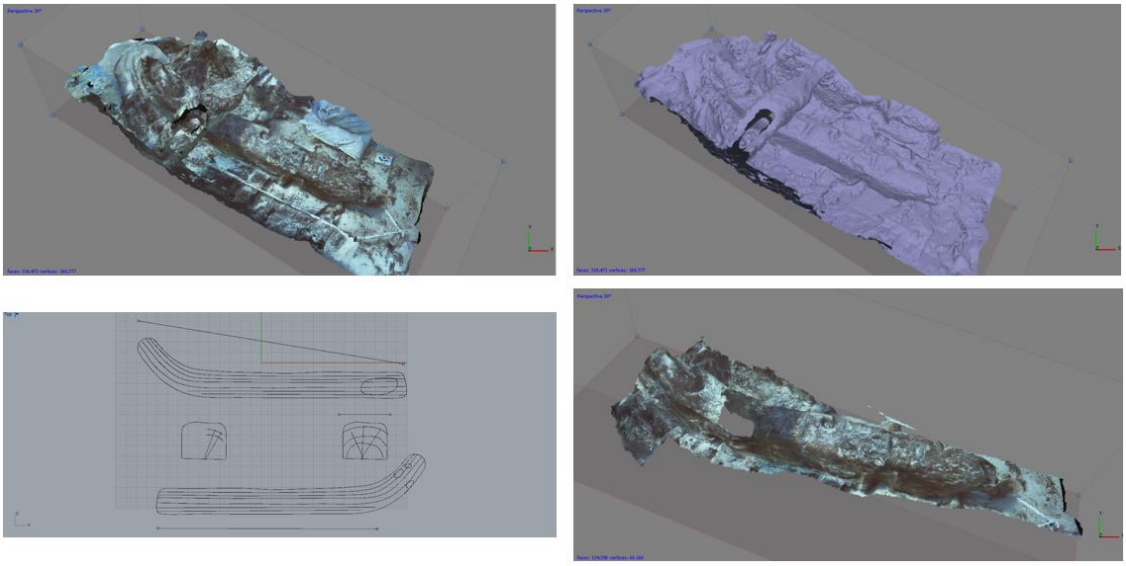


Figure 11 - Digital representation of the floor timber no. T0817 using Rhinoceros 3D and Agisoft Photoscan software (photogrammetry and drawings by the author).

The above screen captures refer to the 3D digital recording performed using the photographs taken for the timber no. T0817. The 3D digital model was achieved by adding 284 photographs and running the photogrammetry process. This included the aligning process followed by the build of dense cloud (Quality; medium; depth filtering: moderate), proceeded by building the mesh (surface type: arbitrary; interpolation: disable) and, texture building (mapping mode: generic; blending mode: mosaic). The 3D model was then calibrated using the Agisoft Photoscan *Point*/*Measurement* tools. Thus, an accurate 3D digital model was built in 1/1 scale, allowing to perform an assay about the correlation between the growth pattern and the timber shape features. The building of a photogrammetric model allowed to digitally isolate the T0817 from the remaining surviving timbers in a way to extract data from the timber`s visible surfaces. The evidence of wood morphology was then exported into Rhinoceros 3D, followed by the comparison between evidence observed in the 3D model and the hand notes taken *In situ*. The timber morphology profile was then achieved (represented above at the left bottom screen capture). The use of compliant tree with the predesigned ship timber became more evident after removing visual noise from the 3D digital model (the above screen capture

bottom right). In this way, the correlation between the tree growth pattern has an evident correlation with the shipbuilding required timber shape. As mentioned in the above case studies and based on the available data, the construction of the Highborn Cay ship comprised a process in which the tree selection and timber conversion/shape suggest a thorough selection of a forest or woodlands — having trees with shapes and growth patterns compliant with the Iberian shipbuilding architectural signature. Thus, employing relatively fast-growing trees with adequate morphologies to meet the requirements imposed by this industry.

The observation of the keel fragment allowed to obtain data about a short extension of the longitudinal timber. This timber highly degraded nested under the ballast stones was populated by the *Teredo navalis* and presenting an active decay of its morphology (Figure 12). Despite the several attempts to obtain a precise observation of its growth pattern, low information was retrieved, which made it impracticable to perform an accurate analysis.



Figure 12 - Digital representation of the keel fragment using Rhinoceros 3D and Agisoft Photoscan software (photogrammetric model produced by the author).

The photogrammetry process followed the above-stated process. Producing a high accurate 3D digital model based on 444 photographs. Moreover, since the visible remains of the keel comprised less than a meter in length, it is not possible to obtain the precision and accuracy required to the wood morphology analysis. Thus, the employed method clearly failed due to a significant lack of available/surviving information.

Nevertheless, a selection of timber was subject to wood sampling (Figure 13) to dating by dendrochronology by Professor Nigel Nayling[19]. The results are still being analysed and are expected to be published soon.

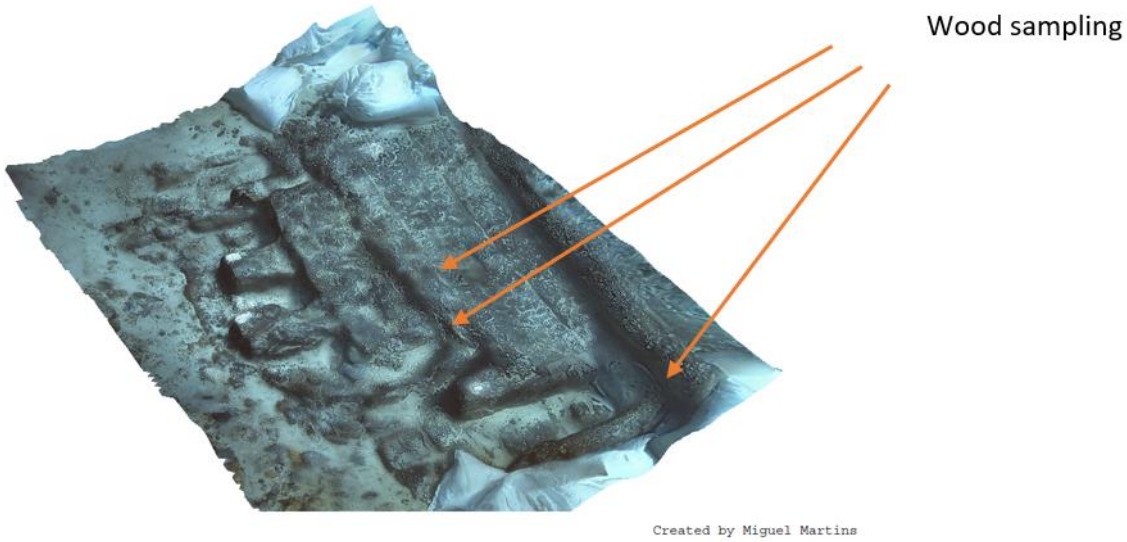


Figure 13 - 3D digital model representing the location of each timber sampling to dating by dendrochronology (photogrammetric model by the author).

THE EMANUEL POINT 1 WRECK.

In 1992, during a government project[20] to record shipwrecks in Pensacola Bay, Florida, the remains of a mid-16th-century vessel were discovered. After the completion of two

[19] The protocol adopted to the wood sampling was developed under the Project ForSEAdiscovery (Grant agreement PITN-GA 2013-607545 (Domínguez-Delmás et al. 2018).
[20] The investigation of this vessel was undertaken within a partnership between the Florida Bureau of Archaeology Research, the University of West Florida and the Historic Pensacola Preservation Road.

archaeological campaigns, the team of archaeologists concluded that the surviving remains of the vessel would be from one of the largest ships of the Tristán de Luna fleet.

Based on the evidence and the archival investigation, archaeologists associated the ship to the transporting of the first settlers to the *New World* (currently Florida, USA) in 1559[21]. The analysis performed on-site concludes that the wreck occurred after a violent clash in a shallow area of the bay (Smith et al. 1997; Smith 2001; Smith 2018)[22]. The remains of the vessel were impressively well preserved despite laying in the seabed at about four meters deep. The *ship's lower hull and the ballast stones have been protected from erosion and storms by a stratum of oyster, clam and mussel shells bound in compacted silt* (Smith 2001, 295). According to Keith Muckelroy (Muckelroy 1979), the existing conditions on the seabed in that area represent the ideal *matrix* for the preservation of the vessel`s remains. However, only 40% is known about this shipwreck and in greater part to the investigation held in the late 1990s.

Nonetheless, an extraordinary collection of over 5000 recovered artefacts including life onboard objects, vestiges of animals and substantial information about the vessel`s construction technology/techniques. The remains yield an architectural signature of a mid-16th-century galleon: amongst carpenter's scraps associated with the pump-box was found a small silhouette of a ship, carved from fir (*Abies*). The architectural hallmarks of a mid-16th-century galleon to heavy beakhead, prominent fore and stern castles, and a

[21] Tristán de Luna had the mission of establishing a new settlement for the Spanish crown, in the natural Bay of Ochuse (modern Pensacola Bay). Two ships sailed off from Veracruz, Mexico in 1559 to this bay having orders to establish military and civil settlements and to provide the necessary conditions for the protection and defence to the Spanish fleets (Smith 2001; Smith 2018).

[22] Despite, considering the Bay as a natural shelter, the vessel and the entire village were ravaged by hurricanes leading to its destruction including provisions and part of the fleet. According to the contemporary documents records only smaller boats were saved. This catastrophe condemned the settlement which ended up being abandoned by 1561 (Smith et al. 1997).

stern gallery have been faithfully reproduced in miniature (Smith 1998). The most important artefact is the ship`s hull. Analysis performed on the selected timbers presented evidence of a consistent pattern found in the Iberian ships: an expanded keelson with mortise and chock, reinforced with buttresses, to accommodate the base of the mainmast; and the remains of a pump well to house the shafts of the ship's bilge pumps.

The stern architecture was exposed during fieldwork, thus exposing the keel, eleven frames, four lower strakes, the sternpost and stern knee (Figure 14). The assessment made to the structure of the keel, allowed to observe that despite being eroded at the ends still contemplates a height of 1.4 m (from the base of the keel to the top of the frames). Wood studies based on sampling revealed the use of European and American oak for the construction (and repairs?) of the vessel.

The investigations also revealed that this vessel had a larger hull structure than its contemporary ships. During its last voyage already benefited from a number of repairs which allowed to trace its voyages and advances in shipbuilding technology. The extensive use of led to cover planking seams and patch leaks, as well as apparent repairs at both bow and stern, indicates that the vessel was quite old at the time of the sinking. This is supported by the analysis of several thousand artefacts and field specimens recovered from in and around the hull (Smith et al. 1997).

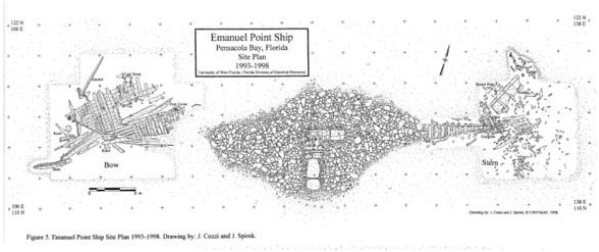


Figure 14 - (top drawing) Site plan (Smith et al. 1997).

The fact of the vessel contained at least two distinct subspecies of oak (European and American oak) revealed an adaptation/adjustment by carpenters to the existing raw material. As referred by the team of archaeologists, the ship was built to higher standards, but during its *life,* other types of wood were used in repairs. This information seems vital to be analysed under the dendrological perspective. To understand to which extent carpenters adjusted their know-how and/or experimentation, it would be suggested a more in-depth analysis of the wood morphology and anatomy. In order to obtain excellent details of this wood mixture, wood density variations, animal infestation resistance and hull dynamics.

Based on the published documentation, an assay was performed in a way to identify potential information about the morphologies of the trees employed to the construction of the ship (Figure 15). Despite not having access on the surviving ship timbers associated to the Emanuel Point Wreck, the proposed assay included the capture of several photographs published by Roger C. Smith (Smith et al. 1997) from timber no. 197 – a Y-frame.

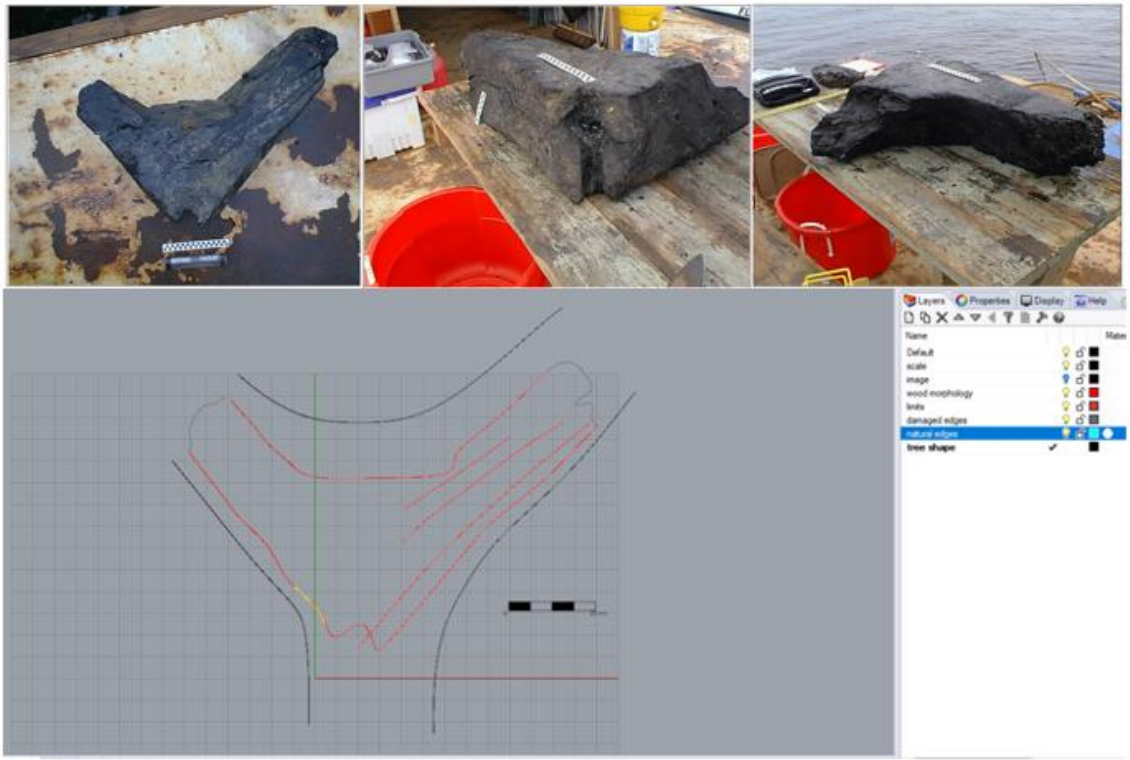


Figure 15 - Timber 197 (Smith et al. 1997) selected to the performing of the assay about the Emanuel Point wood morphologies.

This assay identified the wood patterns mostly found on the Iberian ship timbers in which the wood morphology is in greater used to obtain the predesigned ship timber. In the above figure (bottom right screen capture) may be observed the use of a significant portion of the parent tree sided (left and right) branches where the surviving natural edges are evidenced in yellow colour. On the other hand, the damaged edges (highlighted in grey colour in Figure 15) refers to the missing parts of the branches as a result of the sinking of the ship, *Teredo navalis* infestation and site formation.

Same publication (Smith et al. 1997, 116-118) refers to the anatomy of the Emanuel Point ship timbers. In this section, (Table 4) presents the results from the analysis performed at

the Centre for wood anatomy research[23]. The table mentions the use of oak (white or live group) to the construction of the vessel:

As detected above, the evidence collected from the Emanuel Point surviving timbers is consistent with the information contained in the Post-medieval Iberian shipbuilding treatises. This suggests the use of compliant and suitable parent trees in the industry to obtain the predesigned ship timbers. In addition, by developing the above case studies[24], it became clear the existence of a symbiotic relationship between the forest or woodlands and the shipyards to the construction of the Iberian oceangoing vessel. The morphology of the analysed timber also suggests the existence of a forest practice or management to produce parent trees having suitable shapes to the shipbuilding industry and compliant with the adopted technology at the shipyards.

Wood Sample Identifications from Forest Products Laboratories, Madison, Wisconsin

Hull Timber	Identification
Stern post	oak, white group
Rudder, aft edge	oak, white group
Frame #2	oak, live group
Keel (between frames 9 & 10)	oak, white group
Frame #6	oak, live group

Timber Identification from the Center for Archaeological Research, Southern Illinois University at Carbonadale.

Hull Timber	Identification	Comments
Frame #1	oak, white group	inclined toward European forms
Frame #2	oak, white group	inclined toward European forms
Frame #3	oak, white group	inclined toward European forms
Frame #4	oak, white group	inclined toward European forms
Frame #5	oak, white group	inclined toward the European forms; the growth rings are so well matched to those in the Frame #1 specimen as to suggest that these frames derive from the same tree or at minimum the same forest (certainly at least a neighboring tree).
Frame #6	oak, live group	inclined toward American affiliation
Frame #7	oak, live group	inclined toward American affiliation
Frame #8	oak, live group	inclined toward American affiliation
Frame #9	oak, white group	inclined toward European forms
Frame #10	oak, white group	inclined toward European forms
Hull Timber	Identification	Comments
Planking, upper strake	oak, white group	typical (classic form) of American white oak.
Planking, upper strake, starboard side	oak, white group	typical (classic form) of American white oak. Possibly same tree as above.
Planking, upper strake, starboard side	oak, white group	typical (classic form) of American white oak. Possibly same tree as above.
Planking, upper strake, port side	oak, white group	typical (classic form) of American white oak. Possibly same tree as above.
Second port plank	oak, white group	as in Frames 1, 5, etc., inclined toward European forms.
Keel	oak, white group	classic form of American white oak.
Stern knee	oak, white group	inclined toward European forms as the others above.
Stern post	oak, white group	as the strakes and keel, in the classic American form.
Rudder aft edge	oak, white group	classic American form.

Table 4 - The tables contain the wood anatomy analysis from the samples collected from the Emanuel Point wreck (Smith et al. 1997, 117-118).

[23] United States Forest Products Laboratory in Madison, Wisconsin and subsequent analysis performed at the Centre for archaeological investigations at Southern Illinois University – United States of America.
[24] Case studies: Corpo Santo Wreck, Cais do Sodre Wreck and Emanuel Point Wreck.

THE PEPPER WRECK.

In 1994, the remains of the presumable nau *Nossa Senhora dos Martires*, commonly called The Pepper Wreck, were sighted off the coast of Lisbon, Portugal (S. Julião da Barra). The Portuguese Indiaman sunk a few meters at the entrance of the river Tagus in September 1606 leaving a vast and scattered collection of artefacts. According to the contemporary reports, the local citizens assumed that such devastation would be associated with the wrecking of an entire fleet. A *black* tide made of pepper seeds from India washed ashore. Despite efforts made by the local authorities, the population soon started to salvage all possible objects. Apart from the cannons, anchors and the cargo which immediately nested in the rocks and sand, the white cotton from India, valuable objects and everything else with potential commercial value was plundered (Castro 2000; Castro 2005).

Years after the discovery, archaeologists undertook excavations (1996 and 2000) on the Pepper Wreck site. These campaigns allowed to the rescuing of about 2000 artefacts, including Asian ceramics dating from between the 16th to the 17th-century and an astrolabe dated from the same year of the departure of this ship to India.

The remains of the ship`s hull (Figure 16) consisted in a section of 609 x 1066 cm (Castro 2003) in which survived the fragment of the keel, eleven frames and planking. The entire collection of recovered artefacts were catalogued and preserved, and some of those integrated the worldwide exhibition (Expo98) at Portuguese Representation House. The dating of the ship`s hull is also consistent with the assumed chronology to the artefacts. This made the Pepper Wreck as the first Portuguese vessel from this chronology to be entirely recorded, analysed and published (Castro 2000; Castro 2003; Castro 2005).

Greater relevance was given to the find of this vessel, mainly, because it provides evidence of the Golden Age of the Iberian Discoveries. The ship itself was considered as an emblematic icon of the Portuguese oceangoing ships and shipbuilding. Although, as stated at the introduction of the present chapter, the investigation of wood morphologies evidenced in the Iberian shipwrecks assumes the top priority in the present chapter.

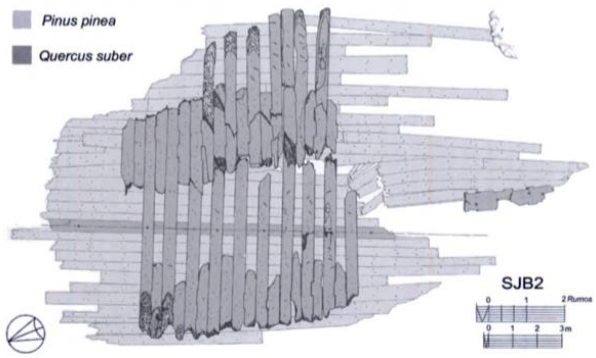


Figure 16 - Pepper Wreck site map (Castro 2003, 143).

The above figure represents the investigation undertaken to identify the anatomy of the surviving timbers. As it may be observed, the majority of the structural timbers including the keel were shaped from oak trees and the planking from pine trees. The investigation directed by the archaeologist Filipe Castro revealed important data about the anatomy and morphology of the surviving timbers:

a) The material employed in the construction of the vessel is consistent with the recommendation stated in the Portuguese shipbuilding treatises (Castro 2000; Castro 2003).
b) The cork oak (*Quercus suber*) was predominantly used to the construction of the framing system. Thus, shipbuilders used their knowledge about wood anatomy to shape timbers having better anatomy (malleability, strength and durability) and suitable morphologies (parent trees compatible with the predesigned ship timber (Castro 2003, 33)).

The wood sampling protocol consisted of in the collection of samples from the transversal and longitudinal timbers for wood anatomy identification (Table 5).

Timbers recorded *in situ* in 1996-1998

Timber	Section	Number of timbers	Wood Sp.
Keel	sided: 25 cm; molded: Indet.	4 sections: Q0 and Q1-Q3.	Cork Oak
Apron	sided: 38 cm molded: 25 cm	1 timber: E1.	Cork Oak
Floor timbers	sided: 23-25 cm molded: 23-24 cm	11 timbers: C1-C11.	Cork Oak
Futtocks	sided: 21-25 cm molded: 23-24 cm	18 timbers: B2W-B10W; B3E-C11E.	Cork Oak
Naval timber	sided: 24 cm molded: 24 cm	1 timber: A4E.	Cork Oak
Planking	sided: 20-35 cm molded: 11 cm	Not totally inventoried	Stone Pine

Table 5 - Wood identification of the selected timbers(Castro 2002, 7).

The Portuguese treatises recommend the use of cork oak (*Quercus suber*) to the hull framing system and pine (*Pinus sp.*) to the planking of an Indiamen. Thus, following the investigation undertaken on the presumable *Nossa Senhora dos Martires,* the construction technology and techniques are consistent with the Iberian ship architectural signature. Although, much has been discussed about the vessel as a tool, including the reconstruction of the ship`s hull and the technology employed in its construction. Although, the published information still has absences in regarding a wood morphology analysis. Therefore, an assay was performed within the theme of the present doctoral studies.

By using the published timber drawings and photographs was not possible to obtain a wood growth pattern and wood morphology characterisation from a selection of surviving timbers (Figure 17).

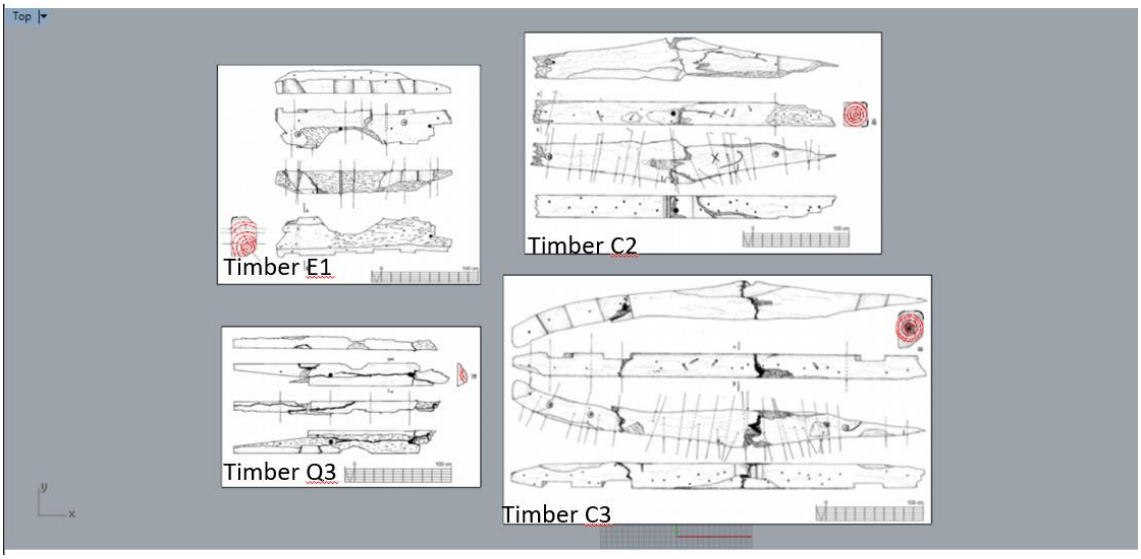


Figure 17 - Assay on wood morphology based on the published timber drawings (Castro 2002, 13-15-17-18) (Sketch by the author).

Based on the assay performed on the drawings from the selected timbers (timbers E1, C2, Q3 and C3), a deeper understanding of the wood morphology has not succeeded. The information recorded on the drawings does not present enough and consistent data in terms of ring-width neither about the growth pattern. The lines representing the growth pattern on the surface of the timber do not show a consistent growth direction as it draws axis in multiple directions. Meaning that these lines could not represent the actual growth pattern of the tree as those lines should flow in a linear direction. The drawings containing the ring-width are also in the absence of data, as it is not clearly understood the number of rings. Although, those drawings comprised a record of the pith location and the tree`s natural edges. Thus, representing important information about timber conversion and the maximisation of the available timber. Moreover, in general terms, the timber shape employed in the construction of the *Nossa Senhora dos Martires* follows the recommendation stated at the Portuguese treatises (Oliveira 1580; Lavanha 1618). The use of a different type of wood anatomy and morphologies is clearly evident in the surviving timbers, although, further investigation is recommended to the better understanding of the ship timbers parent trees employed in this Iberian ship.

THE RED BAY M24 (*SAN JUAN*).

In the early 1970s, Selma Barkham performed an investigation on the Spanish public archives[25] focus on the use of Newfoundland and Labrador regions as centres of dynamic entrepreneurial exploitation (Huxley {Barkham] et al. 2006, 772).

Within the course of this investigation, was found documentation reporting the wrecking of two Basque whaling ships in the Strait of Belle Isle in 1565 – the *San Juan*[26] and the *Maria* (Grenier 2007; Martin 2009, 197). The relevance of these documents triggered survey excavations off the Saddle Island in Red Bay[27]. In the result of these operations, archaeologists found whale-processing facilities and deposits of whale bones. Moreover, a collection of timbers nested in the seabed was also found on site which immediately suggested the existence of a ship´s hull. Although, the first analysis was not conclusive regarding the identification of the wrecked vessel as multiple shipwrecks28 were found in the same area. Thus, further investigation was undertaken in a way to provide relevant information about the overall site, and the identification of a variety of ship remains, Including the presumably Maria (in the Chateau Bay) (Grenier 2007, I-3).

Found in 1978, the 204 tonnes whaling ship of Red Bay (Labrador) was buried on the seabed at about 8 to 12 meters deep and 30 meters from the inner shore of the Saddle Island presented an excellent state of preservation (Grenier 2001). The project aimed to

[25] The archive research was undertaken principally in the archives of Gipuzkoa focusing legal depositions among litigants within the maritime industry (Grenier et al. 1994, 137).
[26] According to Selma and Michael Barkham (Huxley {Barkham] et al. 2006, 772) investigation: documents reported the wreck of the 250 to 300 *toneles* ship San Juan de Ramos de Arrieta by the end of 1565. Same records sated that the loss of the vessel occurred during a storm after the break of the San Juan`s mooring leading it to ran aground.
[27] Fieldwork coordinated by James Tuck of the Memorial University of Newfoundland (Martin: 2009, 197).
[28] Wrecks 24M, 27M and 29M, have similar construction features, but in the author opinion, the wreck the presented evidence of being the San Juan is the 24M at Red Bay.

identify the construction profile of the vessel (Light 1990, 307; Loewen 1995, 157). The fieldwork was undertaken for seven years to excavate, disassembled, recover and reburied the 24M vessel and six other small watercraft (Waddell 2007, 114), which result on 14000 hours of fieldwork was the full excavation of the site between 1979 and 1984. Including the dismantling and recovering of 3000 ship timbers, the recording process (on the laboratory) and their systematic reburial on site. From the research were produced 3000 manuscript pages, illustrated with more than 1200 drawings, maps (Figure 18) and photographs (Grenier 2001, 269; Waddell 2007). Following Richard Steffy´s approach, the team of archaeologists built a 1/10 scale 3D model, based on the information collected from the remains of the ship (Grenier 2001, 273). Details about the keel were represented on this model and complementary drawings. Curvatures, angles and joinery were methodically reproduced on the 1/10 scale research model (Grenier 2001). The employed methods for recording the 24M included conventional mapping techniques involving 1/10 scale drawings[29].

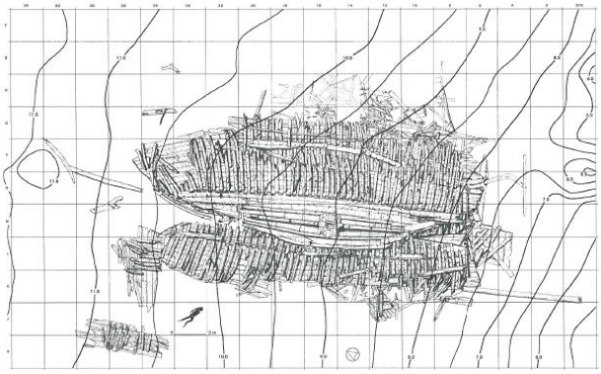


Figure 18 - 24M site map (Grenier et al. 2007, I-126).

Parallel to the investigation developed on the vessel`s architectural signature; Brad Loewen performed wood analysis on the surviving timbers (Loewen 1998). This

[29] Computerized data entry and mapping procedures were not considered given its level of development at the time of the fieldwork (Waddell 2007, 119-120).

investigation based on the documentation found in archives and archaeological evidence allowed to reach conclusions about the timber employed in the construction of the 24M:

a) Oak plantation owners preferred to harvest their trees at the age of 40 to 65 years old (Loewen 1998).
b) Trees used in its construction had the minimum of 19 cm in diameter and compliant curvature to the predesigned ship timbers.
c) Branches were cut, and the trunks had a height between 3 to 5 meters to the canopy.

According to the author (Loewen 1998), Basque carpenters designed their vessels so that the decks traditionally located at the heights where the frames overlap. This way, local shipbuilders would use similar trees[30] to build ships of 100 tonnes and up to 400 tonnes. This method allowed to ensure a permanent supply of timber without needing increasing their efforts on forest management (Loewen 1995, 197).

Further investigation on the vessel´s timber revealed that carpenters produced planking from oaks having at least 80 years old[31], consistent growth pattern to meet the desired shapes and in general absence of relevant knot along with the timber faces. This had an exception identified on the plank TT 1141 (strake 12) and TT 1075/2848[32] (strake 5).

The microscopic analysis performed on the timbers included species identification, revealing that the Red Bay vessel was exclusively made of *Quercus robur*, exception for

[30] Having the same maturation stage and preparation.
[31] Ring width count suggested the oak trees used to build the ship´s hull up to the 25 strake would have at least 80 years old (Loewen 2007, 105).
[32] The growth pattern was not consistent with the timber shape which caused a split (repaired with short nail) (Loewen 2007, 105).

the keel (*Fagus sylvatica*) and the upper works (soft-wood) (Loewen 2007, 267). The tree conversion method can be observed on the planking cross-section (e.g. timber 24M – T1388) (Loewen 2007, 104). The employed technique consisted of tangential sawing as identified on the hull plank TT1243. Archaeological evidence showed that carpenters to convert the tree into timber used the method of pit-sawing in which one sawyer stood on top of the log and other one or two underneath it to operate the saw. Other timbers revealed traces of additional tools such as the adze or axe. For instance, the planking TT591 and TT464 have marks of adzing and saw on the inboard face (Loewen 2007, 105).

Macroscopic analysis complemented the existent data in a way that allowed to identify other wooden features. It seemed that carpenters found a correlation between the desirable timber shape and the parent trees. According to Brad Loewen, the trees used to build the Red Bay vessel were *apparently artificially shaped* to meet the required profiles. The Basque naval forestry practice limited the innovation of their hull design by the long decades invested in *shaping* trees to build the standard frame structure. (Loewen 2007, 253-267).

D*ata suggested strongly that the timber trade was not a passive element in the shipbuilding industry but controlled a certain number of design decisions and woodworking operations that took place before the material was finished and assembled* (Loewen 2007, 267).

The increased demand for wood during the 16th-century encourage the state to increase the importance of the woodlands dedicated to shipbuilding. Oak plantations were

managed, re-planted and seeded, in particular, those located in the highlands[33].

Regarding wood provenance, archive research proved that oak cultivation for shipbuilding subsidised by the crown. Each Valley should produce timber for their ships, although, the demands on wood commonly led to the usage of trees from up to four valleys (Loewen 2007, 267).

Within the theme of the present doctoral studies and based on the published documentation, a selection of drawings (Figure 19) were analysed for wood morphology studies: a 1/10 scale drawings of the keel (Waddell 2007a, 136), a knee and a first futtock (Wilson 2007, 144). Although the drawings did not contain enough information about growth patterns or other wood feature related to the parent tree`s morphologies, which made the assay non-succeeded.

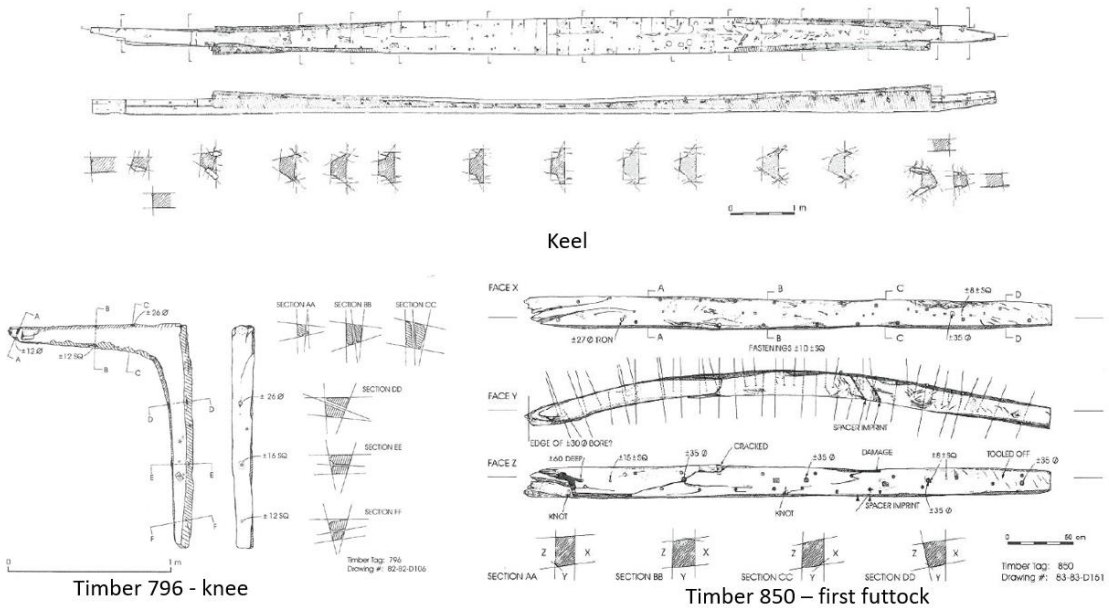


Figure 19 - Published drawings from the above-mentioned timber (Grenier et al. 2007).

Nevertheless, much has been analysed and discussed in turn of the remains of *San Juan*. Following the comparative study performed by Thomas Oertling (Oertling 2001), all

[33] The highlands forests where located within less than eight kilometres of the sea (Loewen 2007, 267).

indicators place the San Juan in the line of the Iberian shipbuilding tradition. The excavation of the surviving artefacts associated with the vessel is still nowadays a landmark in the history of archaeology. Along with the excavation of the Kyrenia Ship (Katzev 1969), the Skuldelev Barrier (Crumlin-Pedersen et al. 2002) and the Graveney Boat (Fenwick 1978b), the Red Bay (Grenier 2007) is also considered a *turning point* in the maritime archaeology.

THE CAVALIER-SUR-MER VESSEL AND THE CONCERNS ABOUT TIMBER SUPPLY AND WOOD PROVENANCE.

The Cavalier-sur-Mer vessel (Figure 20) has aroused great interest to the study of the oceangoing Iberian shipbuilding and timber supply/wood provenance in the 15th and 16th centuries (Loewen et al. 2006). Long-distance shipping was officially encouraged in the Basque Country from the 13th-century. Ships carrying wool and wine across the British Channel returned with wheat, linseed and forest products. On the other hand, commercial fishing was growing in interest which led Basque crews sailing to Britany and Ireland and later to Iceland. This motivated to retrieve an older practice to dedicate *oak forests within 11 km of the sea for shipbuilding* (Loewen et al. 2006). Given the importance of this industry, oak trees plantation was at that time subsidised by the crown, which would only be visible through the archaeological investigation of Basque Country ships.

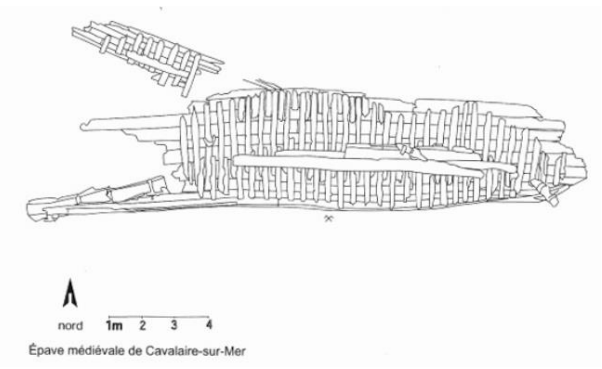


Figure 20 - Site map from the Cavalier-sur-Mer (Loewen et al. 2006).

For this chronology, the Basque Country shipbuilding and its architectural signature characterised by a framing style in which first-floor timbers and first futtocks were assembled, and the planking fasteners held the remain overlapped timbers (Loewen et al. 2006). This framing system is similar to the Cattewater wreck[34] described by Mark Redknap (Redknap 1982; Redknap 1984). This mixing frame style was considered by Loewen and Delhaye (Loewen et al. 2006) a revolutionary link between the concept of shell-first (medieval shipbuilding) and the Post-medieval skeleton-first construction features in the Atlantic (Oertling 2001; Castro 2008). Nevertheless, the investigation was also focusing on the analysis of a potential correlation between the surviving timbers and their parent trees:

Three comparisons were made: the tree`s curvature versus that of the timber: the tree`s branch-free length versus timber length; the tree`s diameter versus the timber`s square dimensions (Loewen et al. 2006).

The study performed by Loewen and Delhaye (Loewen et al. 2006) reached the following conclusions:

[34] The Cattewater wreck was found in 1973 off Plymouth Sound and archaeologists believe that would be dated from the 16th-century.

a) The centre of the growth pattern was traced on both fore and aft faces of the timber. To assume that these patterns have a *good* match, the centre of the grain needed to correspond with the core of the timber. Having done this exercise, archaeologists found that trees did not have a smooth *arc* as they show a high degree of correspondence with the timber. Although, tree shapes were slightly straighter than timbers in particular, at the ends of the inboard face and the centre of the outboard face. – Within the analysed timbers, there was a consistency between the timbers` curvature and the parent trees.
b) Existent waney[35] edges simplified the comparison between the Timbers` square dimensions and the tree`s diameter. – The analysis concluded that the trees were not split into two futtocks.
c) After comparing branch-free length against the produced timbers was found that finished timbers, in particular, first and second futtocks (Figure 21) were all found to be free from significant size branches. The investigation undertaken on this matter concluded that it would appear that those trees were pruned to produce a better quality of naval timber.
d) The authors of this research also concluded that the selection of the parent trees was only interrelated with the predesigned geometrical hull.

[35] Definition of waney: not of uniform size throughout; - said especially of sawed boards or timber when tapering or uneven, from being cut too near the outside of the log. - http://www.thefreedictionary.com/Wany,2017, 20th of January.

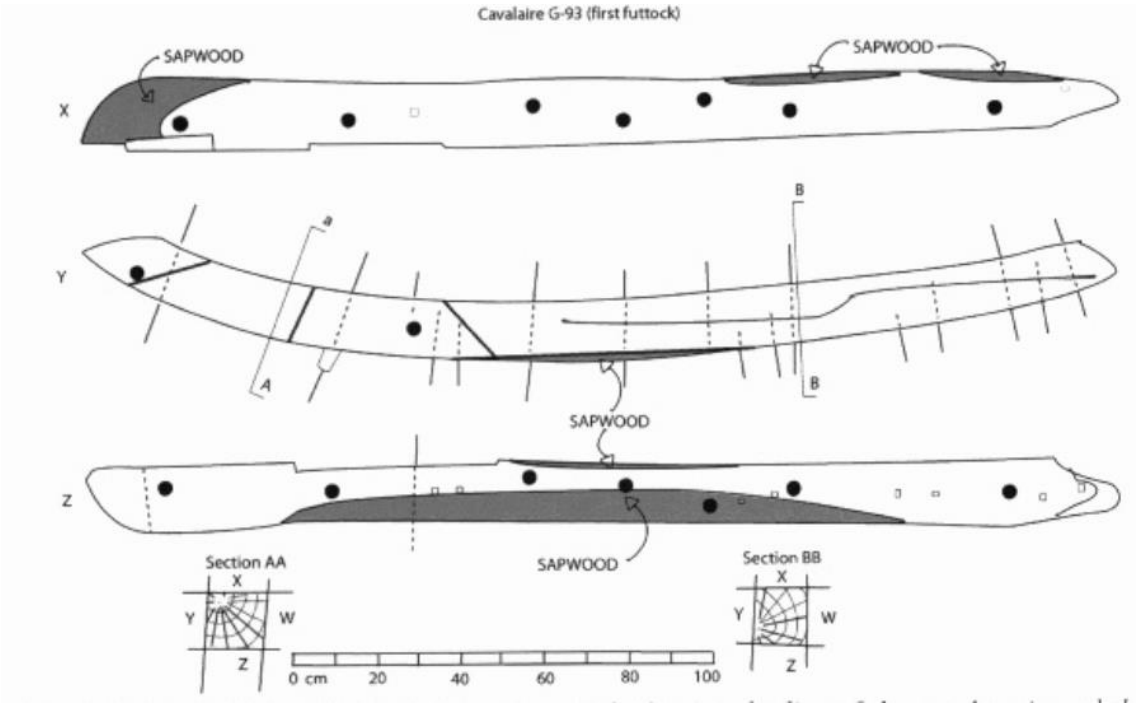


Figure 21 - Drawing made from the first futtock (Loewen et al. 2006).

In completion of the above-mentioned study, the Cavaliere-sur-Mer was built from trees obtained on an abundant forest dedicated to shipbuilding. Oak trees were careful pruned and selected to construct the vessel. Based on tree-ring counting[36] technique was possible to determine in which extent parent trees were managed. Despite the known limits of this process, ring counting by the *naked eye*, became evident that the trees employed for this vessel were felled at the age of around 65 years old (+/- 5) (Loewen et al. 2006). Furthermore, close inspection on the first and second futtock suggested that the parent trees were cultivated and harvested as a single crop. It seems that floor timbers reflect a more *opportunistic* selection of the parent trees:

These findings would be compatible with the practice of pollarding, in which old trees are cut at a height about two meters, and four to six new shoots springing from the stamp are left to grow into branches. These young branches of uniform age could be *shaped* to the

[36] The team of archaeologists opted to perform visual ring counting cross-checked to avoid significant errors.

required curvature by spreading them apart forcibly with props while allowing the heads to return naturally to the vertical position (Albion 1926; Marzari 1991; Marzari 1994; Ballu 2000) (Figure 22).



Figure 22 - Photograph of trees planted in Murua) Basque Country showing evidence of tree managed for the shipbuilding industry[37] (Photographs by the author).

Brad Loewen and Marion Delhaye (Loewen et al. 2006) investigation in turn to the Cavaliere-sur-Mer wreck offered a distinct study about Iberian forest management and timber supply. Although, in this case, study as in the San Juan study the produced drawings from the surviving timbers did not allow to obtain a clear understanding of the timber growth patterns neither other relevant wood features to identify and characterise the ship timber parent trees.

THE NEWPORT MEDIEVAL SHIP.

During the construction of the new Theatre and Arts Centre in Newport (Wales) in 2002, a remarkable clinker-built hull was discovered. Archaeological remains were initially exposed by builders during the process of sediment removal from the cofferdam built

[37] http://2.bp.blogspot.com/-G_hVn_ojrG8/U5I9igXNz5I/AAAAAAAAJQI/J3aZQSgynNk/s1600/Fagus+sylvatica,+hayedo+trasmocho1.jpg - accessed on the 26th February 2017

accommodate the foundations of the building. The dismantling and recovery of the vessel took approximately six months.

Archaeologists undertook survey procedures by excavating a trench to identify the extent of the remains. *In situ* recording processes took place soon after the sediment has been removed from the inboard face of the remains.

Despite the damage caused by the modern mechanical installation of the cofferdam sheet, the timber was in excellent condition (Jones 2009, 37). The timbers were still covered with wood tar, plant and animal fibre. In some of the remains it was also found traces of localised corrosion caused by iron clench nails and roves. Primary analyses revealed that the timbers were not substantially affected by marine life neither by salinity.

Photogrammetry and traditional hand scale drawing techniques were used in two stages: first records included the full timber assemblage and second records after the frame been removed (only focus on the inboard of the clinker hull and keel). The full extent of the remains included at that moment hull planking, frames, stringers, ceiling planking, keel, stern, knees, riders and the keelson (Jones 2009,36).

The overall length and other dimensions of the vessel are still subject to debate. In particular, because the stem and stern fragmentation caused by the cut originated by the construction of the cofferdam. Although, the full extent of the remains comprehends 25m in length.

At the end of 2004, post-excavation investigation comprised a *detailed examination, cleaning and digital recording of individual timbers* (Jones 2009, 38). Several advanced

recording techniques were tested before starting the 3D recording of the timber assemblage. Those methods included laser scanning and the usage of an articulated digitiser arm (Jones 2009, 38). The team of archaeologists developed trial compared test within several recording techniques. Hand drawings revealed to be slow in execution, on the other hand, laser scan was the fastest method, but the point cloud would require extended post-processing. The articulated digitiser arm was considered as the most suitable technique. A compromise between the desirable end product and the decision making by the operator would be reached using this method.

This last technique was considered as the ideal, regarding cost effect offering a high standard end-product[38].

After completing the recording of the ship´s timber assemblage, individual timbers were assessed for dating by dendrochronology (Nayling et al. 2014, 280). The sampling protocol[39] comprised a number of timbers selected[40] for dating and provenance. The wood analysis performed on those samples allowed to:

a) Planks were radially split with carefully hewn scarves and lands (Jones 2009, 37).
b) Initial dendrochronological samples collected from the oak timbers had more than 50 rings.
c) Further samples collected from timbers displayed on the top of the vessel´s structure was dated against British reference chronologies providing felling dates

[38] The three-dimensional drawings produced using a 3D digitizer arm in conjunction with Rhinoceros 3D software (Jones 2009, 39) had an accuracy of 0.25 mm.
[39] Samples were taken by hand-saw slices.
[40] The criteria for selection of these timber was based on the assessment of previous ring counts and presence/absence of sapwood (Nayling et al. 2014, 280).

in the winter of AD 1467/8 and Winter 1465/6 (Nayling et al. 2014, 279). A date that was also corroborated by the Newport medieval ship associated artefacts[41].

d) The keel was built from beech tree having 97-year dendro-sequence. Although, it could not be possible to date by matching its dendrochronological series against other timbers on-site, neither against historical data for medieval beech in Britain (Nayling et al. 2014, 281).

e) For the planking, ring-width analysis proved that individual timbers were obtained from the same parent trees, which also helped to analyse and identify possible construction sequence.

f) Dendrochronological analysis on one of the struts presents a date of 1468/9 as well as some of the timber repairs also from the mid-15th-century. Moreover, other artefacts were found in situ, including stone shots, an archer's wrist guard and several Portuguese coins dating to the mid-15th-century.

g) There was an attempt to correlate strakes on both sides of the hull and along it to identify possible if were shaped from the same parent tree.

The relevance of integrating the Newport Medieval ship case study in the present chapter as two main reasons:

a) It was the first excavation to include a record of detailed and precise wood features on the drawings produced within a 3D digital environment from the surviving timbers (Figure 23).

[41] Post-excavation analysis of the keel revealed a recess into which a French silver coin from July AD 1447 which according to archaeologists implies that the ship could be built before May AD 1447.

b) The success of the developed recording techniques allowed to establish a suitable recording protocol to the recording of clinker-built and carvel-built Iberian vessels, including the record of ship timber shape, wood features, timber conversion methods, joinery and other relevant data in a unique drawing per timber (Jones 2013a).

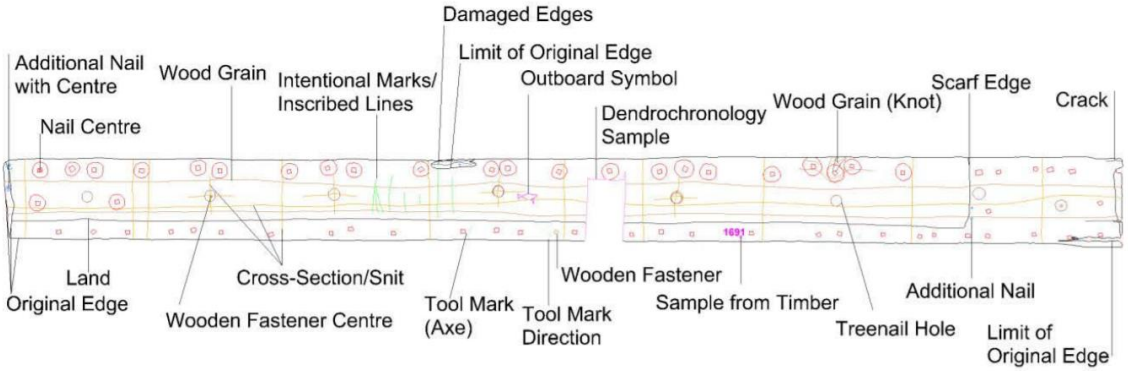


Figure 23 - Representation of the detailed level reach during the timber recording process timber CT614 P15_4 (Jones 2015).

The produced drawing allows conducting further investigations focusing on the wood features from the Newport Medieval Ship timbers (Figure 24). In this way, an assay was performed using some of those drawings to identify potential information about the surviving timbers parent trees.

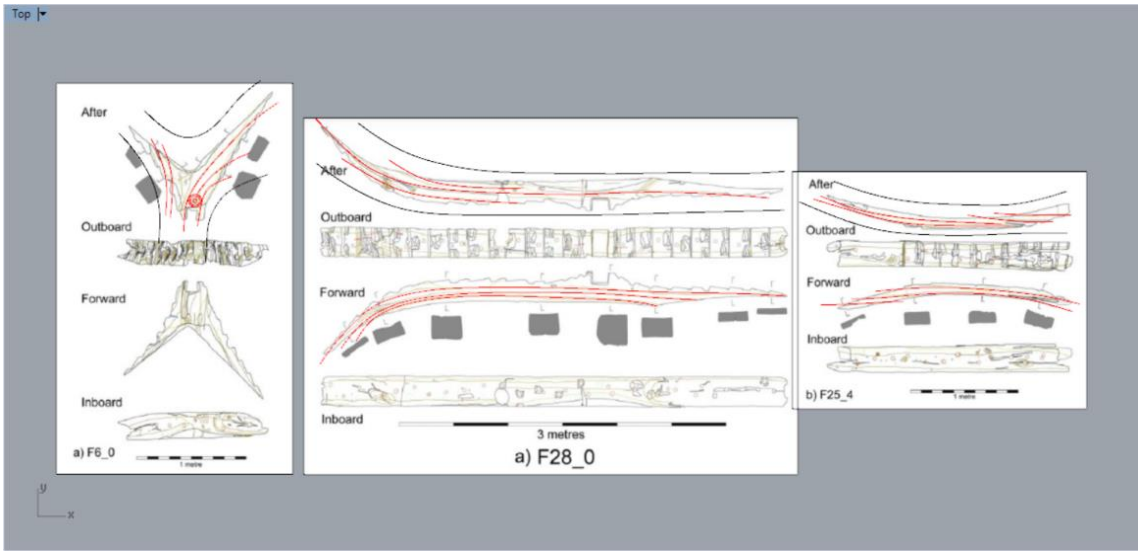


Figure 24 - Use of the produced drawing published to perform wood morphology analysis (Nayling & Jones 2014) (sketch by the author).

In the above figure (Figure 24) may be observed the growth pattern indicated by the red lines and the parent trees morphologies. This assay comprised the use of published data and Rhinoceros 3D within the following methodology:

a) The capture of the select drawing contains relevant data to the wood morphology analysis.
b) Merge the drawings captures into the Rhinoceros 3D as an *object*.
c) Scale the drawings to obtain a direct correlation between the existing scales included in the published drawings and the 1/1 scale preestablished Rhinoceros 3D environment. This task was achieved by drawing a line having equal dimensions to the measurements stated in the drawings. The following tasks included the scaling (*Scale* tool) the object`s scale to obtain a direct correlation between the existing scale of 1 and 3 meters in the drawings an equal measurement in the 1/1 Rhinoceros 3D scale environment.
d) Use the produced lines from the growth patterns reproduced in the original drawings and underline (using the *ControlPointCurve* tool) them with lines having a red colour to maximise its visualisation in the drawings.
e) Use a dark line (using the *ControlPointCurve* tool) to extrapolate the limits of the parent trees based on the growth pattern shape in a way to maximise its visualisation in the drawings.

This assay allowed to identify similar tree growth pattern and morphology to the above-included case studies, which suggest the use of compliant tree shapes to the predesigned ship timbers. The main difference between the surviving timbers from the Newport Medieval Ship and the other analysed vessels relies on the construction technology. The

clinker-built, as opposed to the carvel-built technology, requires a different type of joinery although, in terms of the employed trees to build these (above-mentioned) ships do not have apparent alterations to the employed tree selection process. Nevertheless, as it was expected the growth pattern wider tree rings and consequently its amount is reduced in number in comparing to the Cais do Sodre, Corpo Santo and other mentioned wreck in the present chapter.

EARLY REFLECTION ON THE ANALYSED DATA.

The Portuguese treatises (Oliveira 1580; Lavanha 1618) provide relevant information about the wood specifications to the shipbuilding industry. A collection of documents which remarkably stated the requirements that carpenters should follow to produce suitable timbers having compliant dimensions and shapes. Besides, the information contained on these documents also suggested how to take advantage of the tree`s natural characteristics. It may suggest either the treatises were written after the observation of the routine tasks developed in the shipyards or, a carpenter at the shipyards followed the treatises. This discussion taken in a variety of publications (Domingues 1985; Domingues 2004; Esteves 2011) has its relevance to the study of the shipbuilding architectural signature, advances in technology and equally, in regarding the employed timber in this industry. Although, by this chronology, the knowledge obtained by carpenters is main passed from generation to generation. In some cases, having a direct relationship between the forest/woodland and the shipyards in a close and symbiotic relationship. As the carpenters preferentially required suitable timber logs having compliant morphologies to the predesigned ship timbers and carpenters at the forest had to employ a suitable practice to provide them with the *good* timber.

Within the performed wood morphology analysis based on the archaeological evidence studied and published about the above-included surviving timbers, became possible:

a) To assume that carpenters from the 16th-century already possessed the knowledge to maximise the existing raw material – wood.
b) Carpenters had an exhaustive knowledge about the use of the five distinct parts of a tree: the pith, heartwood, sapwood, bark edge or *Libri* (Desmond 1919) and the bark.
c) From the shipbuilder's viewpoint, the pith provides an accurate understanding of the growth pattern and morphology of the tree to convert in the timbers:
    a. The densest and most durable part is the heartwood, and the softest is the sapwood, where new cells are still open, allowing the sap to flow through the filaments.
    b. The bark edge is the part that divides the sapwood from the bark and defines the limits of a trunk or branch for the shipbuilding purposes.
d) Carpenters knew in which period of the year was more suitable to obtain better-quality wood.
    a. This may vary from country to country, location to location or even from the dockyard to dockyard, although it was mainly correlated to seasonal cycles[42].

[42] For instance, in the temperate areas of Portugal, some carpenters chose to harvest trees in late autumn immediately after leaf fall (Castanheira 1991). Other carpenters such as the *Mestres Carpinteiros do Antigo Arsenal do Alfeite* (carpenters from the *Ribeira das Naus*, Lisbon, Portugal), preferred the month of August, for the pine (*Pinus pine* and *Pinus pinaster*), and between October and February for oak (*Quercus sp.*), when the sap is less active (Valente 1948).

b. Furthermore, they recognised that the size and growth of a tree was not an infallible sign of quality. The combination of the age of a tree and the nature of the soil in which it grew allowed judgment to be formed the quality of the wood (Desmond 1919), which means that a number of different characteristics such as durability, uniformity of substance, straightness of fibre, strength and elasticity were essential for shipbuilding purpose.

Nevertheless, there are no such things as perfect trees to convert in perfect timbers. The carpenter still needed to find the place in the available raw material where knots and cross-grain could be avoided. Notably, because these *imperfections* usually represented weak points in the timber structure, because of an interruption to the natural grain of the trunk or branch. Without this understanding, timbers when subjected to high pressures, these imperfections may generate cracks or holes. After the trees been felled, the growth process is entirely interrupted, leaving the timber exposed to all environmental elements which will inevitably start the degradation process. Therefore, if disregarded proper storage, timbers could naturally split and initiate a process of fast dehydration. A fermentation process could also be initiated if exposed to high temperatures, which would be followed by the loss of consistency and consequently became vulnerable to shipworm attacks. To avoid the loss of these precious raw materials, the timbers had a special place to be stored in the dockyards (Desmond 1919) where they were stacked by using two basic rules:

a) Stacking the timber by shape, avoiding exaggerated contact between them at all cost. This technique helps the circulation of air between timbers and avoid the infestation of harmful microorganisms.
b) Burying the timbers in an anaerobic area nearby a river where the fresh and saltwater meet and avoids the presence of *Teredo navalis* (shipworm).

However, in any of the adopted storage criteria, the timbers should be organised by their particular characteristics: size, function and by typology – hull timbers, rigging curves (Castanheira 1991). The timber seasoning could take months or years depending on the shipyard demand in wood. However, when finally, ready to its primary purpose, carpenters could split them with an axe into radial sections or tangentially cut using a saw. A method that may vary from location to location although, in the Iberian Peninsula, trees were at the first stage converted into timbers with gross forms to store and then shaped in detail when needed.

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CHAPTER 2 – THE IBERIAN SHIPBUILDING TRADITION AND THE WOOD REQUIREMENTS: WOODLANDS, SHIPYARDS AND TREATISES.

Within the previous chapter, much has been argued about the characterisation of an Iberian ship, its relationship with the shipyard's requirements and the forest/woodlands supply. Thus, it became clear the existence of a symbiotic and dependency between tree`s morphologies and the predesigned ship timber shape. In a way to explore this subject and to consider a crescent need of a deeper understanding of those trees, chapter two will introduce most of their features. A characterisation of the broadleaf and conifers will be presented based on the stated requirements in wood supply by the Iberian shipyards. The advantages and limitations in tree selection will also be addressed based on the recommendation mentioned in the major specialised shipbuilding treatises. Chapter two – has its limits in chronology and geographic context, as stated in the preface. Therefore, in the following paragraphs, a greater focus will be given to the visited literature produced and published about the Portuguese shipbuilding[43].

Despite the engineering required to build a ship, the raw material also institutes a fundamental element of its construction. During the Iberian Age of Discoveries (15th to the 17th-century), shipbuilding primarily relied on the existent wooden resources. Trees were being felled and converted into logs and then transported to shipyards. This process could be performed in different circumstances depending on: if, carpenters from the yards personally visit the forests to choose the trees or on the other hand, the logs were sent to the yards without shipbuilder`s encouragement. Indeed, the last option became

[43] These boundaries had their origin in the fieldwork and studies performed by the author of the present thesis during the ForSEAdiscovery Project (a research project fully described at the Preface of the present thesis).

part of the shipyards routine when a lack of raw material motivated the increased importation of timber (Devy-Vareta 1986).

Today much that archaeologists know about ships, shipbuilding techniques and dockyards have been emanated from studies and underwater excavations undertaken all over the world. Theories, assumptions and essays have sought to understand how it was possible to build such a highly complex machine. The primary purpose of such a machine was carrying an enormous amount of cargo, a vast apparatus of provisions, artillery and passengers along with the crew (Martins 2014).

To gain a better understanding, it is imperative to explore a universal context of that chronology, its influence on shipbuilding and, to which extent shipbuilding has changed its paradigm. It is necessary to investigate existing, poorly catalogued or unidentified resources of historical, political and economic documentation, as well as the socio-economic contexts, iconography and ethnographic that can be consulted (Castro 2006, 63).

The information about the first 150 years of the Iberian seafaring history is rare. Nowadays, historians still have little knowledge of those journeys considered as the maximum exponent of the Age of the Discoveries. The caravels *crossed the seas* along the coast of Africa since the first quarter of the 15th-century, but no standardisation of shipbuilding techniques/technology is known. The iconography illustrates different types of vessels, and it is more oriented to small coastal settlements and probably to the daily activities (Figure 25). The search for information related to the bigger ships, with the shipbuilding and consequent mutation of this industry, remains in an almost embryonic stage. Nevertheless, it is possible a conciliation of the preserved written and iconographic

information, to theorise that the Iberian ship suffered its more significant influence from the Italian shipbuilding. However, it is not possible to prove such conjecture.

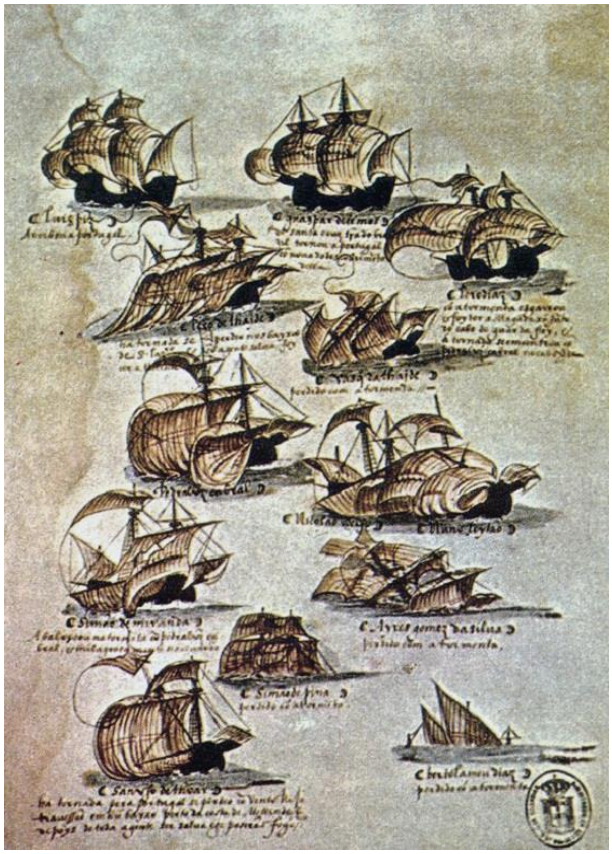


Figure 25 - Portuguese Armada under the command by Pedro Alvarez Cabral (1500 AC).

Since the end of the 19th-century, Spanish scholars have undertaken scientific studies exclusively devoted to the theme: Iberian Naval Archaeology. Due to geographic proximity or the common events (discoveries, joint crown, Iberian political treatises), this research interest expanded to Portugal, where the investigation was also initiated (Domingues 2000, 13-56). Researchers from both countries have encountered no evidence of traces resulting from natural phenomena such as fire, earthquakes and tsunami[44] (Castro, 2008, 63) alternatively, by the natural decay of the surviving artefacts.

[44] In 1755 the coast if Portugal suffered from an earthquake followed from a tsunami which practically destroyed the city of Lisbon.

IDENTIFICATION OF CULTURAL INFLUENCES IN THE IBERIAN SHIPBUILDING TO A BETTER UNDERSTANDING OF WOOD REQUIREMENTS.

Mediterranean influences on Iberian shipbuilding integrated the techniques/technology of the long-term economic and commercial relationship with the city-state of Genoa. The relation between both countries is duly documented from the beginning of the 12th-century, when Italian shipwrights by the invitation of Bishop Gelmirez, were contracted to build and navigate ships capable for the defence on the Galician coast.

The Italian influence in the Iberian Peninsula is continuous between the 13th and 15th-century and is heavily reported. At the end of the 13th-century, Genoese merchants open their maritime routes to the North, aiming to establish commercial relations with the North Atlantic. In this way, the Bay of Biscay became an intermediate port between the Mediterranean and the final destination. This commercial and cultural exchange strengthened relations between Genoese and Portuguese. The most tangible proof of this relationship can be found in the units measured from the 16th-century onwards. The Portuguese (shipwrights) used the *goa* that corresponded to 77 cm and the *palmo de goa* with correspondence of 25.67 cm. Both have an exact match with measures used by Genoese shipwrights (Castro 2008). During the Age of Discoveries, it was common for the Portuguese crown to contract shipwrights from Italy to work in the country shipyards[45]. This has exponentially increased the Italian influence in the Iberian maritime industry. Their know-how and technology in the Naples, Genoa or Venice shipyards were already well organised and played a major role in the economy. The guarantee of construction in

[45] As the example of Pantaleone Queirolo who will have abandoned his village in Italy and with a group of shipwrights will have had as destination Portugal with the aim of constructing and Operate ships for the king of Portugal (Cicillot 2000).

these yards is considerably superior to any contemporary *competitor*. The organisation of manufactory departments and the high-skilled carpenters guarantee greater efficiency and speed in the completion of the contract (Lane 1934a; Lane 1934b).

Also recognised as highly skilled navigators, the *Arabians*, fearless and innovative. For an extended time period, they shared technology with the Iberian countries becoming major influencers of Iberian shipbuilding. Between the 12th and 15th-centuries, more than ten generations shared periods of peace and cooperation, thus guaranteeing cultural and knowledge interchanging. The adoption of expressions and terminologies by the Portuguese reveals the proximity of the two cultures, for example, the word *almogama*[46], which translated into Arabic, means meeting point. Despite the already establish Latin terminology[47] (in the Italian technical language) for this timbers, Portuguese shipwrights choose to adopt the Arabic word which reveals the extent of Arab influence in shipbuilding (Castro 2008). Fernando Oliveira, in his reports, made mention of this exchange: *some in the lands of the Moors* where the author observed how they built their ships. Oliveira also wrote about how had practised with their [Arab] carpenters and learning their styles, and carpentry customs, and construction traditions (Oliveira 1580).

From the 17th-century under the ruling of the House of Habsburg in the two countries - Portugal and Spain, legislation was created aiming to standardise the shipbuilding industry in the Iberian Peninsula. Experts from both territories discussed sizes and shapes

[46] The balance frame/tailframe/loof frame is the distance of the breath measured on the first deck at the fore and aft end of the pre-designed frames.
[47] Italian term for almogama: Cavo de sesto (Venice), chodiera chorba, quartiere.

for the creation of the concept of Iberian ship and common characteristics of shipbuilding (Figure 26).

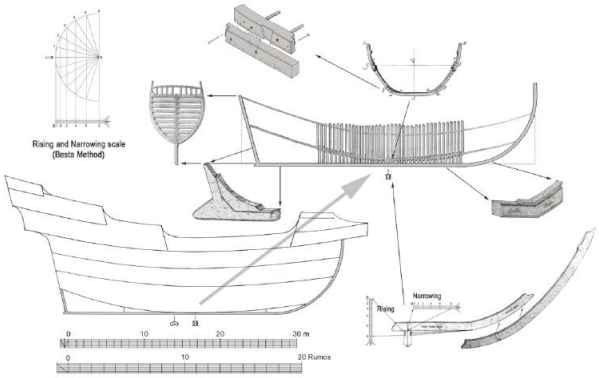


Figure 26 - Some of the Iberian shipbuilding features illustrated by Filipe Castro (Castro 2008).

Some treatises refer these similarities between the vessels built under the two crowns, as well as the definition of the type of vessel to be used on each of the chosen routes. The descriptions of each type of vessel, such as galleons and caravels, are identical for the two countries. Sizes vary, but standard features are present in the documents, including tasks and functions within each navy. Fernando Oliveira in the *Liuro da Fabrica das Naos*, dating from 1580, mentioned the similarities between the Portuguese vessels that left to Africa which did not contrast much from the vessels known as lapstrakes/clinker-built from Galicia (Oliveira 1580, 76). Contemporary texts and iconography found, confirm that all oceangoing ships were designed identically regardless of region or shipyard. They were constructed empirically, within *father to son* knowledge which made them lack in geometric plans or schemes. These vessels were only based on proportion and scale (Reith 1996; Castro 2008). The method of construction dates back to ships, traditionally built in the Mediterranean, with the choice to carvel style with flush-laid planking fastened to the frames.

The conceptualisation of the Mediterranean ships for this chronology was thought of as a skeleton-first on which the plank was fastened. This construction method dated at least to the 12th-century and consisted in placing a number of frames from the keel and fastened a few stringers called by *armadoras*. This wooden slat helped to visualise the hull shape, but above all to define the shape of the remaining frames and futtocks.

Unfortunately, the vast number of the surviving remains of the Iberian ships only comprise fragments of the central structure, the actual knowledge from the top of the first futtocks upwards is non-existent, as well as the whole method of the construction sequence. Based on the principle, all measures are related and directly proportional to each other (Barata 1989, 212-223). However, based on this theory, the methodologies employed in shipbuilding and the different units of measurement ensure the variation and uniqueness of the produced vessels. The shipbuilding industry is based on manufacturing requirements and has been one of the first industries to segment work in construction stages. Although this does not guarantee, that all sequences and specificities are subject to any validation using geometric plans, rules or practices. They were based on the human capacity to create symmetry. In Portugal, the oceangoing vessels would have distinctive characteristics since were built to the exchange of commodities for uninterrupted periods of no less than six months. All these vessels were gradually increasing in size until 1571 when was determined their maximum capacity at between 350 and 500 tonnes.

PREDESIGNED TIMBERS, DIMENSIONS AND SHIP PROPORTIONS TO IDENTIFY SUITABLE TREE´S MORPHOLOGIES.

The investigation of a potential correlation between the forests and the shipyards has several challenges in which is included the hull shape, measurement units, and other technical features. By understanding that the shipbuilding industry was based on empirical knowledge and oral transmission, it became evident the absence of shipbuilding technical standardisation until the beginning of the 17th-century (Dell 'Amico, 2002, 21-25). Within this knowledge transfer between generations, a challenging path to the understanding of the main principle of Iberian shipbuilding had to be made. In the event of finding stated standardised measurements and proportions, the entire process of investigating an Iberian ship would be considered as a less complex task. Until the late 16th-century, the entire information about how to build these vessels was *stored* the mind of shipbuilders. Although, the first treatises in shipbuilding were more knowledge possession orientated rather than to the purpose of transmitting knowledge. Moreover, as it stands were not written by shipwrights and did not seem to have been written for shipwrights (Castro 2006, 67).

The discoveries triggered a profound destabilisation of the traditional Western paradigms of knowledge. The pressure exerted on Europeans before the newly discovered regions and new problems, put in question many of the bases of knowledge in which most of them were inherited from the Middle Ages and Ancient Mediterranean. Forcing these people to step back before the authorities who guided the thought. The answer to this challenge in the 16th-century is not univocal. When confronted with the empirical verification of the partial inaccuracy of the texts where they founded their wisdom of

things. There were several alternatives for this position: in large part, they took place not only in personal development but also in the diversity of the fields of knowledge. Fernando Oliveira is in what we can call technical-practical area of knowledge. In particular, because the author provides the majority and most important of the texts in the ambit of the Portuguese Renaissance: fundamentally, nautical and geography whose results are intimately related to the maritime discoveries (Domingues 1985, 4).

Treatises such as the documentation produced by Fernando Oliveira attempted to provide a compilation of the most employed techniques and recommendations. In addition, these documents attempted to conceptualise a standardisation by referring to the previously used terminologies[48].

The Iberian vessels called *Naus/Naos*[49] were designed as floating boxes to carry commodities between India and Portugal. Therefore, the central area had a more or less cylindrical shape, determined by the master frame. The bottom floor timbers were almost flat and two circle or ellipse arcs, which define the shape of the side (Castro 2008). The compatibilisation of the master frames with the forward and aft frames - the *delgados*[50] was facilitated by the gradual raising and gathering of the bottom of the frames as they were placed on the keel, filling the spaces between the master cave and the *delgados*. The frames were connected by scarves and bolts until the first futtocks before being placed on the keel, forming complete frames - *balizas*. As this process implied an absolute control of the *balizas* shape, they were sketched from a set of moulds and scales and

[48] *Less than forty years ago the names zabra and lancha were not known on this land (Portugal), and now they are common* (Oliveira 1580, 76).
[49] A type of vessel used by the Portuguese merchants on the routes having a tonnage capacity ranging between 500 and 600 tonnes.
[50] Aft and forward thiner part of the ship`s hull.

were referred to as *balizas gabaritadas* or *graminhadas*[51]. This designation was given by the *graminho*[52] which determine the dimensions, *recolhimento*[53] and *levantamento*[54] required for the determined hull shape (Barata 1989; Castro 2007). The last *balizas graminhadas* were the *almogamas* which were placed on the keel at the aft and forward.

The Portuguese ships were usually depicted in a very simplistic way, practically devoid of decoration apart from a red cross represented in the sails. Although, it is possible to identify three specific types of contemporary vessels at the time of discovery: ships, galleons and caravels. In a very brief way, we have:

a) *Nau/Nao* - boat composed of 2.3 or 4 differentiated decks with fore and stern castles. It usually has three masts with square sails;
b) *Galleons* - vessels with a more military character, normally composed of two or three decks, with a fully integrated bow and stern castles having 3 or 4 masts;
c) *Caravelas* - ships with lateen (triangular) sails with one or two masts and more suitable for fishing activities. These ships progressed from their creation (12th-century) until the 16th-century when they appeared with four masts, armed and integrating fleets as warships. The Caravela or Caravela Latina played a leading role in the 15th-century, it had on average 50 tons of capacity while 16th-century ships already reached 400-600 tons, as was the case of the *Carreira das Indias* (Domingues 2004). Capacity was seen as a measure of the internal volume of permanently closed areas that were occupied in commercial activity, although this assessment is often controversial. In marine commerce, the increase in the

[51] *Balizas graminhadas* are the predesigned framing timbers.
[52] *Graminhos* were an instrument to calculate the proportion between the different places in the ship`s hull.
[53] *Recolhimento* is the narrowing of the ship`s hull.
[54] *Levantamento* is the place in the ship`s hull starting from the turning of the bilge to the upper works.

capacity of the ships tried to compensate for the cost of distance (Moreira 1984) (further information about ship`s proportion will be discussed within the next subchapters).

These vessels are also described in Spanish treatises from 16th and 17th-century such as *Itinerario de Navegación de los Mares y Tierras Occidentales* (1575) by Juan Escalante de Mendonza, *Arte para Fabricar, Fortificar y Aparear Naos* (1611) by Tomé Cano and *Instrucción Náutica para el Buen Uso de Las Naos, su Traca, y Gobierno Conforme à la Altura de México* (1587) by Diego Garcia de Palacio. These manuscripts combined with the legislation created at the time and commonly identified as *Ordenanzas,* provide the largest source of information on this subject and constitute the main Spanish reserve for shipbuilding (Phillips 1987; Phillips 1993; Castro 2008, 81). Although well documented, it is possible to perceive that there was no uniformisation of measures or forms. Thus, Escalante de Mendonza, in the middle of the 16th-century, concludes that the most appropriate vessels for the routes to the New World would have 500 tonnes of capacity. However, Garcia de Palacio in 1587 indicates that in his opinion, the vessels should have 400 tonnes to satisfy both commercial and military purposes. Thus, in Portugal and Spain during the 16th-century physical dimensions of a tonne and a barrel, respectively equivalent to two barrels of wine or water weighing 404 kg and that the result of its sum would occupy the equivalent of 1.4 m³.

The attempt of standardisation went further in theory, as the authors of these treatises tried to divide vessels sharing similar features into different groups of vessels – designations. Although, the adopted measuring units consisted of one of the major difficulties of such a complex task.

Measure units were at that chronology close related to their natives. Parts of the body were used as scales such as foot length, hand width or finger thickness, palm length and stride, or they still used a stick (*vara*). The measurements were so arbitrary that they were defined by the anatomy/size of the parts of their ruler. Namely, the anatomical size of his hand (*palmo*), thumb (*dedo*), forearm (*codo*), arm or even of his nose, whose distance to his thumb was conventionally called a yard. In this way, a purely arbitrary system was used, which proved to be an obstacle to commercial trading (national and international) (Table 6).

SPANISH AND PORTUGUESE SHIPBUILDING UNITS IN THE SIXTEENTH CENTURY

Unit	Metric System Equivalent	Country
Codo castellano	55.7 cm	Spain
Codo cantábrico	57.5 cm	Spain
Vara castellana	83.6 cm	Spain
Palmo	20.9 cm	Spain
Dedo	1.74 cm	Spain
Tonelada de carga	1.382 m^3	Spain
Tonel macho	1.521 m^3	Spain
Rumo	154 cm	Portugal
Goa	77 cm	Portugal
Palmo de goa	25.667 cm	Portugal
Vara	220 cm	Portugal
Palmo de vara	22 cm	Portugal
Dedo	1.83 cm	Portugal
Tonel	1.275 m^3	Portugal

Sources: Casado Soto 1988; Castro 2005.

Table 6 - List of arbitrary reference measurements in the Iberian Peninsula (Castro 2008).

Correspondence is the convenience and proportion of the parts among themselves. Which is such a way must correspond to each other and be measured with the limbs of the human body from which the finger, the hand, the foot, the covado and other like are commonly measured[55] (Lavanha 1618, 20).

IBERIAN SHIPBUILDING, TREATISES, SHIP`S GEOMETRIC PLANS AND PROFILE.

Initially written by mathematics and clerics, the shipbuilding treatises were rich in technical descriptions and played a vital role in the industry (Figure 27, Figure 28). Although, it lacks almost in total the information regarding the design and construction of the 16th-century oceangoing Iberian vessels. This lack of information is common across Europe of the same century, which makes treatises being considered as *precious* documents (Castro 2008, 1). Until the mid-17th-century ships were built without having a graphic conception. Moulds and scales were directly applied on the timber's surface and cut, which means that there were not previous drawings to carpenters to follow (Oertling 1989, 246). The master carpenter would have the keel length firstly and estimate the remain measurements proportionally from the reference timber/scale. Fernando Oliveira defines a substantial number of measures from simple arithmetic relationships with the value of keel length, evidencing the Mediterranean (Italian) origin of this method of conception (Castro 2008, 7).

The Spanish *Ordenanza* of 1607 came to legislate rules to be adopted in both countries. Measured, cargo capacity, as well as the function of each of the vessels, as been defined

[55] Original (Portuguese language): *A correspondência é a conveniência e proporção das partes de toda a obra entre si. As quais de tal maneira devem corresponder umas as outras e medir-se com os membros do corpo humano do qual é comum medida o dedo, o palmo, o pé, o covado e outras partes semelhantes* (Lavanha 1618, 20).

in this document. The *Ordenanzas* also defined the purpose of larger vessels: galeonzetes of approximately 300 to 500 tonnes have intended the ships of war, as where galleons with capacities between 550 and 750 tonnes.



Figure 27 - Spanish *Ordenazas* (from left to right) *Itinerario de Navegación de los Mares y Tierras Occidentales* (1575) by Juan Escalante de Mendonza, *Arte para fabricar, fortificar y apareiar naos* (1611) by Tomé Cano and *Instrucción nautica para el buen uso de las naos, su traça, y gobierno onforme à la altura de México* (1587) by Diego Garcia de Palacio.

Portuguese treatises were documents of enormous relevance containing detailed information about shipbuilding from the end of the 16th-century to the beginning of the 17th-century. In this way and among the most emblematic documents are the: *Ars Nautica* (1570) and *Liuro da Fabrica das Naus* (1580) by Fernando Oliveira, *Liuro Primeiro de Architectura Naval* (ca.1610) by João Baptista Lavanha and the *Livro de Traças de Carpinteria* (1616) by Manoel Fernandez (Figure 28). In these documents, it is possible to find a unanimous opinion on the capacity of vessels, which according to the judgement shared by all authors should be between 500 and 600 tonnes. This capability would be indicated for the *Carreira das Indias,* and it was concluded that by the distance travelled or by the constant load, the advised dimension would be justified. These vessels were undoubtedly much larger than their contemporaries, destined to the European market, Mediterranean and the coast of Africa having around 100 tonnes of capacity.



Figure 28 - *Ars Nautica (1570)* and *Liuro da Fábrica das Naus (1580)* by Fernando Oliveira*, Livro Primeiro de Architectura Naval* (ca.1610) by João Baptista Lavanha and the *Livro de Traças de Carpinteria* (1616) by Manoel Fernandez.

These treatises provided guidelines for the shipbuilders by the moment that carvel-built started to spread across Europe. Shipwrights' plans were sketched having precise indications about proportions and requirements for each type of vessel.

Contained drawings represent sophisticated knowledge for that time and a combination of a variety of sciences. Shipwrights needed to understand the complexity of Astronomy, Arithmetic, Geometry and Engineering (Lavanha 1618, 42; Domingues 2000, 60). This included the method to produce the ship plans and other details[56] that should be followed by carpenters. The included drawings in these treatises represented: *The perspective figures the whole plans as if it represents the views according to the posture of the eyes. It is in this comfortable part and so that the whole ship shape in a paper is considered to be represented and in it are understood all the fourth parts because in the model are shown the entire plans, the longitudinal, transverse and perspective views*[57] (Lavanha 1618).

The imperative task of identifying the adopted measurement units was crucial to obtain a better understanding of wood requirements. In the case of mentioning a specific

[56] From the *planta* shipwrights made a model of clay to visualize the hull shape and its features (turn of the bilge, fore and aft curvatures ad other particularities).
[57] Original (Portuguese language): *A perspectiva é a figura de toda a fábrica como se representa a vista segundo a postura dos olhos. É nesta parte agradárarevel e para que que se veja debuxado todo o edificio em papel (…) e nele estão compreendidas todas as outras quarto partes porque no modelo se vê a planta, a montra, o perfil e a perspectiva* (Lavanha 1618, 20).

measurement to a particular timber to be included in the vessel`s framing system, carpenters had to have a clear indication of which tree to select and their suitability to provide the contractor with *good timber*. Once forest carpenter had the general information of which tree species, morphologies and dimensions, their work started to be performed. The other reason why the dimensions and standardisation of the vessels were equally crucial, is entirely related to the forest renovation and forest practices. The following discussion will address this subject, in a way to provide relevant information about those requirements and the suitability of each tree species, namely the oaks and pines.

RECOMMENDATIONS ON TREE SELECTION, TIMBER SUPPLY AND ITS USE AT THE PORTUGUESE SHIPYARDS FROM THE 16TH-CENTURY.

According to the author of the *Liuro da Fabrica das Naus* (Oliveira 1580), two types of wood were required by the shipyards – a hardwood type and other more flexible. This prerequisite is deeply related to the structural elements of the *Nau/Nao*. The first element consisted of the framing system which would only be sufficiently robust if built from stronger wood. In a way to allow efficiently carry an enormous amount of weight such as crew, supplies, commodities and to survive in challenging climate, weather and swell conditions. The second element comprised the planking made of a more flexible wood to allow the joinery and shaping of the hull to fashion the framing system. Oliveira (Oliveira 1580, 63) established an analogy between the use of different type/features of wood and the animal's anatomy. The robust structure of the animal is compared to the framing system and the animal skin to the more flexible type of wood.

Iberian ships conceptual design was then materialised by employing suitable timber morphologies and wood anatomy – using *good* timber. The supply of that wood would not be from long distance woodlands, once Oliveira (Oliveira 1580, 63) stated that in this land [Portugal] are two types of adequate trees to the construction of such vessels[58]. The author refers to the local cork oak (*Quercus suber*) to the framing and pine (*Pinus sp*.) to the planking. Moreover, the author justifies this selection of tree species based on the knowledge that: the cork oak is a hardwood which becomes harder when preserved in moister and does not rotten in water (Oliveira 1580, 63). These tree species were considered of such strategic importance that Fernando Oliveira suggested its exclusive use in the shipbuilding industry and to avoid wasting them in the production of charcoal and cork.

Furthermore, the author reinforced this opinion by stating that cork oak and pine trees are slow-growing trees which take at about 20 years to be ready for the naval industry. Therefore, oak and pine woodlands should be cleaned by pollarding and protected from lumberjacks[59]. This included the seeking of the more favourable woodlands to supply the shipyards (timber provenance), depending on the soils where trees were planted[60] (Map 1):

[58] Original (Portuguese language): *Nesta terra temos dous generos de madeira muy appropriados pera estas duas partes das naus* (Oliveira 1580).
[59] Original (portuguese language): *E mays se deuem poupar estas aruores, por que crescem de uagar, tanto, que em uinte anos se não acaba de fazer hua souereya aruore formada, para poder dar madeyra que nos apoueyte. E também se deuem criar as nouas pollas charnecas onde as há, / mandar aos lavradores uezinhos, que as alimpem, / criem, / defendao dos mateyros, / lenhadores, / fazerlle por isso algum fauor* (Oliveira 1580, 63).
[60] Fernando Oliveira stated that the nutrients in the soil would have a direct relationship with the quality of the timber, but *enformese dos moradores das terras onde forem ter, como fica dito, & saybao de que madeyra usao nesta fabrica [carpenters should be informed by the local population about the timber employed in the shipyard* (Oliveira 1580, 67).

a) In Sintra and Peralonga – higher levels of moister which made different trees and plants.

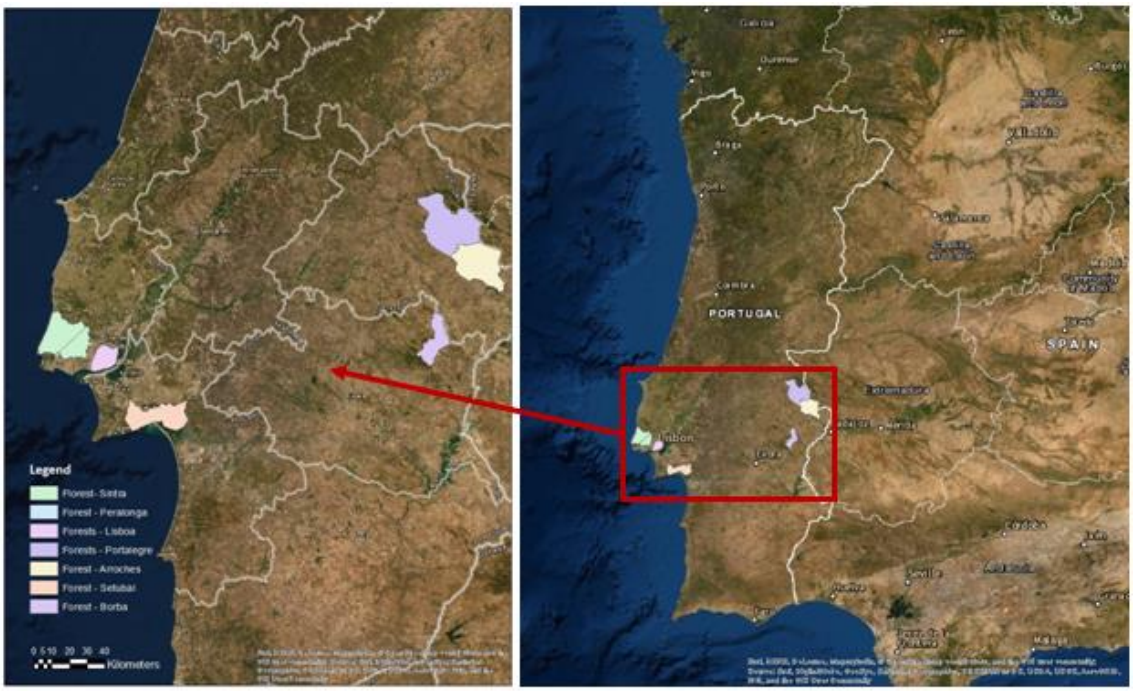
b) In Borba – chestnuts and evergreen oak.

c) In Portalegre – Cherry tree (*Prunus cerasus*).

d) In Arroches – dryer trees.

e) In Lisbon – better and dryer trees than in Setubal.

f) In Ribatejo – better trees than in Lisbon.



Map 1 - GIS map representing the mentioned forests by Fernando Oliveira for timber supply (map elaborated by Adolfo Miguel Martins).

In these places, the tree selection should be a focus on the existing signs in each tree. These signs could be found in the bark, leaves and fruits. As the comparison between the trees and the human body – the bark as the *skin*, the leaves as the *needles* and the fruit as the *hair* (Oliveira 1580, 67). The analogy that would mirror the tree was presented within the following criteria:

a) The red mould – is similar to the blood colour in the head and hair, such as the symptoms of a low level of testosterone.
b) The blond/yellow colour – similar to the symptoms of cholera.
c) Dark colour – associated with despair and melancholy.

This, comparison according to Fernando de Oliveira allows to memorise tree`s most common symptoms and a direct correlation with the dominant element which made them unsuitable for harvesting and consequently to provide timber (Oliveira 1580, 67-68).

As stated before, Fernando Oliveira considered the cork oak and the pine the most suitable tree species to the construction of the ships. Although, in the case of timber shortage, the author presented a solution which resides on the evergreen oak (*Quercus ilex*) and the kermes oak (*Quercus coccifera*) species. These trees could also be used as a secondary option since possessed similar characteristics but could only be found in distant regions in the inland of Portugal[61]. Nevertheless, an interesting statement by Oliveira slightly reviled some clues about timber provenance since the author refers to the cork oak as a Portuguese autochthonous tree, more than the evergreen oak (Quercus ilex)[62] (Oliveira 1580, 64). Another tree species mentioned in the *Liuro da Fabrica das Naos* (Oliveira 1580) is associated to the genus of oak trees family which is also suitable to the shipbuilding industry and commonly used to the construction of galley. Despite the author not mentioning to which oak subspecies refers to, Fernando Oliveira stated that such tree species were supplied from the French and German woodlands. The appointed

[61] Original (portuguese language): (…) *por que he tambem a madeira destes ryja, & semelhante ha do souaro: mas não se acha della perto do mar* (…) (Oliveira 1580, 64).
[62] Original (portuguese language): *mays que o azinho* (Oliveira 1580, 64).

differences between the two species of oak were the relatively explained and a justified by Oliveira: the French and German oaks were higher, free from knots[63] which made possible to use them as long structural timbers such as the planking. Thus, establishing a comparison between the use of different tree (sub)species in the shipbuilding industry. As opposed to the Portuguese oak, which is not suitable to the planking since its commonly harder, dryer and cracked (Oliveira 1580, 64). Considering the comparison between the autochthonous tree species and the timber supplied from foreign woodlands, it seems that the author refers to a low-density in anatomy since mentioned that the wood is lighter than the cork oak, more vulnerable to the shipworm infestation and softer to shape.

On the other hand, Fernando Oliveira considered that the French and German oak was not suitable to the Portuguese shipbuilding industry because it was softer and therefore, more susceptible to the *Teredo navalis.* The reason for this affirmation relies on the experience taken from the navigation on the southern hemisphere where the French and German oak decays and rotten when sailing in warm water. The author continues his considerations on tree selection. The chestnut is not also adequate to the Portuguese shipyards since it cracks easily, which made unsuitable to employ in the framing and planking despite growing faster than the cork oak and evergreen oak. In completion of the analysis performed by the author of the *Liuro da Fabrica das Naos*, the cork oak was on sufficient abundance by the late 16th-century. Its anatomy and morphologies resulted in extended use of oak and pine timber employed in the construction of the *naus/naos* to

[63] Original (Portuguese language): (…) *a que nace nas terras frias de franca, & e Alemanha. Nas quais terras fazem também desta madeyra de carvalho o tabuado das naos: por que naquelas terras cresce maus os carvalhos, q nestas, & fazem laa a madeyra mays coprida, & limpa sem noos, & mays tapada sem gretas, ne fendas que prejudique: & tao branda como caa he a do pinho* (Oliveira 1580, 64).

employ the *Carreira da Indias*. To the planking, the author suggests the use of stone pine (*Pinus pinea*) rather than the maritime pine (*Pinus pinaster*). The reason for this selection lays on the anatomy of the stone pine, which is larger in dimensions and harder. The use of pine to the planking is also related to the experience obtained in warmer waters.

To the planking [we] use the pine, because it is softer and its closed [closed cellules] and absence in cracks and do not crack. Its sap allows to a consistent layer which resists to the water and ensures the waterproof. It is also resistant to the infestations since it repels the animals inside and outside. Has it said Vitruuio, it bitters to the sea life. The pine that [we] are talking is the stone [pine], the one that fluoresces the pines that we eat that also provides good timber to the planking, as opposed to the pines with long cones [maritime pine] and pines to eat and having dryer and thin timber which made it only possible to only use in the upper works, (…) masts, and other parts [of the ship] that requires timber having long dimensions, light and absence in knots (Oliveira 1580, 64).

The renovation of the stone pine woodlands was also a cause of concern, as stated by the Fernando Oliveira (Oliveira 1580, 65). Suggesting that those trees should be exclusively employed in the shipbuilding industry and seeded with mature pinions rather than green ones which rotten and consequently waists the opportunity to grow a *good* tree. This observation was based on an event marked by the ordered of the Portuguese king to storage and plant mature pinions. However, this order, in some cases, did not have the desired results by ignorance or sneer, because people use green pinions which rotten when seeded (Oliveira 1580, 65). Moreover, the author stated that if those mature pinions were planted during the maturation of the pine cones, the woodlands would enter in an auto renovation to provide *good* timber to the shipbuilding industry – and

then renovates the woodlands by felling some pines and growing another[64] (Oliveira 1580, 65).

Other tree species were included in the *Liuro da Fabrica das Naos* by Fernando de Oliveira (Oliveira 1580). The author established a comparison between the pine trees (*Pinus pinea* and *Pinus pinaster*) with the firs (*Abies*), cedar (*Cedrus*) and the cypress (*Cupressus*). Although, Oliveira focus in the firs trees, since it has smaller, but similar needles to the pine (*Pinus Pinea*) and the pinecones are round and also smaller than the pine. This tree species has branches *touching the ground*[65], long and straight trunks and branches so curved that *do not enter inside the trunk*[66]. To these trees, Oliveira made a correlation based on the experience obtained in the Mediterranean shipbuilding by stating that: the *Latinos* call it *fusterna*. Considered as not advisable to industry based on the number of knots, roughness contradictory to the requirements imposed in shipbuilding. The anatomy of the cedar and cypress was, therefore, not recommended as the timber logs should be obtained from trees absent in knots and healthy in particular to the planking where water tightness and wood strength was essential. Although, the firs[67] were recommended as a secondary option to the stone pine and maritime pine. The trees grew in abundance in the woodlands of Castile (Spain), in particular in the reign of Toledo and forests of Segovia.

[64] Original (portuguese language): *& assy se reformao os pinhaes cortando hus pinheyros & nascendo outros sem os semearem mays que a premeyra uez* (Oliveira 1580, 65).
[65] Original (portuguese language): (…) *rama atee o chao* (Oliveira 1580, 65).
[66] Original (portuguese language): (…) *ramos tao delgados, que não penetrao dentro do tronco* (Oliveira 1580, 65).
[67] According to the author the Latinos called these trees by faya, but the author disapproves since Plinius the Ancient attributes the qualities stated to the firs and not to the faya (*Fagus Sylvatica*). The timber from faya is dryer, has round leaves and their seed are berries as opposed to the firs more resistant to fire, animal infestations and neither easily cracks made them much more similar to the pines(Oliveira 1580, 65).

The moister of each tree was also subject of concern. The author stated that depending on the soil quality, the trunks may have more air and water and therefore, more permeable to animal infestations and of lower quality in strength and resistance. This analysis and comments evidence the differences between the location of the woodlands and also the location of the tree in the woodlands. To the selection of a tree was recommended to obtain timber from trees located facing the sun are dyer than the trunk and branches in the shadow (Oliveira 1580, 67).

Considerations were made to the plantation and tree selection concerning the place from where timber should be obtained to the shipbuilding industry — the differences between woodlands located in the hemispheres and the woodlands situated in the tropics. *The timber facing the sun is dryer than the other in the shadow as stated by Palladio since the trunk of a tree facing the north is more corruptible than the other side facing the south*[68] (Oliveira 1580, 67). Thus, the woodlands closer to the tropics would take the advantage to start producing sap in an earlier stage in the year; rather, the others where the summer lasted for a couple of months. The proximity to the tropics also would allow the harvest in two periods during the year. These trees were known by having two *deaths* across the year. Although, these trees were not due to employing in shipbuilding as the more suitable trees – the *perennaes*[69] (Oliveira 1580, 70).

On the other hand, to the oaks, it would be desirable to harvest in places having a longer winter period allowing an extended period to the selection and cut. Therefore, in

[68] Original (Portuguese language): *A madeyra qu estaa frente do sol he mays enxuta, que a sombra: tanto q diz Palladio, que em um mesmo tronco dhua mesma aruore, a parte q estaa pera sol he melhor, & a do norte mays corruptível* (Oliveira 1580, 67).
[69] The first fruits fluoresce at a late stage in the year which do not allows a second fruiting (Oliveira 1580, 70).

Portugal, the oaks should be harvest between February and part of March. As opposed to the warmer places which in February trees are already receiving the nutrients[70]. Another consideration was made by Oliveira concerning the leaves. If the leaves started to fall – it is the adequate moment to start harvesting the trees, but according to the author, this process should only start after the solstice, closer to waning gibbous and after the midday. The other trees species (evergreen trees[71]) may also be harvested when the fruits became mature, which corresponds to the reduction of sap flow across the trunk and branches (Oliveira 1580, 70). Similar properties were observed in the tropical woodlands since they Oliveira concluded that in these regions' trees were evergreen. In this way, the author considered that trees planted in these regions having warmer and sunnier exposure and fertile soil, generate *good*, softer more durable. This knowledge refers to the experience obtained in the harvested trees from India – the red angelim (*Dinzia excelsa*), Brazil – the teak (*Tectona grandis*) and Guinea other similar. The cut of these trees would also follow the sun rotation, as they should be harvest during the new moon.

Do not touch the timber on the first or last quarter but after seven days it is possible to harvest/cut. However, it should be stored, or it will dry[72] (Oliveira 1580, 71).

[70] Original (Portuguese language): (…) *mas nas quentes não. Por que jaa em fevereyro começão abrir alguas, & quasi todas jaa então começão a trazer humor da terra, & abalarse, & fazerse tenras & mimosas* (Oliveira 1580, 70).
[71] Original (Portuguese language): *Porem, diz elle, que aquellas que tem juntamte fruyto nouo & uelho, como são o acipreste, pinho, & larangeyra, estas taes tem sempre uez em todos os tempos do anno. Por que parece que sempre tem sua força inteyra, poys sempre mostrão o uigor della, & cursão de continuo sem antrepor ferias de cansaço algum* (Oliveira 1580, 70).
[72] Original (Portuguese language): *Nao toques em madeira no meyo da lua: mas day a sete dias a podes derribar, & cortar: porem guarda nao a laures senao seca* (Oliveira 1580, 71).

Furthermore, trees should be cut firstly to the half perimeter of trunks or branches. After trees being felled, sap must be allowed to drain for three to four days to avoid rotting the timbers. Oliveira also stated not as a requirement but more as a recommendation that timber could be pilled in a way to allows draining the remaining sap – such as the human body that after being injured can only work after being healed (Oliveira 1580, 71). The seasoning revealed to be an essential stage in the process of timber selection since the greenwood can easily cracked and/or rotten. Although, if too dry timbers could be placed in water for a few days to allow shaping. Although, the [cork] oaks should be subject to routine tidal flooding to become harder and even more watertight.

TREE´S MORPHOLOGIES AND THE SHIPBUILDING INDUSTRY.

Lavanha suggested the usage of teak (*Tectona grandis*) and Angelin a tropical wood to build/repair the ships. However, the author reasonably mentioned that this might cause constraints and advocated local tree species such as oak (*Quercus suber*) and Pine (*Pinus*). Furthermore, the same considerations were made about the timber features. Shipbuilders should decide for the oak because of its strength and shape, which seem to be created for this art (shipbuilding)[73] (Lavanha 1625, 26). For the planking should be used stone pine (Oliveira 1580, 63) instead of oak once it is easier to bend and are easy to bend in a way to give the correct shape to the hull[74] (Lavanha 1625, 26). Pinus particular features, according to the author, naturally avoid the infestation of sea life (Domingues 2000, 40). Although, if the vessel is due to be used in cooler waters oak from the north must be used It is way less hard moist than the cork tree for which it is more subject to

[73] Original (Portuguese language): *parece que foram criados para esta arte* (Lavanha 1625, 26).
[74] Original (Portuguese language): *acompanhar todas as voltas do costado da nao* (Lavanha 1625, 26).

sealife[75] (Lavanha 1625, 26; Domingues 2000, 208). In particular, if the ship will sail to Guinea and Brasil. Other tree species were also used however, in less quantity, such as pine, spruce, lerez, cedar, acipreste and black alemo[76] (Oliveira 1580, 65; Lavanha 1625, 28). Nevertheless, the author advised that since the Portuguese vessel travels long journeys, it might be possible for a carpenter to find other suitable tree species for shipbuilding.

Lavanha made another important, yet empirical statement about the wood anatomy mentioning that if the trees have *harder bark rough, leaves and hard fruit have dense and strong wood*[77]. On the other hand, if *Have soft bark, smooth leaves and fruit are trees of porous wood*[78] (Lavanha 1625, 28). If trees grow slowly should be stronger than other fast-growing trees. The heavier *are* denser than the others (Oliveira 1580, 64; Lavanha 1625, 28). Older trees *decay slowly, and the less heart is, the more robust* and *resistant are to sealife*[79] (Lavanha 1625, 28). Trees growing *in open fields*[80] are harder, thick and knotty. However, if growing in the valley or sheltered from strong, the winds are softer, higher and less knotty. Recent wooden shipbuilders also suggested: A tree is the result of five distinct parts: the pith, heartwood, sapwood, bark edge, also known as Libri (Desmond 1919, 7) and the bark.

[75] Original (Portuguese language): *a sua madeira menos dura emais humida que o sobreiro pelo que está mais sujeita (…) ao busano* (Lavanha 1625, 26).
[76] Original (Portuguese language): *pinho bravo, abeto, lerez, cedro, acipreste e alemo negro* (Oliveira 1580, 65; Lavanha 1625, 28).
[77] Original (Portuguese language): *casca aspera, de folhas crespase de fruto duro têm madeira densa e forte* (Lavanha 1625, 28).
[78] Original (Portuguese language): *têm casca macia, folhas brandas e fruto mole são de madeira purosa e mole* (Lavanha 1625, 28).
[79] Original (Portuguese language): *corrompem-se devagar e quanto menos coração tanto é mais robusta a sua natureza* (Lavanha 1625, 28).
[80] Original version (Portuguese): *desabrigadas de bosques, e de montes*.

Besides all of them have an important function on a living tree, when the purpose is to have ship timbers some tree components are disregarded. From the viewpoint of a shipbuilder, the pith gives the accurate understanding of the natural grain and shape of the tree to convert in the timbers. The densest and most durable part: the heartwood. The softest part is the sapwood, where new cells are still open allowing the sap to flow through the filaments, which makes it more vulnerable and permeable. The bark edge is the part that divides the sapwood from the bark and defines the limits of a trunk or branch for the shipbuilding purposes. By understanding different wood characteristics, carpenters may obtain the timbers that they need to use for building a ship. Another fundamental aspect was: which moment was the correct to cut a tree? This may vary from country to country, location to location or even from the dockyard to dockyard and was directly related to the astronomic cycles, which means for instance that in the temperate areas of Portugal some carpenters chose to cut the trees in late autumn immediately after the leaves fall (Castanheira 1991, 1). Other Carpenters (Mestres carpinteiros do antigo *Arsenal do Alfeite* – Master carpenters from the old navy dockyard, *Ribeira das Naus*, Lisbon Portugal) preferred the month of August, especially for the pine (*Pinus pinea and Pinus pinaster*), and the oaks (*Quercus suber*) between October and February when the sap is less active (Valente 1948, 52).

Nevertheless, they could not disregard that the size and exceptional growth of a tree are not an infallible sign of goodness of quality in the wood. The connection of the age of a tree with its development and the nature of the soil in which it grew, ought to be inquired into to enable a judgment to be formed of the quality of the wood (Desmond 1919, 8). This means that characteristics such as durability, uniformity of substance, straightness of fibre, strength and elasticity are fundamental for shipbuilding. However, another

challenge exists: there is no such thing as perfect trees to convert in perfect timbers. The carpenter still needed to find the place in the available raw material where the knots and cross-grained could be avoided. These kinds of imperfections usually represented weak points in the timber structure, mainly because it interrupts the natural grain of the trunk or branch and, in the case of being subjected to high pressures may generate cracks or even worse, the promotion of holes caused by natural extraction of it.

Selected trees should be cut Waning *gibbous*[81] between the autumn and January After giving their fruit and gathering all their virtue and strength[82]. Therefore, selecting a suitable tree for shipbuilding also involved cutting them after *fulfilled their task ends with the absence of sun*[83] (Lavanha 1625, 29-31). Once the selected trees were cut, they must be stored in the field, shipyards or salted water. The author suggested that if these protocols were followed by shipwrights, the ships would last longer rather than using trees cut during spring or summer (Domingues 2000, 333).

Lavanha suggests the usage of timber carefully selected for shipbuilding having great care on choosing quality timbers and the important ones for this art (Lavanha 1618, 26). It should be sour, lean of bitter juice and resin. This because strength and fortitude to have sufficient strength to be employed in ocean-going vessels; Lean moisture to avoid rotten and drained to prevent infestation. Finally, the timber must be sufficiently soft to allowed bending (Lavanha: 1610, 26). It should be hard and dried from the sap and resins. This because hardiness and strength were required to ensure enough strength to the ocean-

[81] Original version (Portuguese): *nos minguantes da lua*.
[82] Original version (Portuguese): *depois de darem o seu fruto e recolhida toda a sua virtude e força.*
[83] Original version (Portuguese): *cumprido (…) seu oficio com o frio causado da ausencia do sol se recolhem* (Lavanha 1625, 29-31).

going vessels; dry from moister to avoid being rotten and drained to prevent infestation. Finally, the timber must be sufficiently flexible to allowed bending[84] (Lavanha 1618, 26).

IN THE SEARCH FOR PREDESIGNED TIMBER ADEQUATE TREE´S MORPHOLOGY.

Fernando Oliveira (Oliveira 1580, 66) stated that certain tree species such as cork oak and pines were well known and approved to the shipbuilding industry. A statement that is directly related to the Iberian Age of Discoveries, in way that the author provides detailed information about the wood requirement to construction and repairing of the *naos/naus ships, were sailing* in regions having an absent of cork oak, pines and firs (Oliveira 1580, 66).

The cork oak has curvy branches which made them suitable to obtain Y-frames, knees and other frames. This curvatures/morphologies allow obtaining the predesigned ship timber that seemed to growth having the required shape[85] (Oliveira 1580, 63).

To obtain the shapes of timbers for shipbuilding, trees must also have a similar shape to the futtock, keel and any other part of the ship. To achieve the combination between the form with the hardiness and natural grain, the carpenter had to have in their mind a clear view of what they wanted to find: Specific natural angles, dimension and shapes. This process may be analysed by looking at the four known traditions of land-use and forest management (Rackham 2003, 3); these are:

[84] Original version (Portuguese): (…) *grande cuidado as qualidades das madeiras e delas escolher as necessárias para o suo desta arte* (Lavanha 1618, 26).
[85] Original (portuguese language): *Tem os ramos tortos, & os esgalhos affeiçoados pera picas, & curvas, & outras peças desta fabrica, de tal feyção, que parece, que sem mays artificio uem nacendo pera isso.* (Oliveira 1580, 63).

a) The plantations where we may find a significant number of trees belonging to the same species and having approximately the same age.
b) Woods which are a combination of different species, ages and might have been intentionally planted.
c) Wood pastures where its growth is directly influenced by the grazing animals;
d) Moreover, finally the non-woodland such as hedges, commonly used to separate fields in different countries, such as the United Kingdom and in some parts of northern Portugal and Spain.

MODERN ANALYSIS ON THE TREES TO A BETTER CATEGORIZATION OF SHIPYARD`S WOODEN RAW MATERIAL.

Timber is related to its easy way (in comparison with metal or stone) to work in any design by sawn, split, carved, planed, moulded, bent and bored. It can be solid for its weight and in general, tough, supple and rarely brittle. It is relatively easy to handle and in the shipbuilding industry is much appreciated by its capacity to float, and its low density (in comparison to water) helps on the transportation through watercourses (Rackham 2003, 163-164). Its poor conductivity of heat, sound and water are also much appreciated for building land structures. Timber is moderately durable and receptive to protection substances such as tar.

Tree´s trunk and branches are made of: (Figure 29):

a) Sapwood (commonly removed when employed in the shipbuilding industry) is a living tissue responsible for the breathing process. It is always saturated with water which during the growing season moves from the roots to the canopy and in

winter stays static along the vessels. The propulsion of the sap upwards may lie in the strands of protoplasm that run through the bordered pits.

b) Heartwood (from which ship timber are shaped) is the result of inactive sapwood, and it is never found in younger trees and new shoots on older ones. It only occurs in the inner and lower parts of older and larger stems and, it is not possible for a stem to comprise heartwood solely. The part of the stem is unable of growth, and it only increases in size and length by the transformation of sapwood into the heartwood. The circular layer on this conversion occurs the general trend of the annual ring despite not being coincident with it. When this conversion occurs, all the sapwood tissues of the sapwood are converted at the same time. The heartwood assumes a darker colour than the sapwood. The chemical changes occur to produce the heartwood may increase the durability of the timber. This process helps the tree to be resistant to fungi or animal invasion.

To understand the structure of these trees, (Mitchell 1974, 19) has said that the vessels and tracheids are conducting tissues forming long, wide tubes joined end to end. Vessels have large plates at the ends with perforations to permit the flow of sap, or sometimes they are joined with endplates at all. Tracheid's are joined by a long overlap and their sidewalls communicate by rows of holes. The fibres of hardwoods are entirely for strengthening, allowing the vessels to be thin walled for better conduction of sap. In softwoods, there are no fibres, and the tracheids have to be strong and thick-walled as well as good conductors of sap. Hence a long overlapping arrangement and small pits in their walls are necessary to permit the flow of sap through thick-walled, rigidly joined cells. The parenchyma is storage tissue, holding reserves of nutrients during the winter when the sap is scarcely

flowing, ready for the time of greatest need, in spring when growth must start before the new leaves and roots are functioning. This chemical process is continually generating new rings year after year as long as the tree still keeps receiving all the nutrients that it needs to be alive. Although, we may observe another chemical reaction in the tree structure, promoted by the cells when they become lignified. This process applies from the pith (core) to the bark and is in a straight line related to the death of the cells. Generating the heartwood, which is much darker, stronger and durable and gives the necessary strength to the structure to allow the tree to grow vertically. At the opposite, the sapwood has a pale colour, less strength and is much more permeable.

c) The bark is the protective layer of trees and in its formed by two distinct sheaths of cells. In the inner part has a thin layer of phloem tissue which conveys the sugar sap from the leaves down to the roots. The outer part is waterproof and acts *purely* as protection.

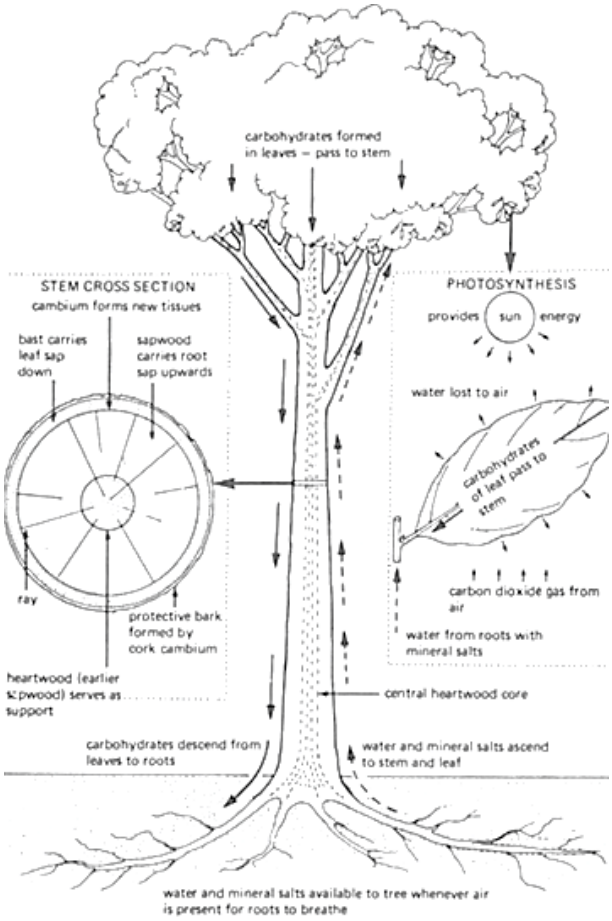


Figure 29 - Chemical compound of a tree (Edlin 1976, 8).

Each region possesses a primitive forest resulted from the influence of several natural factors such as the geomorphology and regional climate variations (Rackham 2003, 97). Shipbuilding in the Iberian Peninsula was for an extended period dependent on the autochthonous forest which consequentially has imposed limitations on the supply of raw material to this industry. To obtain a better understanding of these facts, it was necessary to reduce the area of interest and focus in a particular region. This way, since the present doctoral studies focused on Iberian Shipbuilding, it seemed reasonable to focus the next paragraphs in the Portuguese forest and shipbuilding industry.

The analysis performed on the Portuguese treatises by Fernando Oliveira and João Lavanha provided relevant information about the employed parent trees from the 15th to the 17th-centuries. Although, a further analysis performed in this investigation, aimed to

obtain a clear understanding of the impacts on tree`s growth patterns. To such investigation, a selection of authors was considered to this section of chapter two (CHAPTER 2 – THE IBERIAN SHIPBUILDING TRADITION AND THE WOOD REQUIREMENTS: WOODLANDS, SHIPYARDS AND TREATISES.).

Experts in tree`s anatomy and morphology and forest practice, Herbert L. Edlin (Edlin 1948; Edlin 1976), Fritz H. Schweingruber (Schweingruber 2007) and Oliver Rackham (Rackham 1976; Rackham 2003) were considered as the reference to this. Nevertheless, other authors such as Alexandra Law (Lauw 2011) and Sofia Leal (Leal et al. 2008) were also referenced in this section since conducted their studies in the regions under the theme of the present thesis.

TREE`S MORPHOLOGY.

It is most unlikely to find more than eight orders of branching due to a distinct limit length of life for the most branches. Most probably, even in older trees will only be found about five or six orders of branches (Clapham et al. 1975, 7). Most of the surviving branches apart from the supporting boughs are the leaf-bearing twigs concentrated in the outer shell of a hemispherical canopy. In addition to these factors, if a tree grows close to another having their canopy in permanent contact, both trees will develop a tall branch-free trunk. In contrast, if a tree grows without competition (free-standing tree) to obtain energy from the sun, tends to establish and retain large old branches at no great height from the ground.

Having considered these variables which determine the tree`s growth pattern, three main trees shape variations may be found in the forest/woodlands. This classification was

initially considered (Clapham et al. 1975, 7) as rough-and-ready, but it is still useful to identify the growing patterns (Figure 30):

a) Fir type – this tree shapes have a clear distinction between the main vertical stem and the branches. The branches grow slightly horizontally and may drop down as they became longer and heavier. The main stem overtops all branches and maintains the narrowly conical shape characteristic.
b) Bushy-top trees – the main stem ends in general in a more or less round shape canopy. This tree shape possesses a sharp contrast with the fir tree shape.
c) Poplars – are trees with stiffly ascending side branches which give a thin outline.



Figure 30 - (from left to right) Coniferous forest - fir trees, Bushy-top trees - Oak, beech sycamore and the majority of non-coniferous and Poplars, cypress trees.

The fir and (young) bushy-top tree shapes have branches growing slightly horizontal as a manifestation of what is termed as apical dominance. The growth-controlling chemical substances are produced along the full length of the stem and pass downwards from it in amounts that increase during the growing seasons (Clapham et al. 1975, 7). The top of the stem assumes the highest growth rate of each tree. The differences between the growth rate that occurs between the stem and the side branches happen in part because of its verticality which exerts a chemical dominance over the side branches, making them grow at a different angle from the main stem. As mentioned above (in conifers section of the present chapter), if the tip of the main stem of a fir shape tree is cut off or damaged, one

of the uppermost side branches will turn upwards and take the lead. The apical dominance and vigour of the fir shape trees retain in general for more extended periods than the bushy-top tree shape.

On the other hand, the development of a bushy-top shape tree comprises a round canopy which potentially will trigger a slackening of growth of the main stem and its overtopping by strong-growing side branches which are no longer subjected to the apical dominance. Despite, the internal particularities of trees which determine their shape, other variables also have an impact on the tree growth pattern (Clapham et al. 1975, 10-11). The physical environment has one of the most substantial impacts on the tree shape (Figure 31) such as the:

a) Wind – trees exposed to strong winds have longer branches on the side away from the prevailing wind stream. This impact may be observed in trees having a curvature which significantly bent to one of the sides. These trees may also have a deceptive appearance and lead to a misinterpretation of their shape. In general, these trees have a one-sided canopy/crown which is the result of buds and young branches continuously exposed to the strong wind which drying them out to death and their twigs occasionally snapped off by a mechanical way. The outcome of this is a tree having branches growing out generally on one side and the other the significant or total absence o branches[86].
b) Altitude – trees living at higher altitudes also show evidence of the impact caused by a less favourable environment to grow. Commonly these trees are shorter than

[86] Trees growing by the sea often show on their shape evidence of this negative impact. The wind and salt shape the entire trees because of the desiccating effect of the salt spray which intensifies the absence of branches on the seaside.

others growing at lower altitude once the leaves provide the needed energy in a shorter period of time (shorter growing season) which also explains a thinner annual ring width.

c) Frost and snow – in places where the climate assume low temperatures, as the growth slackens at the end of the season trees such as the oak gradually became hardened for protection against the less favourable weather conditions. However, if the temperatures decrease before this chemical reaction occur, some of the young shoots might be killed by frost, which will have a direct impact on the tree shape. The repeated loss of buds might result in a stunted and misshapen tree, and if the branches are also frosted the tree may come to resemble a much-branched shrub.

d) Lightning – oaks trees commonly are deep-rooted and are relatively large and sometimes standing in isolation which turns them into a potentially damaged tree by lightning[87]. These characteristics comprise a conspicuous deep furrow down of the upper main branches and on down the stem, often having a spiral course. These trees mostly act as a lightning-conductor, once provide an entire conducting path from the top of the tree to the moist soil. In the case of the beech trees, their smooth-barked can (once wet) conduct the energy all over their face provided by the lightning.

e) Animal and human impact – young trees planted in unprotected areas from the animals may rapidly become dwarfed by grazing. Animals by eating young leading shoots and leaves have an influence in shape and growing pattern of these trees.

[87] The energy provided by the lightning flows through the existing moister in the cambium and in exceptional cases the stem may split and/or break the branches.

Humans can also cause a direct bearing on the trees` shape mostly by coppicing or pollarding.

a. Coppicing is repeated cutting of the stem closer to the ground level to generate a stool-shoots which will spring into many slices' vertical branches.
b. Pollarding differs from coppicing in the area where foresters cut the stem, which in general should be about 2 meters above the ground surface.

f) Bark – the interchanges occurred in the cambium may also determine the shape of a tree.



Figure 31 - (from upper left to right) the impact caused by wind, altitude, frost, frost cracks, pollard, abnormalities on bark, lightning, animal, coppicing.

Regarding tree`s morphologies, it is also possible to identify aspects related to the (Schweingruber 2007):

a) Topography: the physical equilibrium of the tree may generate significant alterations on the stem and branches to satisfy their need to grow verticality
b) Mechanical movement: the adjustment made by the tree to grow verticality generates the formation of reaction wood. To satisfy the vertical growth, the tree reacts to stimuli caused by the wind or another agent which might be seen in the root collar or bellow some branches.
c) Geological substrate: to maintain the required verticality and anchorage to the soil trees, the roots must grow, spread or penetrate the soil.

d) Light: this might be the most characteristic feature of trees, and it is deeply related to their need to obtain energy. Tree growing beneath dense crown/canopy produces reduced photosynthesis and consequentially cambial activity.

THE IMPACT OF FOREST PROFILE IN TREE´S MORPHOLOGY.

According to the studies performed (Reboredo et al. 2012; Instituto da Conservação da Natureza e Florestas 2014), it was possible to identify that oak forest after the last glacial period of Würm successfully populated the Iberian Peninsula. From the beginning of the Holocene (11.500 BC)[88], most of the area was populated by deciduous pyrenean oak *(Quercus pyrenaica)* and cork oak (*Quercus robur)*, marcescent[89] Portuguese oak (*Quercus faginea)* or evergreen oak (*Quercus rotundifolia)* and a lesser representation *of* Algerian oak *(Quercus canariensis)*, kermes oak (*Quercus coccifera)* and Lusitanian oak (*Quercus lusitanica)* (Figure 32, Figure 33).



Figure 32 - (from the top to the right) *Quercus pyrenaica, Quercus robur, Quercus faginea, Quercus rotundifolia* and *Quercus suber*.

[88] As an example: in Great Britain between in the Late-Glacial (12000-10000 BC) plants could easily grow in the territory. Trees such as birch (Betula genis), aspen (Populus genus) and (probably) sallow (Salix genus) started to colonize the British Isles. Pines (probably) proliferated in Kent and Hampshire forming a continuous woodland.

[89] Marcescence is the retention of dead plant organs that normally are shed. It is most obvious in deciduous trees that retain leaves through the winter. Several trees normally have marcescent leaves such as oak (*Quercus*), beech (*Fagus*) and hornbeam (*Carpinus*), or marcescent stipules as in some but not all species of willows (*Salix*). Marcescent leaves of pin oak (*Quercus palustris*) complete development of their abscission layer in the spring. The base of the petiole remains alive over the winter. Many other trees may have marcescent leaves in seasons where an early freeze kills the leaves before the abscission layer develops or completes development. Diseases or pests can also kill leaves before they can develop an abscission layer.



Figure 33 - (from left to right) *Quercus canariensis, Quercus coccifera and Quercus lusitanica*.

These dominant tree species has extended over a significant part of Iberia with the constitution of the temperate forests in the northern and central part of the country and, in the south, the Mediterranean forests type where the climate is dryer. In the areas where moister had higher levels or closer to rivers, species as narrow-leafed ash (*Fraxinus angustifolia),* alder *(Aldus glutinosa),* grey willow (*Salix atrocinerea), Salix salvifolia,* black Poplar *(Populus nigra),* silver poplar *(Populus alba), Oleander (Nerium oleander)* assumed predominance over the oak (Figure 34).

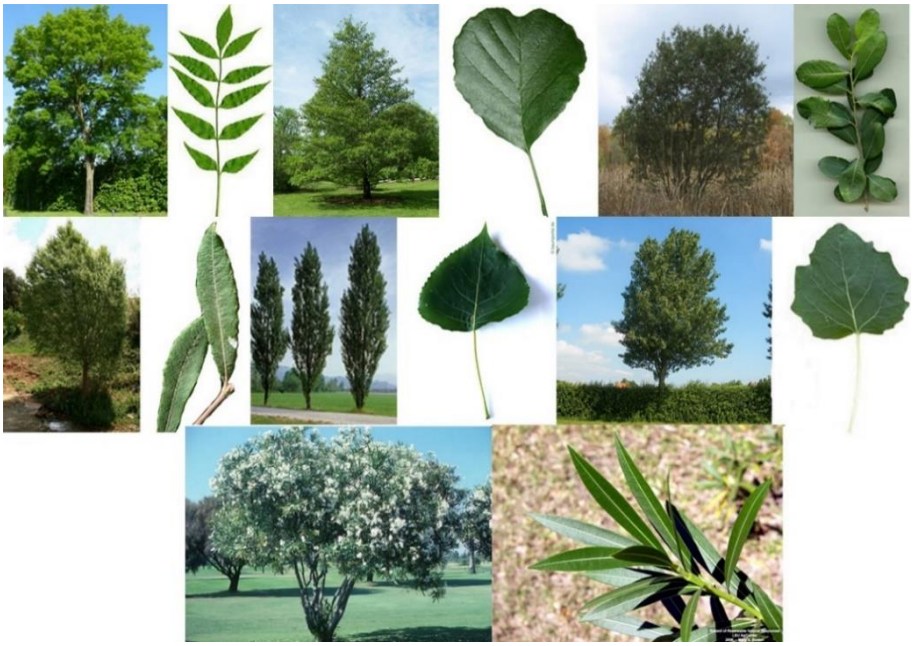


Figure 34 – (from top left to right) *Fraxinus angustifolia, Aldus glutinosa, Salix atrocinerea, Salix salvifolia, Populus nigra, Populus alba* and *Nerium oleander*.

Although among the oaks, other species populated and shared the same geomorphology such as the European holly (*Ilex aquifolium),* common hazel *(Corylus avellane),* field maple *(Acer campestre),* Montpellier maple *(Acer monspessulanum),* strawberry tree *(Arbutus unedo),* Plymouth pear *(Pyrus cordata),* Iberian pear *(Pyrus bourgaeana),* mountain-ash

(Sorbus aucuparia), checker tree *(Sorbus torminalis),* oneseed hawthorn *(Crataegus monogyna) and Phyllirea angustifolia*. Although, other species were considered rare such as the Portugal laurel *(Prunus lusitanica)* and *Laurus nobilis*. This means that the Forest in Portugal was highly diverse and included specimens from several origins (European, Asian, Mediterranean, Mauritanian, Alpine, Iberian endemics) which coexisted in the territory (Instituto da Conservação da Natureza e Florestas 2014).

The Mediterranean climate is characterised by warm temperatures, dry and bright sunny summer but humid and rainy winters. In addition, frost and snow only occur at higher altitudes (Edlin 1945). The Mediterranean climate type enables to farming cereals, vines and olives. Equally, this climate is also adequate to raise flocks and herds of sheep, goats[90] and cattle which production determined the gradual devastation of the primitive forests.

The broadleaved and coniferous trees have particular physical characteristics in the Mediterranean climate forests. Trees growing in this area must be evergreen[91] to operate in the rainfall in the winter and sunshine in the warmer seasons. They also need to be drought-resistant to survive during the long, hot and dry summers. Broadleaves assume a more thick, leathery and waxy leaf in comparison with other growing in colder and moister forests[92] (Edlin 1945). The leaves assume a waxy texture, but as a counterpart

[90] Eldin (Edlin 1945) stated that goats were the principal cause for the destruction of the primitive forests in the Mediterranean region. Goats were the traditional source of milk, cheese, flesh and leather and therefore desirable for economic and social purposes. However, goats kill trees by biting young sprouts within their reach. When kept in greater number shepherds used them for transforming forests into grassy steppes. Grazing is considered as one of the worst agents for the destruction of the forests but there are also other responsible for it such as the fire, erosion, timber harvesting and clearances for arable culture.
[91] Eldin (Edlin 1945) stated that *the evergreen oak restricts water loss by developing a waxy coating over its leaves. These are dark green above with it breathes are situated on the shaded lower surface and their apertures can be readily reduced to lessen the escape of moister whenever the air gest very dry*.
[92] This antagonym may be observed by comparing the *Quercus ilex* from the Mediterranean region with the *Quercus robur* in the Northern Europe (Edlin 1976, 142).

become highly inflammable[93] during their active life. Their growth rate is in general slow and the bark exceptionally thick and waterproof[94].

Coniferous trees in Mediterranean region present similar features to the broadleaf's trees. However, pine trees depending on the sub-species may behave differently, for example, the *Pinus pinaster* as longer needles that readily became in-rolled lengthwise[95] in comparison with the *Pinus sylvestris* from northern Europe. This metamorphosis/adaptation allows pines from the Mediterranean region to restrict water loss from stomata that lie on the needle`s upper surface and the exposure to dry air currents and the thicker bark allows to adequate protection to fire. Timber extracted from the maritime pine is characterised by having more resinous, and it has stronger marked zones of dense summerwood in its annual rings.

BROADLEAVED TREES.

Broadleaves is the name given to those trees which belong to the class dicotyledons. These trees can be distinguished by their enclosed seed-ovules with two cotyledons which are the first leaves within the seed appearing above ground on germination. Their most important feature is the ability to branch in a wide variety of shapes from most of their stems in a highly developed conductive system with large vessels. These trees are not confined to a specific shape as the coniferous. They grow whenever they have

[93] Certain ingredients of the waxes are highly volatile by rising temperatures and might ignite which explains the bush fires. Mediterranean climate broadleaves are remarkably hard – dense wood which can be characterized as close and indistinct annual rings (Edlin 1976, 143). These trees are much appreciated by their main features: moister reduced, solid wood, but considered too heavy for general use.
[94] As an example, the *Quercus suber* has particular features which is commonly harvest for commercial bottle stoppers.
[95] The maritime pine (*Pinus pinaster*) have thicker bark than northern pines such as the Scots pine to avoid moister loss.

favourable climatic conditions as opposed to the coniferous which only grow during the warmer seasons. Sometimes broadleaves also assume the designation of heartwoods and/or deciduous, but according to Eldin (Edlin 1945, 6) this [term] is even more misleading as most of the broadleaves are evergreen trees of the tropical and subtropical zones. Their seed and pollen are carried by insects and other animals indicating a later evolutionary development since their structural, physiological and nutrition methods differ from the conifers.

As an example of the broadleaved trees, the oak trees may be identified in several ways. In the winter, oak trees can be recognised by the pointed many-scaled buds clustered at the tips of the twigs which often present frequent changes of direction. This tendency of a wide-spreading crown/canopy on the open ground trees as opposed to the dense woodlands where they compete with others for the energy made them growing straight (long straight stem). The bark of younger branches is smoother and dark grey, but older branches are thicker, rugged and light grey. The leaves present in general an oval simple shape and delay to appear during the growing season. Oak leaves present a mid-green colour and change to a dull brown in the late summer but slow to fall (Edlin 1945, 35). The male flowers are grouped in knot-like clusters on long pendulous stalks; on the other hand, female flowers are discreet and born in groups of four or five. Oak trees pollination is performed by the wind once only one ovule of each flower develops being surrounded by the enlarging cupule with its roughish exterior, which becomes the familiar acorn-cup

(Edlin 1945, 35). The oak seed[96] is oval in shape, green at first and then become brown having about 2.5 cm long when it falls from the cup.

Oak trees are light-demanding trees (Schweingruber 2007, 28) therefore needs to have an unobstructed *head*. Their *natural enemies* are the insects and fungi although, they are resistant to several forms of harmful influence such as city smoke, salty winds, intense cold, floods, storms and poor soils. Oak trees, despite being a high resistance tree they will only produce *good* timber on the well-drained soils.

The sapwood of oaks is lighter in colour than the heartwood, and it is perishable when exposed to moisture. In younger trees, it constitutes the more substantial portion of the stem, but as it grows, the heartwood assumes the higher percentage of the trees` volume. The heartwood is commonly light brown in colour with distinct medullary rays. This part of the tree is durable under harder conditions due to the presence of tannic acids (Edlin 1948, 37). Oak trees often produce *good* timber at about 120 years of age, but these trees can be left to stand for more than 200 years. Despite oaks can last for more than a thousand years they might cease to expand in girth and any rings *laid down must be quite imperceptible* (Edlin 1948, 39). They can promote growth up to 30 meters and has about 8/9 meters in diameter. In open-ground oak trees, at about 80 years old, the crown/canopy open out in such area that the soil below may often deteriorate by the lack of light/energy.

[96] The oak trees are irregular in its production of seed only occurs scarcely and at varying intervals of years. Their seeds are distributed more or less accidentally by animals and much appreciated by pigs (Edlin 1948, 35).

CONIFEROUS TREES.

The conifers have been called by different names such as pine or fir. They developed separated genus, and the connecting links are rare. These needle-leaved trees are also known as softwoods or gymnosperms. These conifers cover most of the colder regions of the globe. In the northern coniferous forest, the *Taiga* is bounded by the Arctic tundra which is frozen during most of the year. Here the pines bear their needles in groups of two, three or five depending on the subspecies. Pinecones taper to an almost conical shape, and the heartwood only has moderate durability. In the sub-tropical and southern hemisphere, conifers evergreen gains the ability to restrict water loss within their sturdy leathery needles. Some subspecies[97] become adapted to the Mediterranean climate. At the beginning of the growing season each conifer shoot *wakes up* from the winter resting bud as its tip. New shoots are light green and distinct from the dark green of the older needles (Edlin 1976, 133). By the mid-growing season, the shoot has laid down a cluster of resting buds in preparation for a rapid spurt of growth in the next spring. The seasonal shoot extension results in a geometrical pattern of branching. Despite the annual rings, the conifers` growth rate may be observed in each year`s growth is seen as a branchless length between the nodes from which whorls of side-branches originate (Edlin 1976, 133). However, as might be clear on the younger trees it becomes less apparent amid the branches of an old, slow-growing individual. Conifers wood contains no large vessels to carry sap up their stems. This restriction directly influenced the amount of water their foliage can transpire which reason made them develop needle-like leaves. This leaf shape is the most distinctive characteristic of the conifers.

[97] e.g. *Cedrus libani, Cedrus atlantica, Cedrus brevifolia* and the *Cedrus deodora*.

In the case of damage of the leading shoot, the all tree will determine that a side-branch will take the lead and change from the almost horizontal direction to a vertical course. However, if the tree is damaged by the removal of a portion of the main stem, it might never recover from it. This means that the branches bellow the damage will prolong life, but the growth at the damaged tip will not be resumed. Therefore, coppicing should not be a solution to the conifers. Another aspect that incisively affects the conifers is the *impure* atmosphere (e.g. pollution, smoky cities). However, some subspecies made appropriate adjustments to withstand salt-laden winds. The salt cannot pass the stomata, but the gases (sulphur dioxide) can be deadly by poisoning the leaves (Edlin 1948, 72). In the northern side of the Mediterranean, some pine subspecies live in more significant number along with the coastline, in particular, the maritime pine (*Pinus pinaster*), stone pine (*Pinus pinea*) and aleppo pine (*Pinus halepensis*) (Figure 35).



Figure 35 - (from left to right) Maritime pine *(Pinus pinaster),* stone pine *(Pinus pinea)* and Aleppo pine *(Pinus halepensis).*

The regeneration process of the coniferous forest is almost perpetual unless it occurs full destruction of the trees. Male flowers are born each spring abundantly and scatter plentiful pollen on the winds. Female flowers commonly are carried on the same tree but in separated leafy shoots. Most conifers develop resin as a defence against insects or fungal attack. In consequence, their stems and dead foliage are highly inflammable.

One of the largest group of conifers is the pines, having over than seventy species distributed throughout the northern temperate region and subtropical zones. Pine trees may be easily identified by their short-shoots which take the form of a sheath holding a group of needles (Edlin 1948, 94). These groups of needles may vary from species to species which aids tree identification. Young pine trees grow in a rigid pattern and become mature to develop strong, irregular side-branches and depending on the landscape may obtain a crown similar to the broadleaved trees. The bark varies from subspecies but is often very thick, scaly and deeply fissured.

THE IMPACT OF THE SOIL IN TREE´S MORPHOLOGY.

Tree`s natural growth pattern and shape is unique although, groups of trees living in the same area commonly share a few features[98]. Within this environment, two constraints must be explored and analysed, without having a particular order: the soil where trees are living and the climate in which they grow and develop (Edlin 1976, 73; Rackham 2003, 33). By combining these factors, it is possible to identify their organic variables which include the typology, growth rate and shape and even their impact on the establishment of a forest type. In this sense, it is crucial to analyse these particularities carry out this type of analysis before undertaking any activity in the field of forestry (whatever its purpose) (Edlin 1948, 25). The soil is the result of decomposition of rocks in combination with nearby vegetation and climate. In this way, the soil infers on the biogeochemical cycling of mineral nutrients and determines the different ecosystems and habitats. Rock at first is exposed to sun, wind, rain and frost and become cracked and softer which allows plants to take root. Depending on the size of each plant, their roots explore deeper

[98]This concept will be explained in detail within the next subchapters.

in these cracks and slows breakdown the rocks below (Schweingruber 2007, 20). Through these cracks, trees also transport organic matter crowns/canopy down into the soil by the process of root growth (Edlin 1976, 74). Soils are in constant development within an eternal dynamic (Figure 36). No matter how short the time period under investigation is, it is possible to identify soil`s constant transmutation. These changes may be seen in many ways, at the microscopic scale or on a macro scale by studying the climate changes.

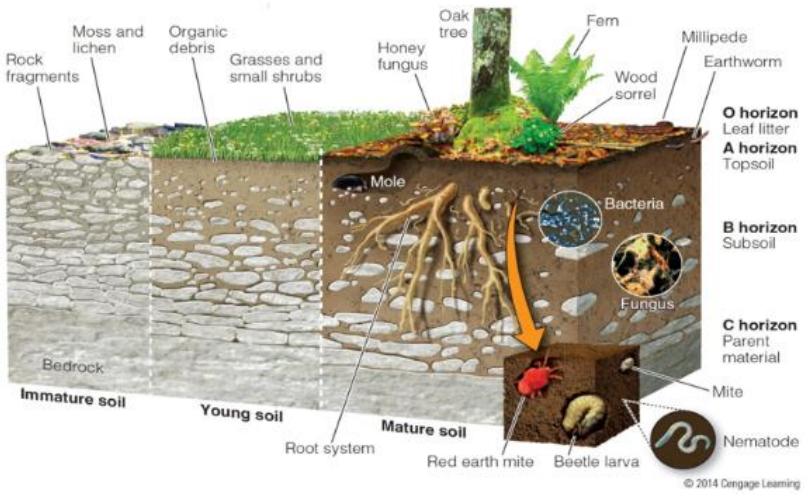


Figure 36 - Soil different stages[99].

The soil is the most visible layer of the earth's crust and includes the mineral salts (dissolved in the interstitial water), living organisms, residues of dead organisms and decomposing rocks. Independently of the distinct types of soils, they are in general composed of four main layers:

a) The first layer is rich in humus and debris of organic origin. It is commonly recognised as the fertile layer essential from which plants find some of the mineral's indispensable for development.
b) The second layer is the stratum of minerals and is divided into three parts:

[99] http://blog.uwgb.edu/env102/files/2014/10/2014-08-06_1015.png assesd at 24th of June 2017.

a. The first part is that of limestone and corresponds to a percentage between 7 to 10% of its total volume;
b. The second part corresponds to the level of clay, usually formed by kaolinite, kaolin and feldspar sediments and comprises between 20 and 30% of this layer.
c. The last of this layer consists of sand and corresponds to the highest volume percentage having an estimated 60 to 70% of the entire tier. It can be characterised by having the most porous layer allowing a greater circulation of air and water.

c) The third layer consists of partially decomposed rocks. As a result of erosion and other external agents, their full decomposition occurs, giving rise to sedimentary rocks.
d) The fourth layer comprises rocks that already started the decomposition process and commonly called the matrix rock.

The development of forests is deeply related to the type of soil. In this way, it is possible to identify distinct usages of the soils depending on the purpose: farming needs fertile soils, but forests can thrive on poor soils. Tree`s roots explore and exploit the soils in which its stem gets a secure anchorage. Therefore, trees and the forest in general influence the soil to an extent degree – *forests not only grow on soil: they help to make it* (Edlin 1976, 73):

a) Loams: are mixtures of varying proportions of fine or coarse grains of mineral matter comprising clay, silt, sand and gravel. Soils of loam type can provide the support of life. The roots can explore between the particles of mineral and organic

matter. The wind is everywhere for the process of breathing and water is available for intake into the tree`s conductive system to support transpiration.

b) Brown forest: in this type of soil trees can grow in a considered *optimum* condition of nutrition. Trees can self-restore nutrients by leaf and litterfall and, the roots can achieve all the required minerals.

c) Blown sands: this type of soil is the result of *land reclamation* by restrained dunes. The sterile sand grains hold enough nutrients to support plant life. However, only particular tree species can live in these conditions[100] due to the wind dynamics, which can blow sand in both directions (horizontally and vertically. Commonly the conifers – *Pinus nigra*, *Pinus maritima*, and *Pinus pinaster* which take root and grow slowly at a younger age and faster in a more mature stage. As their canopy develops, the all tree works as a wind-slower and replaces the brushwood with their pine needles and dead branches, creating a permanent organic cover at the ground level (Edlin 1976, 77).

d) Clays: are the opposite of the sandy soils and in general, are composed of small mineral grains which prove a poor substratum for plant growth — the water and airflow with difficulty which prevents roots from penetrating in the soil.

e) Peats: this type of soil comprises deep layers of dead plant tissues accumulated when climate condition prevent its decay. This is usually due to the waterlogging of the soil so that there is insufficient air for the breakdown of carbon-rich tissue present (Edlin 1976, 78).

f) Chalk and limestone: This soil is strongly alkaline in reaction and poor in water which makes it lack on tree`s required nutrients.

[100] Younger trees and smaller plants can be buried and die by the lack of energy.

g) Podzols: this type of soil on forms on the freely draining land and by derivation from other types of soil.
h) Laterites: this type of soil is the tropical equivalent of the podzol; therefore, a freely draining soil is comprising iron salts which give a soft texture.

Although, trees such as oak trees or elm demand more fertile soils to produce the considered *good* timber. Conifer trees such as pine can develop in minerally poor soils and still produce *good* timber (for shipbuilding). The presence or absence of farms destined for agriculture may provide clues as to the fertility of the surrounding soil, but should not be considered as a determining factor, since soils are not very fertile for agriculture do not necessarily mean poor for forestry, especially for less demanding tree species (fewer minerals demanding). There is, however, an explanation, supported by three facts for this occurrence (Edlin 1948, 27):

a) The tree`s roots may extend indefinitely, and year after year will feed on deeper layers of soil.
b) Trees compete directly with each other and eliminate the weaker competitors. In this way, individual trees will guarantee more space and consequently, more nutrients coming from the new conquered soil.
c) Finally, forests feed on humus, formed by decaying organic matter. The richest humus is provided by the fall of the leaves during the autumn when the nutrients return to the soil from the fallen leaves and branches.

TREES` GROWING SEASON AND WOODSCAPES.

Forest fertility depends on such distinct factors such as the soil physical texture, chemical composition, root depth, drainage, forest practices and cultivation (Edlin 1948, 27). Also important are the available values of phosphorus, potassium and nitrogen. Trees, whether planted by humans or randomly born in the forest, depend to a large extent on the atmospheric conditions that surround them. Rain, sunshine and wind (Edlin 1948, 30) are essential for their growth. It is known that the trees have developed a self-protection system against extreme climatic conditions. However, they still have vulnerable parts such as the branches and the new shoots. One of the most recognises defence mechanism is the fall of leaves which transport the trees to a near-hibernation stage at the end of the growing season. At this juncture, the dormancy allows the trees to overcome the most adverse climates once their nutritional requirements are reduced to a minimum: for example, the amount of water present in the cells is much lower than the number of nutrients. During this stage, the level of growth is also affected by adverse weather, which includes reduced solar exposure as well as the strength of the sun's rays.

In relation to the trees as individuals, they develop a woody perennial stem and depending on these circumstances a single, erect main stem/trunk. This part of the tree provides strength, long life and the direction of growth (Edlin 1976, 5). The starting point of a tree is, naturally, their seed which can assume a variety of shapes, weight and features. The next stage is the seeding which under the warmth of the second spring after it ripened on the parent tree, the seed drew in moister from the soil through its absorbent husk (Edlin 1976, 6). The growth begins with the appearance of a root which promptly turns downwards under the influence of gravity to enter the soil.

Regarding the life process, the tree as in another being (plant or animal) depends on the chemical processes. In this particular case, the chlorophyll gives a green colour to the leaves through a highly complex compound of carbon, oxygen, nitrogen, iron and magnesium. Chlorophyll in the cells of every living leaf can fix carbon, always present as carbon dioxide gas in the air, as solid carbon compounds that the trees can use for energy and growth (Edlin 1976, 9). The photosynthesis is the input of energy provided by the sunlight, which will affect the whole pattern of the tree`s growth. Another requirement for this chemical process is the presence of abundant water[101] provided by the root system, due to the cells of the leaf blade must-have channels available for the free passage of air. The structure is developed in the terminal buds at the recommence of the growing season. These terminal buds are essential for the tree`s growth when related to the leading shoots. During the structure development, the cambium expands in radius to match the growing thickness of the stem. The cambium can grow relatively fast due to its supply of root-sap on the inner face and leaf-sap of the outer face.

The raw material for making new cells reach it in these two opposites, steady sap flows all through the growing season. In a large tree, the rate of cambial activity is adjusted to the size of each part of the trunk of the branch. Woody stems grow thicker in portion to the strains they must bear, and this result in the marvellous and beautiful symmetry and fitting proportions of every undamaged, free-standing tree (Edlin 1976, 13).

Trees, as opposed to the herbaceous, may continue to live year after year at the end of the growing season. Their main stems and branches increase in length and width because of the internal thickening layer or cambium, which adds concentric cylinders of new

[101] The water is evaporated from the leaves which is commonly called by transpiration.

growth towards the outside (Clapham et al. 1975, 6). In the oak trees, young annual rings can be divided into two distinct areas:

a) The inner area side of the cambium endures a chemical reaction to become part of the heartwood. The softwood formed in the spring is in general paler and less hard than the summer wood. This allows to identify each annual ring and therefore be the subject of an investigation by dendrochronology.
b) The outer side of the ring includes the short-lived soft layers. These act as channels to transport carbohydrates and other substances, produced in the leaves and applied in the growth process. Water and other nutrients collect in the soil also flow through these vessels to feed the peripheral part of the tree.

Annual rings[102] will increase in number every growing season (in most of the European trees species used in shipbuilding, each ring equals to one year) depending on the energy collected by each tree (Clapham et al. 1975 6). In fact, a group of trees may share strong similarities/patterns and therefore be used to in wood provenance studies. Although, their shape may have unique features which depend on the way that the main stem and the branch grow. Growth is limited by internal and external factors in which the astronomic cycles have a strong influence (Edlin 1976, 23; Schweingruber 2007, 2). In tree`s structure is reflected in the growth process. By collecting information about the tree`s ring width and comparing, fitting and relating with other specimens/samples *like a puzzle* may allow identifying common patterns of the same tree species. Although, there limits on the dendrochronological analysis such as the comparability of the tree-ring data.

[102] For dendrochronology studies, the tree`s annual rings provide information on two points: climate changes over large areas and, weather conditions in a particular site. However, under a dendro-archaeology perspective the annual rings also may provide relevant information about the age and provenance of the timber employed in shipbuilding.

In many places climate inhibits the tree growth due to a variety of reasons and, on another place of earth, such as in the tropics, the tree does not form regular annual rings (Schweingruber 2007, 24).

The growth pattern of a tree can be observed in several stages of a living tree (Schweingruber 2007, 6). In a young tree having between four and five years of age, a sprout of leaves will grow from large terminal sprout during the spring. Below this shot is located the paired with scars from leaves. The growth pattern of this tree can be identified by the observation of the sequence of the scars. The length of each part of the stem differs from each set of bud scars in from some of which will grow the branches. These ramifications of the main stem have differences within in the growing stages. No auxiliary buds will grow into branches during their first year of life.

In the second winter of life there is the main stem and some branches; in the third winter the main stem with branches and branches of branches – or, in other words, the main stem and two orders of branching. At the end of its tenth growing season, a tree would then have nine orders of branching, and at the end of its 100th season 99 (Clapham et al. 1975, 6).

During the tree`s flowering stage, each shoot opens a cluster designed for wind pollination. However, this complex process assumes a variety of form depending on the tree`s species (see further information below on this subchapter).

FOREST REGENERATION.

The oak trees were considered essential for the regeneration of the forests. These broadleaf species such as *Quercus roble*, *Quercus faginea* and *Quercus sober* have a

relatively slow-growing pattern but requires specific care to avoid the degradation of the soils (Devy-Vareta 1986, 9). In addition, oak trees are considered as light-demanding species; any disturbance on the canopy in dense forests results in a better condition for oak regeneration. If oaks were planted in a dense forest where other tree species were abundant (e.g. beech), the regeneration rate would be slower. On the other hand, if the forests were abundant in oaks, the regeneration of these trees would be faster and in a more consistent growth rate (Annighöfer et al. 2015, 12-13). The growth pattern (as discussed before) of each tree or group of trees is determined by the climate and the landscape/area[103] in which they are planted, but the way trees grow, and the shape they assume depend on even more variables. The oaks are not of dull ubiquity it grows in a uniquely wide range of habitats although, these trees behave differently from place to place (Rackham 2003, 282).

However, the birth of a new forest or reforestation is closely related to the animal life that resides there. For example, frugivorous animals whose food diet lies in fruits, without causing any damage to the seeds. Nature has developed a number of adaptations to ensure that animal dispersal can happen. That way:

a) In the dispersal carried out by reptiles (*Saurocoria*), the fruits usually have an intense odour, red or orange colouring and develop closer to the ground or fall when ripe;

[103] Proximity from the minerals, level of moister, inclination of the of the soil, temperature, energy exposure (sun).

b) In the dispersion by birds (*Ornithocoria*), the fruits do not have an odour, since the animals affected by this type of dispersion have an olfactory sense poorly developed, choosing to identify the foods by the colour;
c) In mammalian dispersal (*Mamalocoria*), the fruit exudes a strong odour and is situated outside the foliage, attached to the stem or close to the ground. In this case, the colour of the fruits does not have high relevance.

The relationship between fauna and flora is significant, and its delicate balance is responsible for the key mechanism in the forest growth cycle. For example, in tropical forests, the percentage of flora spread by frugivores is 90%. That is, only 10% of regeneration is performed using abiotic factors such as rain, wind or watercourses. In this way, avifauna dispersing agents should always be the subject of analysis about reforestation. One group of researchers documented that in places where larger birds had been extinct for more than 50 years, both by predatory hunting and deforestation, palm populations produced only small fruits, while in areas of more conservative forest, and with enough birds to perform their ecological function of seed dispersal, palm trees produced fruits of more varied sizes with small and large seeds (Galetti et al. 2013,1086).

Regeneration of the forests depends on several factors:

a) Wind-pollinated trees: this group of trees contains the alder, beech, birch, hazel, hornbeam, oak, poplar, chestnut, walnut and plane with catkin-like flowers and the ash and elm with flowers in clusters (Edlin 1948, 7). Despite wind pollination is considered as less advanced than pollination by insects, in the case of deciduous trees, it seems to be more efficient. These trees by flowering before the leaves, the wind helps to spread of pollen without having restrictions caused by the

foliage. Broadleaved trees have flowers of one sex only which lessens the risk of self-fertilisation.

b) Insect-pollinated trees: maples, horse-chestnut. Lime and others (not described above) have more conspicuous flowers which petals sepals to protect them, usually have both sexes in the same flower. However, the pollination cannot be affected by the warmer season when the insects are more active. This form of pollination is subject to a much higher risk than wind pollination. While the wind can spread the pollen and seeds for a broader range, insects, on the other hand, are limited to a particular area.

c) Human-interaction: (e.g.) Seeds collected from the oak trees during the later growing season may be stored in a fresh and moister place until the beginning of the next growing season (Edlin 1948, 36). In the oak woods, it is possible to provide a nursery[104] to the main species. This forest self-control can be achieved by planting fast-growing conifers along with hazel and birch or by planting the oaks less than one meter from the others.

FOREST PRACTICE AND TIMBER CONVERSION TECHNIQUES.

Measuring trees is always considered a complex process, although some rules can be employed. To measure a felled tree the trunk is divided into the number of useful lengths which it contains, and each length is considered as a log. For the straight trunk trees, only one measurement is taken from the cut to the maximum useful point – the timber-point, meaning that the total height of the tree is not coincident with the timber height.

[104] The absence of oak forest nursery might result on a slow growth rate in particular, because of the death of new shoots by late frost (Edlin 1948, 36).

On the other hand, standing trees present a much more complex measuring method. To obtain an accurate timber height carpenters need to climb to that point which involves a certain level of logistic support and time consuming when regarding a significant group of trees. These disadvantages can be avoided by estimating the volume of a standing tree (Equation 1) by placing a scale adjacent to the trunk and visually multiply that scale until the timber height (Edlin 1948, 147).

$$\frac{\pi\left(\frac{diameter}{2}\right)^2}{10{,}000} \times \text{length} = \text{volume in cubic metres}$$

Equation 1 - Estimating the volume of a standing tree (Edlin 1948, 147).

Timber is commonly measured in volume (Equation 2) rather than other raw material which the weight is the quantity reference scale (Rackham 2003, 161):

$$\frac{\text{Length (feet)} \times \text{Breadth (inches)} \times \text{Thickness (inches)}}{144} = \text{Volume (cubic feet)}$$

Equation 2 - Calculating the volume *(Rackham 2003, 161)*.

Its value varies with the quality of the wood, accessibility, quantity offered and the current demand for supply.

Regarding the carpenter's need to find specific natural angles, sizes and shapes, there were only two ways to achieve the purpose.

a) By pollarding or lopping which consists in the practice of cutting a tree above the ground between 6 and 15 feet [182.8 cm and 457.2 cm] avoiding to the essential leaves for the photosynthesis to be eaten by animals. (Rackham 1976, 9; Rackham 2003, 3).

   a. This technique may also be seen in a different called by shredding, in which side-branches are continuously cut off, leaving the tuft at the top of the tree — providing precise shapes for converting the tree into the timber.

b) The second tradition is coppicing and suckering, which consisted of cutting the tree at the lower part of the trunk. However, this increases the risk of losing the tree if the animals eat the initial regrowth by preventing the trunk from receiving energy for photosynthesis.

Tree´s value is primarily related to the quality of the timber logs (Edlin 1948, 126-127). Young trees or branches are easily cut out with the billhook, hatchet, hand-axe or bowsaw or by the combination of these tools.

Coarse-grained and knotty logs may only be used in roughest work. The coarse grain interferes with the cut and inhibits a clean-cut and smooth shape. The knots often represent a weak point on the logs and therefore should be avoidable. The shakes also called lengthwise cracks in the trunk follow the medullary rays and if widespread the log will fall to pieces when sawn up. The upsets are caused by a sudden shock such as the impact of hitting the ground when felling the tree. Rotten in the heart which may appear in different ways depending on the tree species. In the broadleaves, rot gains entry through dying branch and therefore damages the higher level of the tree. In the conifers behaves like the opposite once the rot arises from the ground level as the infection occurs through the roots. Embedded iron is also a cause of low-quality timber. If the tree occasionally becomes embedded in the trunk such as iron nails, pieces of fencing or fragments of tools it will increase the difficulty of sawing the log (Edlin 1948, 126-127).

For bigger trees, two people usually need, and they resort to the use of felling axes, felling saws and steel wedges. A note: each pair of tree-fellers is paid by results according to the volume of timber which they bring down (Edlin 1948, 114). Once the tree is down the fellers, proceed to trim out the trunk with their axes and saws (Edlin 1948, 117). The top of the tree is then cut away beyond the point, which is unlikely to provide timber, known as *timber point.* Larger trees are usually sold in full, is the responsibility of the buyer to dismantle and transport. However, the forester must have sufficient knowledge to ensure the care and survival of his forest. Given that, if it is endowed with knowledge as to the cutting and transport of the material, the commercial value can double about selling the whole tree (Edlin 1948, 114).

Trees after being felled lose a significant amount of moisture and become lighter in weight. This process leads to shrinkage lengthwise and along the radius of the log. Although, if left to season in the log, the tangential shrinkage may result in radiating cracks (similar to the shakes). The seasoning of the timber may be achieved by employing one of two possible methods (Edlin 1948, 127). The purpose of seasoning the timber is to ensure the stability of the logs and planks and, therefore, more reliable[105] to employ in building, ships or other structures:

a) Naturally seasoned: the timber is stored in piles in the open air in a way to allows ventilation. This can be achieved by placing each timber perpendicular to the previous, forming a box shape. The seasoning may last months or years until all the moister evaporates and shrinking ceases.

[105] Timber without seasoning cannot be safely cut into smaller pieces, planed or moulded within accurate dimensions due to the risk of wrapping, shrinking or other form of distortion.

b) Artificially seasoned: in this method, the timber is stored in a brick chamber in which the moister and temperature is carefully controlled.

Once the timber is seasoned, it is ready to be cut into the required shape, form and size (Edlin 1948, 131-132). There are many ways of converting logs into timber by:

a) Hewing with axe or adze: considered as the oldest method of conversion and commonly used in shipbuilding. It consists in reducing the round log to a rough square or rectangular baulk by using a specific axe. This tool is flat on one side and bevelled on the other and then with the adze carpenters trim up the surface. Hewing present advantages about the sawing, since the surface fibres are not cut across the downside is that it requires from the carpenter great strength and skill.
b) Cleaving, with an axe, wedge or froe consists in splitting the logs lengthwise along the radius and is commonly employed to prepare barrel staves, shipbuilding (shell-first technology), roofing shingles and fence posts. Cleft timber is very durable and highly waterproof, wherein each timber contains at least one broken medullary ray. Although, this method may only be used in logs provide from trees having medullary rays such as the oaks.
c) Sawing, with saws of many types, is the most common tool in carpentry, and despite the variable design, the principle is always the same. Saws are a group of tiny chisel blades set to run in line one behind the other. The saw teeth are sharped on both sides or just in the cutting face. Some saws also have their teeth bent towards opposite sides.
d) Slicing, by forcing against a knife-blade: this method is mainly used to obtain thin planks having less waste than sawing.

e) Peeling, by rotating against a knife-blade: this method is similar to slicing but in this case, is the log that is rotated against the blade.

f) Turning, by rotating against a chisel: this method may be employed to obtain a certain shape by spinning the timber against a chisel blade.

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CHAPTER 3 – SHIP TIMBERS PARENT TREES: THE PROGRESS MADE TO OBTAIN EVIDENCE OF WOOD MORPHOLOGIES FROM ARCHAEOLOGICAL DATA.

The thesis introduction and previous chapters aimed to transmit the fundaments of an approach in which the employed in the shipbuilding industry is at the centre of discussion. The reason why themes such as forest practices, timber supply, shipbuilding, tree anatomy and morphology were merged into an approach focus on the quest for answers about their relationship. At this point, much has been argued about:

a) The requirements imposed on the woodlands dedicated to the supply of *good* timber to the shipyards.

b) The laws produced by governors to the protection of such valuable raw material.

c) The correlation between existing forest practices and shipbuilding technologies.

d) and, about tree´s anatomy and morphologies and their suitability to the construction of vessels in the Iberian Golden Age of Discoveries.

In this way, it was possible to provide the fundaments of each subtheme discussed in the present doctoral studies and the conceptualisation of a methodological approach to the thesis´ central theme. In fact, it was not considered as reasonable to present a collection of case studies focusing on tree and landscape reconstruction investigations based on archaeological evidence without providing the reader with a substantial and thorough contextualization of its main theme – *Reconstructing Trees from Timber Assemblage*.

Moreover, the merging of the subthemes mentioned above, and their symbiotic relationship revealed to be a herculean exercise, in particular, by its complexity and demanding criteria, triggering the development of new skills and a deep understanding of the approached subthemes. Rooting a deep understanding of these subjects is the key-strategy to the development of a methodological approach in which the ships, the trees and the shipbuilding are at the centre of a combined/integrated investigation. Therefore, every detailed have been analysed within this conceptual approach to reach a better understanding of the Iberian shipbuilding wood requirements and its supply of timber.

Although, the following *step* in this investigation would lack in information without performing an analysis focusing on previous studies and/or contributes to the reconstruction of ship timber parent trees. Therefore, in the present chapter was included in a collection of case studies focusing on the investigation undertaken by archaeologists about tree reconstruction studies. A number of case studies partially mirror the information included in the literature review produced within the present doctoral studies. Thus, considering the relevance of the consulted published work the collection of case studies includes the investigation was undertaken on the remains of the Graveney boat (recording and wood studies), the Skuldelev Barrier (wood section), the Latenium boat (wood morphology analysis) allowed to produce a critical analysis/review of the published results.

By focusing the attention on this work lead by Valery Fenwick (The Graveney boat) (Fenwick 1978a), Ole Crumlin-Pedersen (Skuldelev Barrier) (Crumlin-Pedersen et al. 2002) and Béat Arnold (The Latenium boat) (Arnold 1992). It was expected to obtain

relevant information about the employed methods to identify the record and formulate theories about timber conversion, tree reconstruction and the use of forest resources.

GRAVENEY BOAT POST-EXCAVATION ANALYSIS: LABORATORY RECORDING TECHNIQUES AND DENDROCHRONOLOGICAL ANALYSIS.

The Graveney Boat found in 1970 was jointly excavated by the National Maritime Museum and the British Museum (Throckmorton 1987; Greenhill et al. 1996, 178; Flatman 2010, 8). The remains of the clinker-built hull comprised at about 10 meters in length and 3.5 meters wide. Samples were collected for Radiocarbon dating at the British Museum Research Laboratory (BM - 660; 1080? 40 years B.P.) (Oddy et al. 1972, 30) and later dendrochronology data collected from the strakes matched with the date of 927 AD (Fletcher et al. 1978, 123).

Considerations were made in order to assess, record and recover the surviving timbers. The team of archaeologists adopted the method consisting in the removal of the framing system timber-by-timber preceded by capturing the hull´s morphology using a plaster mould. The obtained imprint allowed maximising the collected information. Once completed, the 1/1 scale mould of the hull took place the disassembling of the strakes. The recovering of the vessel in parts, allowed obtaining a clear understanding of the surviving individual timbers and, also allowing to ensure the protection and integrity of the find (Oddy et al. 1972, 31; Oddy 1975).

The high standard level of success achieved during the excavation of the Graveney boat results in the highly technical publication edited by Valery Fenwick (Fenwick 1978a). Most of the methods employed during the recording and analysis of the boat of Kent are

nowadays still in practice. In particular, the techniques developed by Eric McKee (McKee 1978) resulted in a manual to the recording of boats and ships surviving timbers. The use of the mould to obtain an imprint of the hull was not innovative as it might be read in the Sutton Hoo publications (Carver 2000; Carver 2005; Ruffin 2006). However, the data recorded in the laboratory from individual timbers can be usefully complemented by the data extracted from the mould (Oddy et al. 1978, 17). Team effort to reduce the impact on the structure was efficient once it allowed a detailed recording of the artefacts, salvage and preparations to the reassembling of the vessel´s structure (which have not yet accomplished).

According to McKee, the recording process of the vessel had three primary purposes: site mapping and artefacts catalogue, identify construction techniques employed to build the ship and the production of a detailed manual to the reconstruction process (McKee 1978, 37). Therefore, a detailed recording work plan was developed in which were integrated the following stages:

a) Immediately after the recovering of individual Ship timbers, each timber was carefully wrapped in plastic film and transported to the British Museum or/and to the National Maritime Museum facilities[106].
b) The timbers were then submerged in tanks filled with freshwater with fungicides.
c) At the laboratory, timbers were unwrapped and washed with a brush to remove mud and encrustations to eliminate everything irrelevant, or that would interfere with the tracing.

[106] According to Fenwick (Fenwick 1978, 177) two factors were in the concerns of archaeologists to transport the timbers: firstly, they had to withstand the journey to Greenwich (about 30 miles from the wreck site); secondly, they had to be ready for immersion in water immediately on the arrival at the National Maritime Museum, without being unpacked.

d) After cleaning each timber, archaeologists recorded their features by hand notes, contact tracing, measurements and photographs (McKee 1978, 37).

e) To record timber measurements, each timber was placed on a 10 cm square grid board to set the datum lines. Planks were placed with their inside uppermost and bottom edge towards to the draughtsman and the rib on one of its flat sides with the notch for the keel parallel to the edge nearest the draughtsman (McKee 1978, 39). Direct measurements (length, width, thickness and cross-sections[107]) were recorded on individual timber sheets with the catalogue number and date.

f) The keel and sternpost were too bulky for the grid table (McKee 1978, 39). To obtain its measurements, archaeologists used the datum line on the underside of the keel and the port side of the sternpost from which all the other measures were related (triangulation).

g) After completing the direct measurements record, archaeologists used the same grid as before for the tracings. The timbers were wettened and brought to the table again, where a polythene sheet was placed on each surface at the time and added tension to obtain transparency. On each sheet was recorded the catalogue number and performed the tracings with felt-tip pens[108] (McKee 1978,41). To highlight different features on the drawings, the team used three distinct colours for tracing:

    a. Black to draw the existing features on each face – the edges, fastening holes and tool marks.

    b. Blue to record signs of wear and damages.

[107] Sections were taken using straight edges and set squares with metric graduations (McKee 1978, 39).
[108] Felt-tip pens were trimmed with a razor blade to give a line no more than 2 mm broad.

c. Red to indicate the location of the cross-sections.

h) Ever since an archaeologist completed a drawing, other person cross-checked the entire record in a way to identify possible misunderstandings or errors. Once this stage was considered complete, and the drawings were dried and stored in cardboard tubes.

i) To achieve more manageable tracings, archaeologists reduced them onto 1/10 scale drawings.

   a. This process was performed by using a grid similar to the one used before. Each 1/1 scale drawing was placed on top of the grid, aligned and secured. The 1/10 scale drawing was made on the transparent sheet, which had been fastened over a 10 mm grid on a small drawing board. (McKee 1978, 43). Once completed each scale drawing, complementary information was added to the same document.

   b. The laboratory recording process was undertaken during 32 weeks for the completion of 55 1/10 scale drawings from 62 major parts of the vessel. This effort was considered as *extravagant* (at the time) if compared with the time consumed developing photogrammetric models. According to McKee (McKee 1978, 45), Photogrammetry would have produced only projections, and the work of reconstructing the vessel based on photographs would be even *more difficult*. The usage of recording methods involving direct measurements (Figure 37), tracings, scale drawings as appose to photogrammetry, was considered essential for archaeologists to obtain full knowledge of the individual timbers.

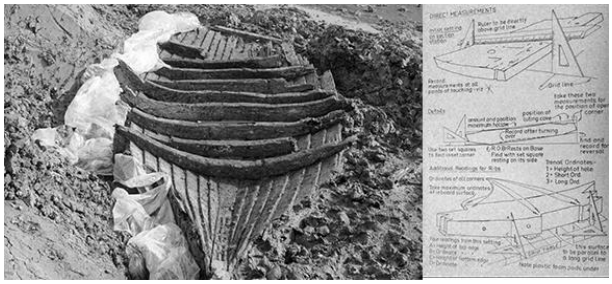


Figure 37 - The Graveney Boat / direct measurements (McKee 1978).

Although, publications (Fenwick 1978a; McKee 1978) referred to a comprehensive recording of the ship timber features. Although the adopted recording strategy did not consider the recording of existing wood features on the timber surfaces. Consequently, the growth patterns and evidence of knots were not subject to record or interpretation and therefore, does not contribute to the study of wood morphologies and its correlation with the shipbuilding techniques.

Associated to the fieldwork and laboratory work performed on the remains of the vessel, a sampling campaign took place in which included dendrochronological and radiocarbon dating. The process comprised a sampling strategy[109] in which: the first stage consisted of the cut of four pieces of about 50 mm wide and the second stage of another seven samples if the previously showed relevant results. Each sample was cut having 19 cm to 26 cm in length and 2.5 cm thickness.

The wood studies also comprised visual inspections to allow acquire relevant data about the employed timber conversion method. This process proved that planking made from oak trees and achieved by radial split using the tangential medullar rays followed by trimming presumably using an axe (Fletcher et al. 1978, 115).

[109] This strategy allowed avoiding unnecessary cutting of the planks, in particular to a shipwreck destined to reconstruction after finishing the conservation procedures.

The first six strakes made of oak trees were subject of a sampling procedure to radiocarbon dating by a cut to obtain samples of about 100 gr each. Thus, several pieces were taken from each plank to increment the level of success by this method of dating. The same approach was taken to the dendrochronological dating method, to allow overlapping equal rings at the different parts of the ship timber, in a way to obtain a better collection of rings series and therefore, a better sequence of annual rings.

To the radiocarbon dating, four samples were taken from tree *A* and tree *D*, which apparently had similar provenance or were the same tree felled to use in the construction of the vessel.

a) Tree A – two planks.
b) Tree B – three planks.
c) Tree C – one plank.
d) Tree D – one plank.

Each result derived from the radiocarbon dating by making two corrections to refine the dating accuracy. The half-life of C14 and the calibration for the fluctuation in C14 and C12 ratio. The chronology derived from this dating method year 926 (with an uncertainty of about +/- 38 years). Although, increased to +/- 51 years associated to the revised half-life and further uncertainty of about +/- 33 years from the calibration which place an overall uncertainty of +/- 85 years (Fletcher et al. 1978, 118-119).

The dating by Radiocarbon indicated a sequence to cover from c. 500 to 960. Within the selected artefacts, there was a discrepancy in date varying from 30 to 113 years, giving a degree of uncertainty to the radiocarbon results. The Graveney Boat had over thirty years

of sapwood which match against the early 9th-century, meaning several decades before the C14 latest date (c. 950) The strakes dated from 875 to 890 ± 5, the frames between 893 and 895 and a presumably reused strake from 978 (Fletcher et al. 1978, 119-120).

To the dendrochronology dating, samples were stored in deep-freeze equipment to allow some evaporation of moisture from the timber face (Fletcher et al. 1978 115). After two, days successive rings were exposed using a razor blade and measured by the scale under a 10X eyepiece. This method yields the following results:

In terms of timber provenance, a sequence of narrow rings was consistent with slow growth rate trees employed to the construction of the vessel. Moreover, as discussed in the radiocarbon dating recorded evidence in tree *A*, and tree *D* suggest the use of the same tree or equal timber provenance. This conjecture relied on the shared 107 years/ring-width between both trees (Fletcher et al. 1978, 115). The number of remaining sapwood rings revealed to be highly relevant since it provided clues about the tree´s felling year. The correlation of sapwood ring average presented by the author to the regions of Southern England and Western Germany placed the last sapwood ring close to year 239 with the felling in 240 (with the uncertainty of about +/- 2 years).

SKULDELEV SHIPS AND THE TEST OF NEW METHODOLOGIES.

Between 1957 and 1962 archaeologists investigated five Viking ships forming a barrier in the Roskilde Fjord, Denmark. The evidence yields relevant information about the vessels and the reason behind the construction of such submerged barrier dated from the 11th-century.

The investigation conducted by Ole Crumlin-Pedersen and his team concludes that the *pile of ships* were deliberately sunk to protect the channel from maritime raiders (Steffy 1994, 108). The entire collection of sunken ships comprised:

a) Two of the vessels were identified as warships,
b) Two cargo vessels,
c) and, a smaller watercraft of unknown function.

The Skuldelev barrier was very different from most terrestrial excavation sites in which, timbers are commonly presenting significant levels of decay or in most of the cases already vanished. In the archaeological site, timbers were softened by the underwater environment but sufficiently preserved to be recorded and studied (Crumlin-Pedersen et al. 2002, 50).

These wrecks were considered as remarkable examples of Viking Age shipbuilding tradition[110] and therefore, subject to an intensive scientific programme for their conservation and reconstruction.

It would be difficult to find any cultural group in Europe or anywhere else, that, like the Scandinavian, can illustrate in so many ways and such detail the history of its ship construction, and thereby that cultural contact with the world outside that is the result of intensive sea traffic. (Ole Crumlin-Pedersen: 1972) (Hocker, 2014, 170).

In 1962, the finest developed techniques of excavation and recording were adopted with a view towards to avoid damaging the timbers. The complexity of the site demanded the

[110] The Skuldelev ships are approximately contemporaneous to the Normand conquest, and its representation would be much similar to the vessels depicted on the Bayeux tapestry[110] (1066 AD) (Gould 2000, 176).

implementation of a cofferdam, surrounding the barrier. Stones and timbers were exposed by using water pumps and waterjets and finally by sediment hand removal. Archaeologists considered this method the most efficient considering of the specificities of the site, in particular, because it formed a *pile of ships and stones in an exposed on a channel with strong currents* (Crumlin-Pedersen et al. 2002, 51).

Scattered timbers and significantly fragmented planking had to be recorded *in situ*. This, in a way to carry out satisfactory results and avoid exceeding time-consuming archaeologists undertake photogrammetrical survey (Crumlin-Pedersen et al. 2002, 51). The process consisted of positioning 32 fixed triangular markers, which were conventionally measured. Artefacts were then photographed during each survey from many angles with one or two dual cameras (Zeiss DK). The method involved capturing at least three fixed markers to plot the measurements into the general plan. Particular photography techniques were disregarded, such as the distance between the camera and the artefacts except for the angles of shooting, which should be either 15º or 30º. The plotting process was carried out on a Zeiss Kleinautograf. This, took place during the post-excavation period and by merging the controlling plans against the photogrammetry, archaeologists find out that the accuracy equals to traditional methods of documentation (Crumlin-Pedersen et al. 2002, 51). The disadvantage of this technique (at that time) related to the delay in the plotting process which determines the inability to check if all sections of the site were covered by this technique and to ensure that all cameras were working according to the required technical demands.

a) The Skuldelev 1 – A large trading vessel was found in 1924 and discussed within a few parallel discoveries known at that time (Crumlin-Pedersen et al. 2002, 49). The

ship has 16.5 m long, 4.5 m of the beam and 2.1 m depth, which made it a deep-water cargo ship (Steffy 1994, 111; Heide 2014, 104). The employed techniques to build such vessel are somehow similar to the smaller craft. Heavy side stringers, carved stem and stern pieces and half-decks at the ends are its main features. The frame system is complex by combining floor timbers and separate side frames. Rather than other Viking ships, the wreck one planking was made of pine while the other structural timbers were built from oak.

b) The Skuldelev 2/4[111] – Based on two samples dated by radiocarbon techniques, the vessel would have been built on the 10th-century as the creation of the barrier itself. At this period, the dating had not yet been established but based on the vessel features was possible to demonstrate for the first time a sequence of cross-sections illustrating the transformation of the framing system in Scandinavian cargo ships from the 11th to 13th-century (Crumlin-Pedersen et al. 2002, 49).
c) The Skuldelev 3[112] - The best-preserved wreck, was reconstructed as having 13.8 m in length, a beam of 3.4 m and a depth of 1.3 m. It was assumed by archaeologists, that the vessel had a crew of five or six sailor's assumption made based on the analysis performed on the signs of wear in the oar wholes.
d) The Skuldelev 5 – A small warship having at about 17 m in length and 2.5 m wide and would have had a crew of about 30 people. The vessel was built from local (Roskilde) new and reused oak, pine, ash and alder dating from 1030 AD.

[111] The evidence suggested the existence of two vessels, but further investigation revealed to be only one ship.
[112] Evidence of remarkable shipbuilding technology has shown advanced techniques in comparison with the older Norwegian vessels.

e) The Skuldelev 6 – A vessel of unknown purpose having at about 11 m in length and 2.5 m wide propelled by oars and a sail. Built mainly from pine, would have had a crew of 5-15 people

On the Skuldelev Barrier:

The position of each timber taken about the internal coordinate system given by each vessel structure[113]. This, the process was designed to be used on sites with wrecks that have been flattened out and which did not contain significant amounts of associated artefacts (Crumlin-Pedersen et al. 2002, 52).

a) Once the timbers were removed from the site, a full-scale recording of each element was performed. This process was chosen in order to help to find patterns for fitting the fragments together. It was also used to analyse the conservation effects on the wooden structure, by comparing the 1/1 drawing of the waterlogged wood against the shrinkage caused by the preservation process.
b) Full-size drawings were performed on limpid drafting folio displayed on a glass plate over the timber (Crumlin-Pedersen et al. 2002, 54). Features were projected directly onto the folio and by using colour codes[114] to record ship timber features. This method revealed to be very precise to draw the planking, but not sufficiently accurate the flattened stakes.

[113] With the keel as one axis and the mast-frame as the other, if no mast-frame was found other timber would assume this coordinate (Crumlin-Pedersen et azl. 2002, 52).
[114] Archaeologists used similar technique at the Graveney Boat.

c) During the excavation, the planking of the Skuldelev ships was analysed by simple visual inspection to identify the tree species used to build the vessels: oak, pine and other tree species were identified at that time.

d) Further microscopic analyses were carried out for a total of 254 samples from the ships at the barrier which confirmed the previous examination. This also gave more detailed data about the tree species used to build the Skuldelev Ships: ash, alder, lime, beech, birch, hazel and willow. The identification of the tree species proved to be essential to categorise the building location as well as repairs and modifications (Crumlin-Pedersen et al. 2002, 56).

e) Wood anatomy analysis has shown that boatbuilders carefully selected trees for the construction of the vessels.

f) The building methods are not uniform across the ships, but regarding the right species, sizes, shapes and quality seemed to be the best option for the purpose (Crumlin-Pedersen et al. 2002, 56).

g) The dendrochronological analysis concluded that annual rings have considerable variations. The average rings on the oak planks vary from 3.2 mm to 0.71 mm and on the pine samples from 2.73 mm to 0.41 mm.

h) In general, the oak planks were radially orientated in the log. This suggests the method of the radial splitting of the parent tree to produce *cloveboards* from which planks were cut and then finished with the usage of axes (Crumlin-Pedersen et al. 2002, 56). A few planks from the Skuldelev 3 were made of a log with a different form of conversion (Heide 2014, 97). All pine planks were tangentially converted. The planks were *evidently* made by splitting it into two halves and

cutting these to plank shapes (Crumlin-Pedersen et al. 2002, 56). Individual elements were cut in a way to avoid cutting across the grain.

i) Archaeological evidence from the Skuldelev ships shows that boatbuilders took exceptional care and effort to build the vessels. Some of the timbers are strongly curved and cut very slender, which required specific knowledge about the timber.

Ole Crumlin-Pedersen also attempted to reconstruct trees based on the archaeological evidence. This approach was taken to identify the construction process of individual timbers.

a) The Skuldelev 1 planking was built from pine of high-quality pine trees (having just a few knots) (Crumlin-Pedersen et al. 2002, 129).
b) Dendrochronological analysis of 14 samples gave the youngest tree-ring between 921 AD and 1025 AD and a high correlation value against the mean curve for samples from Kaupanger and Urnes stave churches in western Norway (Crumlin-Pedersen et al. 2002, 129). From these 14 dendro samples was possible to identify the orientation of the tree stem and most likely that only two planks were processed from the same tree stem.
c) Some of the planks have a curved shape, in particular, the hooding ends which were cut from planks of straight growth as indicated in the cracks in the planks (Crumlin-Pedersen et al. 2002, 129). According to the studies performed on the preserved planking and the analysis made on the ship reconstruction model, it was possible to identify the maximum length of the pine planks needed to build the vessel

d) Based on the analysis and the assumption that only two planks could be extracted from a parent tree, to build the Skuldelev 1 boatbuilders would need:
    a. Three largest trees have a trunk with the minimum height of 10.5 m to 12.5 m and the width after removing the bark of 45 to 55 cm (minimum).
    b. For the hooding ends would be needed six smaller trunks in length having from 2.5 to 4 m.
    c. For the bottom, planking boatbuilders would need curved tree trunks having between 6.5 to 9 m and a minimum diameter of 35 cm.
    d. For the hooding ends and the smallest amidships planking straight tree trunks with a minimum length of 2 to 6 m, and a diameter between 25 to 35 cm would be needed.
    e. For the 18-35 cm wide planks of the lower eight strakes, a total length of ca. 165 m was required on each side (Crumlin-Pedersen et al. 2002, 129).
e) Evidence showed that the majority of the planking integrated the vessel´s hull having the pith location inwards orientated from strake 5. However, from bottom to strake five had the opposite orientation (exception for the hooding ends) (Crumlin-Pedersen et al. 2002, 130).

Regarding the framing timber, it was possible to observe in particular on the Skuldelev 2, that five frame timbers cut from oak trees at the junction from the trunk width a thick brunch and one frame timber was built from a curved tree (Crumlin-Pedersen et al. 2002, 156), which means that the framing system was built within a lack of tree shape consistency.

BATELLERIE GALLO-ROMAINE SUR LAC DE NEUCHÂTEL: THE LATENIUM **BOAT.**

Initially discovered during a reconnaissance flight by M. Michel Egloff[115] in 1970 the very narrow long (182 AD) Gallo-romaine boat. However, a ferocious storm which completely tared the boat apart forcing archaeologists: An unusually powerful storm completely dismantled the boat and the vestiges were able to be extracted from the lake with the limited means then available (the energy of three people, and a private car), requiring a division of the large planks in order to handle them[116]

The reason this case study was included in this chapter is not Egloff´s techniques, employed on the rescue of the Gallo-romaine boat remains, but the pioneer study (Crumlin-Pedersen 1992) developed in the early 1990s (Arnold 1992; Arnold 2011). The archaeologist investigation focuses on finding evidence of construction techniques, boatbuilding tools and timber conversion methods. Arnold also performed an attempt to reconstruct the parent trees from the archaeological evidence, which is the most relevant part of his studies for this thesis chapter.

From Beat Arnold´s study, it was possible to conclude that:

a) On the mast step was possible to identify tool marks made by chisel used to build the step mortise (Arnold 1992, 54).
b) Only in one of the frames was identified tool marks made by a broad-edge axe (Arnold 1992, 55).

[115] M. Michel Egloff – Cantonal archaeologist of Neuchâtel.
[116] Original version (French): *Une tempête particulièrement puissante a totalement démantelé le bateau et les vestiges ont pu être extraits du lac avec les faibles moyens alors disponibles (l'énergie de trois personnes, et une voiture privée), nécessitant un fractionnement des grandes planches afin de pouvoir les manutentionner*.

c) From the timbers faces evidence shown the used tools such as long, square and saws, narrow or wide edged axes, planar or concave edges, scissors the last layer belongs to a drill spoon[117] (Arnold 1992, 55).

d) A substance was used to drive large nails, and a lighter hammer for caulking the nails and a caulking chisel used to insert the sealing material into the slots (Arnold 1992, 55).

e) This vessel led to the confirmation of a previous theory: Roman boat building techniques, profiles and particularities are still being used nowadays (Crumlin-Pedersen 1992; Arnold 2011, 22).

For the present study, the most relevant part of Beat Arnold´s investigation on the Gallo-romaine boat is the method used to identify tree shapes selection, timber conversion and growth patterns (Figure 38 - *Analysis performed by Béat Arnold on timber conversion and tree growth patterns (Arnold 2011, 58-60).*.

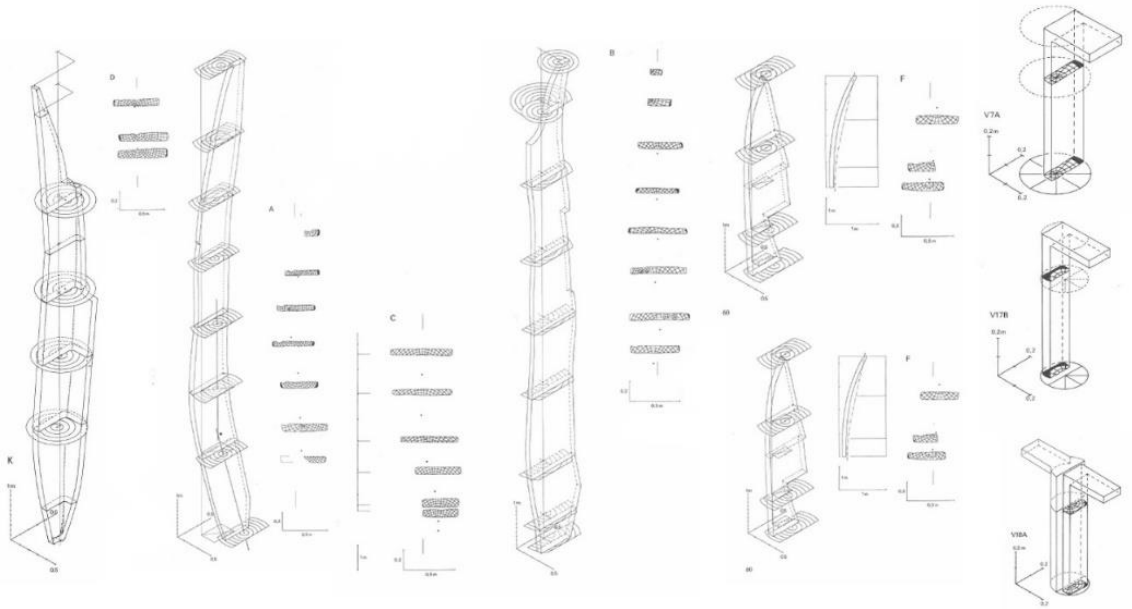


Figure 38 - Analysis performed by Béat Arnold on timber conversion and tree growth patterns (Arnold 2011, 58-60).

[117] Original version (French): *un foret à cuillère*.

The boat was found in an area under the tidal influence in which storms and warmer temperatures would result in its accelerated destruction. To recover the vessel remains, its hull was cut into several sections. This, allowed researchers to investigate in in-depth the wooden features, construction techniques, building sequence, timber conversion and timber shaping techniques (Arnold 2011 22).

SHIP TIMBERS AND THE EARLY ATTEMPTS TO RECONSTRUCT PARENT TREES.

Beat Arnold developed a technique which enabled the archaeologists to have a comprehensive understanding of how carpenters achieved particular timber shapes. The researcher concluded that:

a) Trees were chosen by their shape to be converted into timbers with specific forms. Carpenters used the inner part of the tree stem to build the frames and the outer part to build the aft and forward end timbers (Arnold 1992, 58).
b) The planking was built from oak trees and converted by sawing (Arnold 2011, 25).
c) The *L* shaped frames, or knees were built by carving individual trees to achieve the required shape.
d) Both timbers *A* and *D* were built from the same tree. From these timbers, the author also concluded that part of the curvature of the longitudinal profile was produced during sawing and then by bending of the board (Arnold 1992, 58).
    a. For this process, two techniques might be employed by the boatbuilders: This operation could be achieved either by exposing the board to steam or by submitting it directly to fire, its other face being then kept continually moist. The heating was limited to a very restricted zone, not exceeding a length of one and a half meters, which is why the second hypothesis

should probably be considered. These two techniques make it possible to fold a board without breaking it. It will then be slowly cooled to the desired shape, which it will retain without excessive stresses [118] (Arnold 1992, 58). Although, the author considers the second technique as the most plausible.

e) Both planks *B* and *C* were built either by splitting or tangential saw. In *B* plank, the stem seemed to be reserved for shaping the part of the curling initiating the start of the sheer of the bow (Arnold 1992, 59).

f) The concave shape of the plank *F* was obtained by sawing the required form.

g) Despite the absence of the pith location and most of the heartwood, dendrochronological analysis shows that the parent trees were cut at the same time. This means that timbers were not subject to storage or seasoning, which made them more vulnerable during the construction and useful lifetime of the vessel (Arnold 1992, 61) Equally, the absence of using a maturation technique did not facilitate bending the planks to provide a smooth shape to the hull.

EARLY CONTRIBUTES TO THE RECONSTRUCTING TREES FROM SHIP TIMBER ASSEMBLAGES.

During the excavation of the Graveney boat, a notorious method to the recording of individual ship timber was developed that still is a landmark to the recording of these types of archaeological artefacts (McKee 1978). A remarkable achievement was also the

[118] Original version (French): *Cette opération a pu s'effectuer soit en exposant la planche à la vapeur, soit en la soumettant directement au feu, son autre face étant alors maintenue continuellement humide. Le chauffage n'a porté que sur une zone très restreinte, n'excédant pas une longueur d'un mètre et demi, raison pour laquelle c'est la seconde hypothèse qu'il faut probablement envisager. Ces deux techniques permettent de plier une planche sans le briser. Elle sera ensuite refroidie lentement dans la forme désirée, qu'elle conservera sans tensions excessives* (Arnold 1992, 58).

subsequent studies was the attempt to reconstruct the trees cross-sections by Fletcher and Trapper (Fletcher et al. 1984, 121) and to theorise about the landscape in which tree grew which had to come from trees left to grow to suitable lengths in woods, forests or hedges often coppiced to encourage straight and prolific growth (Hinton 2011, 424).

The publications mentioning the use of dendrochronological and radiocarbon dating (Fletcher 1978, Fletcher 1984) revealed to be slightly confused since it documents a back-and-forward process of dating using both methods within a potential wiggle marching technique[119]. The employed technique or way to transmit results seemed inconclusive as it presents several levels of uncertainty and therefore, different dates for the year/annual ring 290 to which dates were matched with the year c. 500 to 960.

The other aspect refers to the theorisation in turn of the trees employed to the construction of the Graveney boat, by mentioning slow growth specimens from which two timber present similar climate signature or derive from the same parent tree. This result seems to be achieved accordingly to a potential shortage of wood samples collected from the surviving timbers. The limitations imposed by the destination to be given to the timber (full reconstruction of the vessel after completing the conservation process) dictated the sampling strategy by causing a severe limitation on the quantity of available material to analyse. Accordingly, to the consulted publications, no tree reconstruction studies were performed on the vessel´s surviving timber. However, some documentation suggests the use of similar technique between the construction of the

[119] Wiggle matching, also known as *carbon–14 wiggle-match dating* (WMD) is a dating method that uses the non-linear relationship between ^{14}C age and calendar age to match the shape of a series of closely sequentially spaced ^{14}C dates with the ^{14}C calibration curve. A numerical approach to WMD allows one to assess the precision of WMD chronologies.[1] The method has both advantages and limitations vis-a-vis the calibration of individual dates. High-precision chronologies are needed for studies of rapid climate changes.

Sutton Hoo and Graveney boats (Fletcher et al. 1984, 121). A drawing was published showing the likely position of the 400 mm long timber made of oak found in the Sutton Hoo ship. The illustration shows the presumable edges of the tree, the pith and the first annual rings which match against the existent in the oak timber. The raw material used to build both ships (Sutton Hoo and the Graveney Boat) had to come from trees left to grow to *suitable* lengths in woods, forests or hedges often coppiced to encourage straight and prolific growth (Hinton 2011, 424).

Nevertheless, the Graveney boat was fully excavated and recorded in the late 1970s using the existing methods at that time and yet developed recording techniques still in use nowadays. The considered traditional method of ship timber recording method has been widely employed in excavations and a significant complement to more modern digital methods of recording this type of artefacts.

Crumlin-Pedersen´s studies on the Skuldelev ships were *by far* one of the most remarkable investigations until nowadays. His approach was multidisciplinary long before it became fashionable, and he was interested in the opinions of technicians as much as academics (Hocker 2014, 173). The way he conducted research has inspiring generations of archaeologists, and the majority of his methods are still in practice. Crumlin-Pedersen was a central figure to establish maritime archaeology as a valid sub-discipline. After all, from a *pile of ships and stones* (Crumlin-Pedersen et al. 2002, 51) it was possible to make science happen, to create a new museum and to establish an educational, cultural centre for new generations of archaeologists from around the world.

Ole Crumlin-Pedersen left a remarkable legacy through his integrated studies. The employed recording techniques were, in fact, innovative, with the usage of accurate

photogrammetry, precise two-dimensions drawings and wood analysis (which included attempts on tree reconstruction).

Based on the published conclusions by Beat Arnold, carpenters in the 2nd-century were already familiarised with techniques to optimising the forest resources to avoid waste of wood. These carpenters converted trees accordingly with the required shapes in boatbuilding and taking the best possible advantage of the natural trees` growth patterns.

The above-included case studies aimed to provide relevant information about authority publications about the correlation between tree morphologies and ship/bait building. The adopted criteria by Valery Fenwick (Fenwick 1978a), Ole Crumlin-Pedersen (Crumlin-Pedersen et al. 2002) and Beat Arnold (Arnold 1992) provided clues to develop further investigation on tree and landscape reconstruction and their relationship with boat and shipbuilding. Having performed a thorough analysis of the accessed data, allowed to strengthen the acquired knowledge and therefore, continue the present doctoral investigation.

Within the following chapter will be addressed improved techniques focus on the acquiring data about wood morphologies, tree`s growth patterns and their use as a legacy of former landscapes, tree selection techniques, timber provenance and shipbuilding symbiotic relationship with the woodlands/forests. This exercise will be presented within a digital environment, in which methodologies were theorised, developed the studies and a sequence technical procedure were tested and retested.

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CHAPTER 4 – A PROPOSED METHODOLOGY FOR THE COMPREHENSIVE UNDERSTANDING OF SURVIVING SHIP TIMBERS: THREE-DIMENSIONAL TREE RECONSTRUCTION.

The previous chapter aimed to discuss the legacy of earlier studies in maritime archaeology. The associated publications consulted within the selected case studies were analysed in a way to obtain knowledge about the employed methodologies and techniques, but also to identify gaps in acquaintance about how researchers must extract information from ship timbers (Creasman 2010). This conceptual yet philosophical exercise have significantly contributed to the course of the present research and provided a solid contextualization of the subject under investigation. In addition, it has provided sufficient support to the following chapters once it mentioned the doctrine and the fundaments of the employed approach for the present study.

Since the late-1960s maritime archaeologists have been recording artefacts using sophisticated techniques and innovative technology to capture data (McKee 1978; Crumlin-Pedersen 2004; Hocker 2004; Bass 2006; Jones 2009). The recording methodologies may vary but are still the most critical process of excavation. This task usually involves a significant part of the project's financial resources and team effort. The recording of selected timbers (and other artefacts) intend to be undertaken with an exempt of any personal imprints. Having a clear and comprehensive record of an archaeological site and associated artefacts allows separating the evidence from the possible interpretations. These distinct moments allow us to leave raw data for future projects/studies and equally to reduce the level of misinterpretations caused by assumptions. However, the achieved conclusions during the data analysis process are the

result of archaeologist's viewpoint, skills and knowledge but must of all, their own experience(Bass 1990; Bass et al. 2014). Archaeologists across decades have been using the most modern technology for recording. Direct measurements (McKee 1978), stereophotogrammetry (Crumlin-Pedersen et al. 2002), laser scan (Ditta 2014), photogrammetry (Yamafune et al. 2017), and other techniques gain relevance in the development of archaeology programmes for artefact rescue, commercial archaeology and investigation. For example, on different occasions within the last decade, photogrammetry was established as one of the primary options for the recording of archaeological sites. Although the process of creating accurate 3D models based on photographs taken is still under development. As seen during the excavation of the Roskilde Ship Barrier (Crumlin-Pedersen et al. 2002), stated that this technic presented several disadvantages in particular due to the data processing. In the past decades, computers were not sufficiently developed and fast to process large quantities of photographs and identify correlations within it (for detailed information see **CHAPTER 3 – SHIP TIMBERS PARENT TREES: THE PROGRESS MADE TO OBTAIN EVIDENCE OF WOOD MORPHOLOGIES FROM ARCHAEOLOGICAL DATA.**). Nowadays, photogrammetry is being widely used, and significant advances have been achieved as may be observed in the recording and analysis of the Gnalic project (Casaban et al. 2013). Software such as Agisoft Photoscan/Metashape, Rhinoceros 3D (5.0), Autodesk Maya and others were developed for architecture, digital animation and engineering, but yet widely employed for an archaeological investigation. Several projects rely on photogrammetry for the recording of the archaeological site and/or to record artefacts. Laser scanning is also being used for high accuracy digital recording and on some occasions, the 3D digitiser arms. The recorded data is then analysed using a variety of software and exported to the

traditional 2D drawings or a compatible 3D format file. These tools (digitisers and software) may offer an integrated product; however, to obtain accurate raw data, a methodical recording protocol must be employed. Despite the innovative recording techniques, the traditional 2D artefact drawings are still in practice. Using a marker or a laser point to draw in plastic film or mylar is commonly employed in excavations due to the associated financial implications of the 3D recording techniques or by option of the project director (

Figure 39).



Figure 39 - Illustration of a traditional record using a slate and pen to sketch a section of a shipwreck (Troia 1 shipwreck, 2012 (Martins 2014)

These drawings can be remarkably accurate and potentially will be considered as the only existent data for future generations to re-analyse. However, in most cases, these drawings are interpretations and assumptions and not a highly accurate record of the evidence. In the case of revisiting or re-analysing a not preserved or destroyed archaeological site/artefacts, inaccurate and/or incomplete drawings from previous investigations may lead to inconclusive results. For instance to analyse the remains of the Cais do Sodre Ship (C14 – c. 1500), or the Corpo Santo Ship (C14 – c. 1400), or even the Ria de Aveiro A Ship (C14 – c. 1500) it is possible to observe comprehensive and

professional drawings representing the edges of each timber, the fastening and scarfs, and a few tree knots. Nonetheless, these drawings only present limited data about timber as a raw material. Therefore, to develop a theoretical approach to recreate the parent tree's morphologies or any other wood feature, timber conversion method and growth pattern, it would be necessary to re-record the surviving timbers.

The present chapter aims to discuss potential 3D digital recording techniques and methods for data analysis focus on ship timber`s morphologies and tree reconstruction studies. The advantages and limitations of performing these studies will be addressed within the next case studies as examples in which different techniques were employed in order to perform ship timber`s morphology analysis and tree reconstruction based exclusively on the archaeological evidence:

a) The first case study, the French corvette *Bayonnaise* is focused on the usage of photogrammetry in conjunction with Rhino 3D to identify, record and analysis of timber shape and wood morphology and ship reconstruction. In addition, it will also be discussed wood density, flexibility and buoyancy.
b) The second case study focuses on the analysis of the Bremen Ship timbers and the methodologies to extract data related to timber (wood) morphology and shape using 3D digital techniques. Within the study, three strakes were analysed, and the selected planks subject to tree reconstruction studies.
c) The third case study focuses on the investigation performed on the Dutch Indiaman *Batavia* in order to discuss the limitations of the process of tree reconstruction studies.

In completion of the present chapter, a general digital tree reconstruction study and analysis will be discussed in a way to explore the undertaken approach.

1ST CASE STUDY - THE LATE 18TH-CENTURY FRENCH CORVETTE *BAYONNAISE*, FINISTERRE, SPAIN: DATA ANALYSIS TO THE RECONSTRUCTION OF SURVIVING TIMBERS.

In the scope of the ForSEAdiscovery Project, the *Bayonnaise* surviving timbers were investigated during two seasons (2014-2015) in which a section of the vessel's hull was uncovered, fully recorded and samples collected for dendrochronology dating purposes.

This case study was developed focusing on the surviving ship timbers from the *Bayonnaise* corvette built in the French Basque Country, more specifically in the town of Bayonne. Even though the construction technology does not correlate with the traditional Iberian shipbuilding from the Iberian Golden Age of Discoveries, the location of the construction yard had a direct association with the northern Spanish shipyards and the interexchange of knowledge within this region (Loewen 2000, 149-151).

In line with the undertaken approach adopted to the previous chapters, in which each case study was preceded by an overall conceptualization, it seemed justified to include a resume of the historical facts analysed within the literature review produced to the present doctoral studies.

In 1793[120], when the corvette *Bayonnaise* was built, Europe was at war. In France, a sequence of events led to severe political instability and profound changes in the western

[120] After 1782, France built a *new and reinforced* battle fleet at a significant cost. Aiming to gain the control of the seas to assume a superior position against British naval supremacy the shipbuilding industry assumed at that moment a preponderant role in the economy and political situation. Despite, the substantial effort made by the French crown such fleet became unsustainable to mobilise which condemned the project to

social order. During the last decades of the 18th-century, the three major Western European political authorities were managing influences in order to increase naval firepower. War vessels were being developed and modified in Britain to accommodate 90 to 100 cannons and in Spain and France between 112 and 118 cannons. The seafarer doctrine was pressing the development of bigger and stronger ships and having much more firepower than ever[121]. The demands on raw material such as wood and in working power significantly raised the state costs and the pressure on woodlands to consume by the shipbuilding industry.

Within a highly competitive scenario[122], the French *Ministre de la Marine* order in 1793 the purchase of the French corvette *Bayonnaise* to a privateer. Built-in Bayonne, the *Bayonnaise* became famous for having captured a 5th-rate British ship. According to William James (James 1837), this battle was driven by a series of unfortunate events[123]. The British navy questioned how it would be possible the 5th-rate ship with approx. 684 tonnes be captured by a 24-gun Corvette having less than 581 tonnes; when on several other occasions the British navy captured 24-gun corvettes[124] having similar features such

abandon just six years after its beginning. The main reason for this unsuccessful investment was the lack of funds and an inefficient management by King Louis XVI.

[121] For instance, the Bourbon navies symbolised by the new three-deckers and the conversion of the Spanish three-deckers into unique four-decker threat adversaries at sea but weakening internal budget and policies.

[122] The continued battle for control the seas had then many fronts. The British Prime Minister William Pitt mobilised a fleet in 1787 to overthrow the pro-French regime and its influence in Holland, another fleet was also mobilised by Pitt to force the Spanish crown to abandon the seizure against the trading station and shipping at Nootka Sound (Vancouver Island) (Lambert 2000, 150).

[123] Woodman (Woodman 2001, 117) described, in his book, the combat between the 24-gun war vessel commanded by the *Lieutenant de Vaisseau* Jean-Baptiste-Edmond Richer and the HMS *Ambuscade*[123] of Captain Henry Jenkins[123].

[124] The designation of Corvette would have begun in the French navy at the end of 17th century. These vessels were smaller in length than frigates and larger from the sloops-of-war. Early Corvettes had the maximum of 18 meters in length and armed with between four and eight guns on a single deck. These highly manoeuvrable and fast ships grew in size and number of weapons. During the last decades of the 18th century, they had 30 meters length in average and up to 32-guns. The rigging comprised four masts (forward, main, mizzen and the bowsprit). These vessels due to their main features were commonly used for coastal surveillance or to give protection to merchant convoys. In comparison with the British navy

as the *Bienvenue*, *Belette*, *Mignonne*, *Blonde*, *Touterelle*, *Unite*, and *Republicane.* The author suggested a reason that might have implicated to such phenomena:

a) The *Bayonnaise* was at that time transporting 30 Alsace veterans and 120 crew members among other soldiers to the port of Rockford, which significantly would give an advantage in case of close combat or boarding episode.
b) The HMS *Ambuscade* had a crew of 170 seamen complemented with 20 young Marines.
c) In the course of the battle, the HMS *Ambuscade* suffered from an explosion near the gunpowder room, generating a negative impact on the crew's morale and triggered the panic aboard. The French Captain took advantage of this situation, *throwing* the *Bayonnaise* against the opponent.



Figure 40 - Battle between French corvette *Bayonnaise* and English frigate (unknown author).

ship`s profile, a similar vessel to the Bayonnaise would be considered as the sloops-of-war or corvettes. Having 18 cannons in average on a single gun deck and used for coastal patrol, considered small combats and supporting large fleets.

Lieutenant Richer was succeeded in his investee, achieving what it seemed improbable - the capture of the 5th-rate ship *HMS* Ambuscade and the commissioning of the vessel into the French Navy fleet (

Figure *40*).

Although, in 28th of November 1803, five years after this remarkable achievement to the French Navy, the *Bayonnaise* on the route from Havana (Cuba) to Ferrol (Spain)was ran his ship hard aground[125] and set on fire on the beach of Langosteira, Finisterre, Galicia (Woodman 2001, 176).

RECONSTRUCTING PARENT TREES FROM THE CORVETTE *BAYONNAISE* SURVIVING SHIP TIMBERS.

In order to undertake ship timber morphology analysis and tree reconstruction studies to identify the prerequisites in timber supply (required tree morphologies and timber log dimensions) archaeological evidence should be considered as the first source of information. However, when the surviving timbers do not possess enough data, other methods may also be applied. This could involve the analysis of the ship`s construction plans, iconography or descriptive documentation. Circumstances that may be observed in the case of the corvette *Bayonnaise*, which despite the above painting of unknown author, the archaeological remains are very limited in information and no references were found yet referring to the ship`s plans or geometric drawings.

[125] The French veteran ship was at that time being chased by the *Ardent* with 64-cannons, which determined the actions of Leblond-Pleasant. Avoiding the imminent capture by the British navy of the French vessel and crew, dictated by the unbalanced firepower between the two ships.

As result of a substantial lack of information, but in a way to perform an investigation to identify the tree morphologies employed in the construction of the corvette *Bayonnaise*, a selection of identical ships were analysed from the William D. James (James 1837) publication about similar captured vessels[126] by the British Navy ships: *Bienvenue*, *Mignonne*[127] (1797), *Belette*, *Blonde*[128] (1793), *Tourelle*, *Unite*[129] (1794) and the *Republicane* (1794). Which despite having lower yardarms but in general, still resembles with the *Bayonnaise*. In addition to this selection of vessels, the Corvette built in Rockford in 1783 with 22-guns *La Favorite*[130] was also included due to its high similarities to the *Bayonnaise*.

The lack of information about the tree's shape employed to build the *Bayonnaise* imposed an implementation of a key strategy in which became mandatory the development of an accurate 3D digital model of the vessel. In this way, individual timbers (framing and planking) could be extracted from the 3D digital model to identify the required tree morphologies. Therefore, this case study consisted of on a mental exercise to the conceptualisation and theorising about the potential of employing tree reconstruction studies to gain a better understanding of the tree´s morphologies employed in shipbuilding from the late 18th-century. In addition, this case study will also

[126] With 24 long 8-pounds canons on main deck approximately 220 people on the crew, c. 32 meters in length and between 579 and 581 tonnes (Winfield 2008, 173).
[127] *Mignonne* was built in Cherbourg from 1794 to 1797. The ship took part in the Caribbean Campaign under Lieutenant Yset on a fleet commanded by Admiral Luis Thomas Villaret de Joyseuse in 1803. In the same year, it was captured by the captain of the HMS *Goliath* when was sailing off Cape Nicholas Mole (Haiti) during the blockade of Saint-Dominique. The *Mignonne* was renamed as HMS *Mignonne* and recaptured by the French navy off Port Royal (Jamaica) and end its service in 1804 in the same location.
[128] *Blonde* a French 28-gun corvette with 210 crew members and it was captured 1793 serving the Royal Navy under the same name.
[129] French corvette *Unite* was launched in 1794 in Le Havre and captured by the 5th rate 36-gun frigate from the Royal Navy *HMS Inconstant* in 1796 and renamed as HMS *Surprise*.
[130] The *La Favorite* became famous for being used by Cyrille Pierre Theodore Laplace[130] during his circumnavigation.

focus on the pressure exerted on individual and groups of ship's timbers to learn about wood features, tree species characterisation, seasoning technics, conversion methods and growth pattern.

As mentioned before, shipbuilders have had, in general, a deeper understanding of tree`s morphologies and species properties. Carpenter used trees planted in distinctive locations depending on the morphologies required to build the different parts of the vessel. The control of the number of trees planted within an area and the use of pollarding and coppicing techniques are examples of forest management methods, which in fact, can improve timber`s quality (Taylor et al. 2011, 1).

Upstream to the technical complexity inherent to the shipbuilding industry, a number of concerns about wood requirements refer to the adopted options. Carpenters' task involved seeking trees suitable for shipbuilding, characterised by higher levels of durability, uniformity, strength and elasticity. In theory, these trees would also need to have a trunk morphology in direct correspondence to the required timber shape (length, width, torsion, curvature and durability) imposed by the shipwright (geometric plans). Decisions based on relatively empirical knowledge and definitely on the acquired experience would include the following information:

a) (…) *A layer of alburnum is deposited each year, the process of transformation of it into the perfect wood. Otherwise heartwood is slow, and consequently, the alburnum or sapwood comprehends many annual layers.* This *becomes denser as the tree grows aged, and when there is a significant number in a tree of small diameter, the wood is heavy and hard also* (Desmond 1919, 8).

b) *The size and fine growth of a tree are not an infallible sign of goodness of quality in the wood. The connection of the age of a tree with its development and the nature of the soil in which it grew, ought to be inquired into to enable a judgment to be formed of the quality of the wood.* (Desmond 1919, 8).

c) *The oak, for example, raised in a humid soil, is more proper for the works of the cabinet-maker than for those of the ship-carpenter; because it is less robust and stiff, and is softer and more easy to work than the same wood raised in a dry soil and elevated situation: it is also less liable to cleave and split. Its strength, compared with that put forward in drier soil, is about as 4 to 5, and its specific gravity as 5 to 7.* (Desmond 1919, 9).

d) *Wetlands are only proper for alders, poplars, cypress, and willows. Several other species incline to land which is moist or wholly wet; but the oak, the chestnut, the elm, thrive only in dry situations, where the soil is good, and where the water does not stagnate after rain but is retained only in sufficient quantity to enable the ground to furnish aliment for the vegetation.* (Desmond 1919, 8).

e) (…) *trees which grow in poor and stony soils, and generally in all such soils as oppose the spreading of their roots, and do not furnish a supply of their proper sap, are slow and stunted in their growth, and produce wood often knotty and difficult to work, and which is mostly used as veneers for ornamenting furniture.* (Desmond 1919, 8).

f) *Knotty and cross-grained wood is hard to work and should be rejected, especially for use in pieces subjected to significant strains. The knots are always a source of weakness because the straightness of fibres, which gives strength, is interrupted.* (Desmond 1919, 8).

g) *The timber used for shipbuilding should be free from cracks radiating from the centre (called "clefts"), from cracks which partially separate the layers (called shakes), and from sapwood (the light-coloured wood nearest the bark), and should be properly and thoroughly air seasoned.* (Desmond 1919, 9).

The general consensus is that juvenile wood is undesirable for products requiring stability or strength. Bigger, faster growth is not better growth for all forest products (Senft et al. 1985, 482).

Despite Desmond's contribution to a better understanding of the timber and tree's requirements, it became mandatory to analyse contemporary information to the construction of the *Bayonnaise*. The knowledge transmitted by Desmond's legacy is relevant regarding the understanding of tree's properties and their application in the shipbuilding industry. This author stated in the early 20th-century about the ideal timber properties, but at that moment, shipbuilding was already at a significantly advanced level of technology (if compared to the *Bayonnaise* building date). Some aspects are for this reason, not applicable to the study of the French corvette.

On the other hand, Juan Jose Navarro's book (First Marquis of Victoria) was, therefore, analysed as one of the potential references\sources for the late 18th-century shipbuilding technology. Navarro's document (Navarro 1756, 21) provides detailed information about how ships were built during that century and included sketches of wood as a raw material in its bearish shape. These illustrations also comprise the most important timbers from the vessels framing system. In the author's drawings, it is possible to perceive sections of the keel, floor timbers, Y-frames, futtocks, beams, stringers and deck knees and which shape timber logs would need to have to meet the requirements for this industry.

The following figure (Figure 41) shows the raw timber having an adequate morphology after trunks and branches were already roughly shaped according to the design requirements but meeting the tree`s natural shapes and growth pattern (Aizpuru 2003, 15). In the drawings, small branches were not considered. Presumably due to the representation of the timber logs already having ship timbers rough shape. Providing the idea of a previous bark and sapwood removal, to avoid fermentation of the sap and consequentially wood deterioration (Valente 1948).

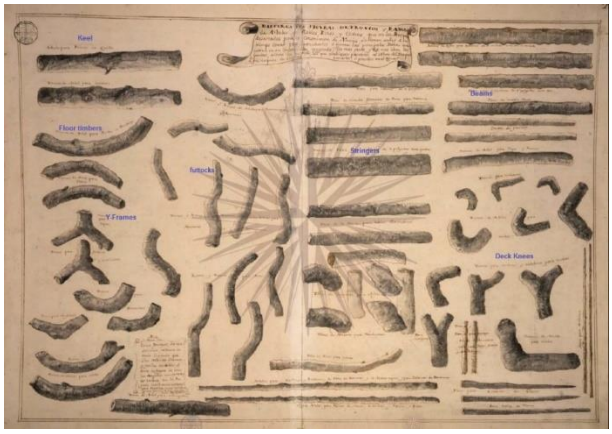


Figure 41 - *Diferentes figuras de troncos y ramas de árboles para dar una idea de saberlos apropriar a todas las piezas que entran en la construcción de un navío* (Navarro 1756, 21).

3D DIGITAL RECONSTRUCTION OF THE *BAYONNAISE* AND THE ARCHAEOLOGICAL EVIDENCE.

Ships were built following an idea or a purpose (Steffy 1994, 5); however, that purpose would change when required. The corvette typology was characterised by having around 30 meters in length, lightweight and fast sailing, which made them ideal for patrolling the coastline and engaging small battles (raids). Although these vessels may have been transformed and adjusted depending on the captain's mission. Apparently, the number of guns on board may also vary as well as the crew (Winfield 2008). Some examples of the so-called adaptations can be observed in ships as:

a) The *Republicane* and *Bayonnaise* are examples of ships built by privateers and commissioned by the French Navy as war vessels.
b) The *Unite* was operated under French captains with 24 eight pounder and eight 4-pounder long guns. After being captured by the HMS *Inconstant* changed to 32 and ten 18-pounder carronades and two 4-pounder chase guns.
c) On the other hand, *Blonde* after being captured kept the 28 guns.

These mutations suggested that the hull structure and eventually, the rigging had to be readjusted or reinforcement according to the *new* purpose of the vessel. The increase of firepower in number and weight would necessarily cause tensions on the ship structure and consequently, increase the risk of floods by the cracking the of joinery between the planks and the framing. Plus, increasing the crew in number as in the HMS *Surprise* (*Unite*) from 172 to 220 crew members would force the captain to make decisions on the hull´s available room for supplies, ammunition and undifferentiated cargo.

In order to perform wood morphology and tree reconstruction studies, it would be preferable to use both archaeological evidence recorded from the *Bayonnaise* surviving timbers and archival information. However, and considering the lack of data available about the *Bayonnaise* geometric plans, the corvette *Le Brave* was used as a substitute (Figure 42). Both vessels were constructed following the same technology and to the same purpose[131]. This vessel was built in 1797 (five years after the *Bayonnaise*) in Nantes relatively close to Bayonne, had c. 27 m in length, 33 m in max. length on the gundeck and approx. 10 m max. width. In comparison, *Bayonnaise* had 38 m in length on the gun

[131] The *Bayonnaise* and the *Le Brave* were built by privateers (Winfield 2008) and requested to serve in the French navy.

deck (plus five than the *Le Brave*) and same width against the other vessel and had two more French 8-pounder and six 6-pounder cannons (Winfield 2008). This comparative study made possible to establish a pattern between ships and began to investigate relevant information about the *Bayonnaise*.

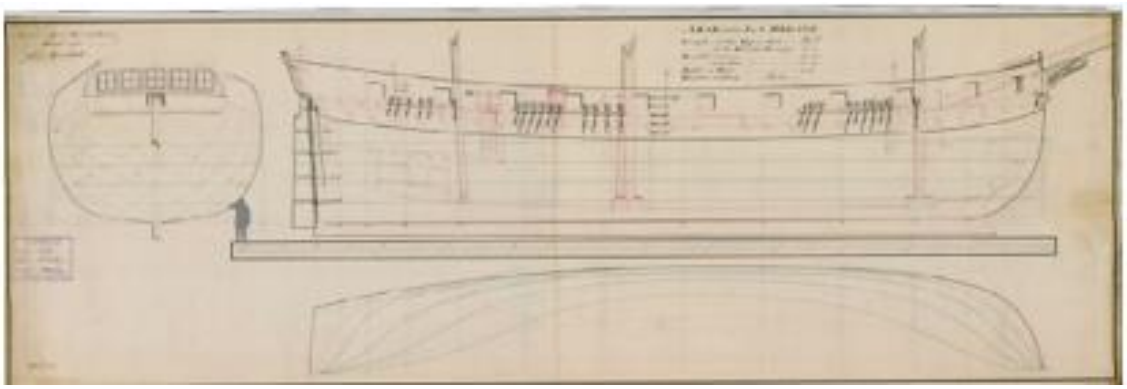


Figure 42 - Ship geometric drawings[132] from the corvette *Le Brave* 1797[133].

The plans (Figure 1) have shown that the ship´s profile for this topology has a relatively short depth in comparison with bigger ships as frigates and others. The water line has a maximum of 3.93 m on the after (from the outboard face of the keel) and 40.6 m on the bow. The full hull height (including the aft castle) is 7.47 m and 6.68 m on the forward face. The rigging comprised four masts – the mizzen, mainmast, foresail mast and the bowsprit. The first two having the mast step moved to the aft from the mainframe and the foresail mast closer to the stem post. It seems that the three vertical masts have their mast step on the keelson and the bowsprit caught on the anvil closer to the foresail mast. These three-deck ships had the cannon hatches immediately below the handrail. Such corvettes had three decks – the main deck or gun deck, two lower decks and the bilge. The main deck concentrated the forced labour such as dealing with the rigging and cannons and an all range of tasks. The first lower deck accommodates the cabinets for

[132] https://collections.rmg.co.uk/collections/objects/83586.html (information accessed in June 2019).
[133] https://threedecks.org/index.php?display_type=show_ship&id=19373 (information accessed in June 2019).

passengers, officers, part of the crew and the kitchen. The second lower deck accommodate another part of the crew, cargo and commodities. Underneath the lower deck was the bilge where the ballast and heavy cargo was accommodated.

According to the investigation based on geometrical plans, it was possible to conclude:

a) The turn of the bilge is located at 15.55 m from the far end of the keel (stern), and it has a 0.78 m height from the outboard face of the keel until it turns.
b) The mainframe is located at 15.47 m from the stern and 11.97 m from the forward face of the keel.
c) Hull´s maximum height is 7.71 m from the outboard face of the keel to the handrail on the stern and 7.56 m on the forward face of the keel to the handrail.

The 3D virtual reconstruction of *Le Brave* as a *Bayonnaise* identical vessel, allowed to develop digital techniques to identify potential tree shapes based on the ship geometric plans. These lines produced by shipwrights determined the shape of the vessel according to with its purpose and consequently which type of timber, carpenters would have needed to find in order to meet the required hull shape and match it with the established plans. According to this method, by constructing *Le Brave´*s hull using a 3D engineering software such as Rhinoceros 3D, individual hull´s timber can be reproduced following the same plans. Once the model is completed, each timber can then be extracted and analysed to identify its potential parent tree. In this way, tree reconstruction studies allow demonstrating the tree shapes required to build the *Bayonnaise.* Based on the knowledge that no tree has an exact match to its position on ship's hull, these timbers would need to have been bent to fit in its place. Although, carpenters have tried along the time taking the maximum advantage of the growth pattern to obtain the required shape.

It also became apparent that shipbuilding techniques and technology during the late 18th-century have reached a significant level of complexity. Due to these demands, the empirical knowledge that carpenters possessed about trees and wood morphology assumed even higher relevance.

To understand how these corvettes were built, the research led to developing methodologies, which allowed to reconstruct the vessel based on the plans found in the Royal Museum of Greenwich[134]. The method involved using Rhinoceros 3D 5.0 and merging the plans into the software (Figure 43). The process started by scaling the drawing with the known dimensions of a corvette (*Le Brave* as an identical ship of Bayonnaise). After setting up the correct scale, Rhinoceros tools were used to reproduce the ship plans main lines, such as transversal, longitudinal and tangential. These lines provided the curvature of the framing system from the aft to the forward part of the vessel. As known the shipwright transversal cross-section drawings, have the forward on the starboard and the aft on the port side. Each transversal line or frame was found after multiplying each one and rotate the replicate them to the other side. As an example, the first aft frame line was replicated and mirrored on the port side.

[134] http://collections.rmg.co.uk/collections/objects/83586.html

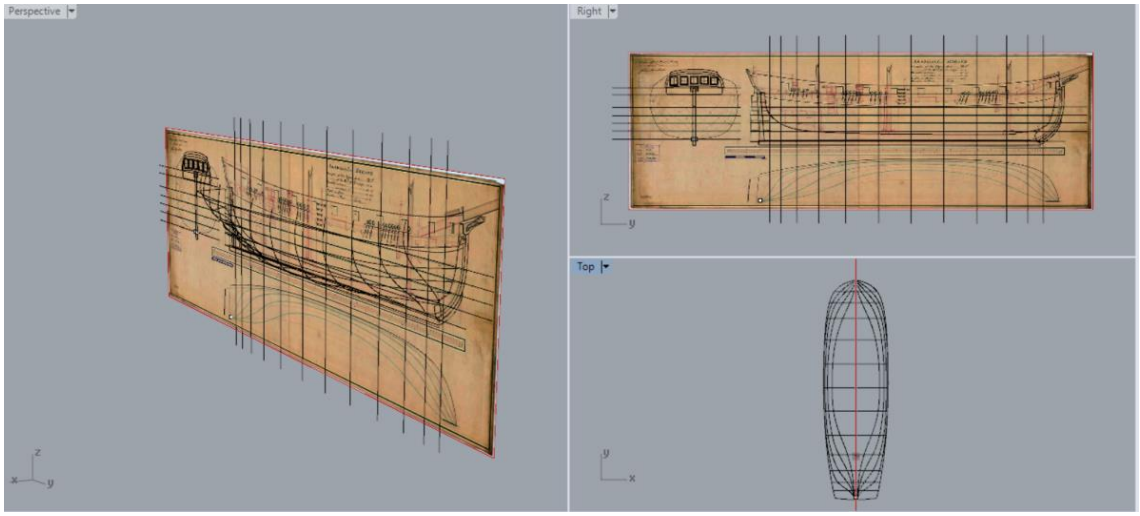


Figure 43 - Illustration of the developed method to the digital reconstruction of the French corvette (drawings by the author).

The second task was to find the tangential lines which define the turn of the bilge and the width of the ship´s hull. This exercise provided the corvette hull shape (Figure 44). By following this technique, it was possible to achieve a 3D digital model of the ship from the 2D ship plans.

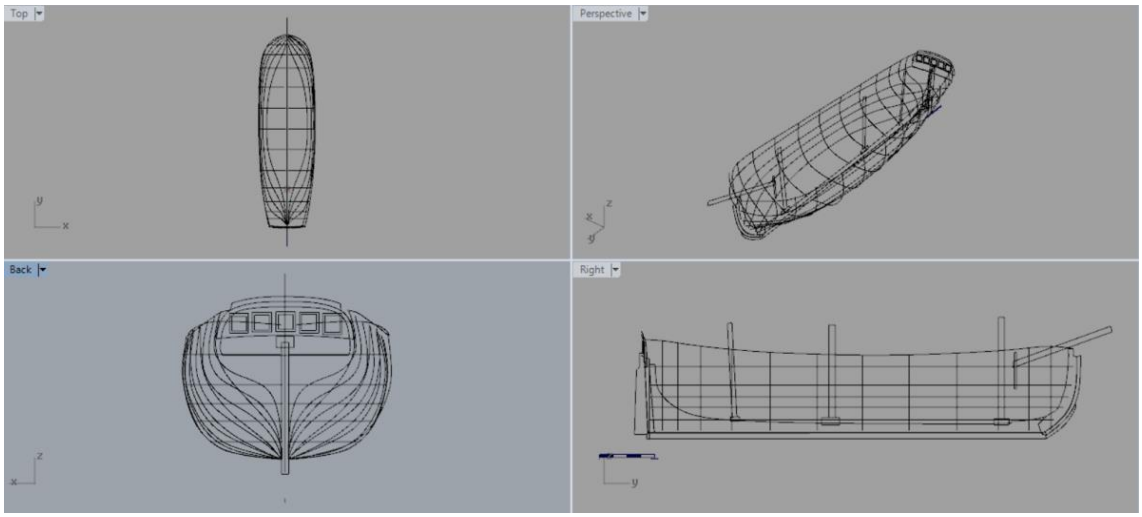


Figure 44 – End-process of identifying the turn-of-the-bilge and the position of each predesigned frame (drawings by the author).

The next step was to find the thickness of the sternpost, stem post and the keel. The drawing has shown the angles on the tangential cross-section drawing and the thickness on the tangential. By matching both, it was possible to achieve with reasonably accurate measures the height, length and width of these timbers. The positioning of the

transversal lines was completed by following the instruction on the plans. Small dots show where the transversal lines should be displayed and where it meets the tangential lines. Furthermore, obstacles and challenges were experienced regarding wherein the model; the tangential lines should meet the stern and stem post. On the bow, a centre line that follows the stem post defines the encounter of the tangential lines on the far end of the bow. On the after part of the vessel, the central line only defined where the first four tangential lines should meet (from the bottom to the handrail). To find the last two was needed to replicate the first frame from the after to the forward face of the vessel, to achieve the corvette dovetail. This process consisted of in scaling the lines with the plans and rotating in a way that encompasses the angles described on the plans which would follow the tangential lines in length and angle. These procedures ended with the scaling of the 3D digital model at a 1/1 scale. The produced lines helped to identify the dimensions of every other part of the hull. In this way, it was possible to conclude that the keel has 27 m in length (as stated in the ship's plans as well as heights, widths and lengths of its framing system). These dimensions were also re-checked by merging the accurate Photogrammetry produced from the surviving timbers with the 3D digital model based on the ship's plans. The result was an acceptable accurate correlation between archaeological and archival sources (Figure 45).

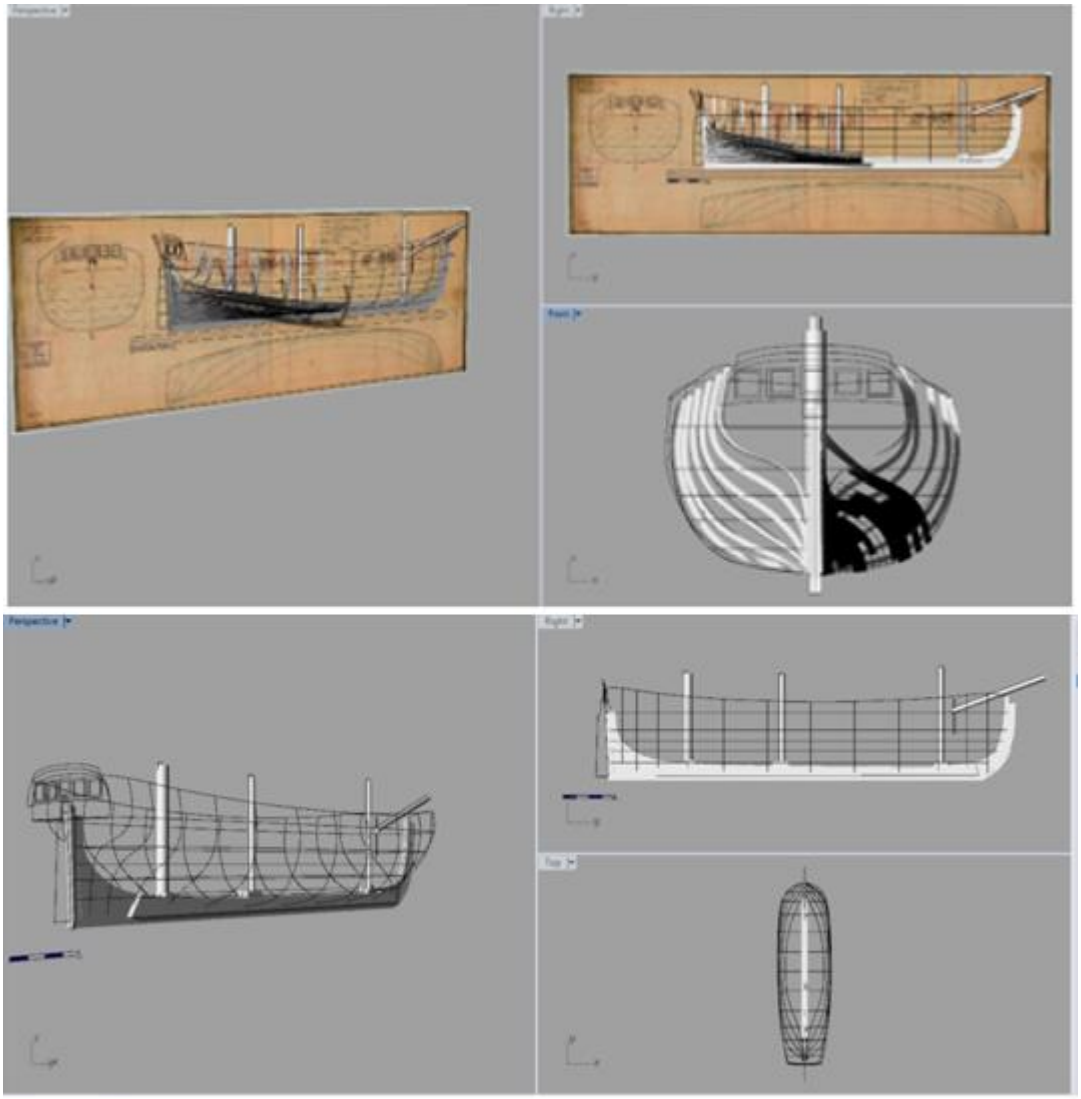


Figure 45 - The picture above the method of converting 2D ship plans into a 3D digital model by (drawings by the author).

Next step was to analyse the distortion of the hull planks. Based on the data collected on the *Bayonnaise* shipwreck, the hull planks have an 8 cm width between 20 cm and 21 cm height and unknown length. The produced model has an 8 cm width on each plank and c. 20 cm of height. The first built planks were in the after higher part of the stern on the port side. A 2D section has been constructed with these measurements and positioned on the limits of the first transversal line from the stern. Due to the distortion generated by the turn of the bilge, each timber model (plank) needed to be created in four steps. Rectangles with 8 cm x 20 cm were displayed on each end and positioned according to

the angle of the transversal lines. From the handrail to the keel, the rectangle merges in a way that would reproduce a carvel build hull shape. The third task was to link each of the four ends of each rectangle with a line from the stern to the bow. Finally, with the Rhino 3D tool designated by *Surface1rail* generated the surfaces made of the virtual outer hull planks and added it a wooden texture.

The 3D digital model produced following the above methods allowed to gain a clear understanding of the demands imposed on the raw material (Figure 47). Tree's would need to be chosen to meet the length and width of the required angle defined by the ship´s plans. In this way, it became possible to visually and geometrically observed a pattern on the trees felt to build the Bayonnaise.

DEVELOPED TECHNIQUES AND EARLY CONCLUSIONS.

The investigation undertaken at the *Bayonnaise* wreck site involved digital 3D recording techniques and the visual assessment of the surviving timbers to collect data about wood morphology. In addition, samples were collected following a protocol (Domínguez-Delmás et al. 2018) by cutting a slice of the selected timbers for dendrochronological dating and wood provenance studies.

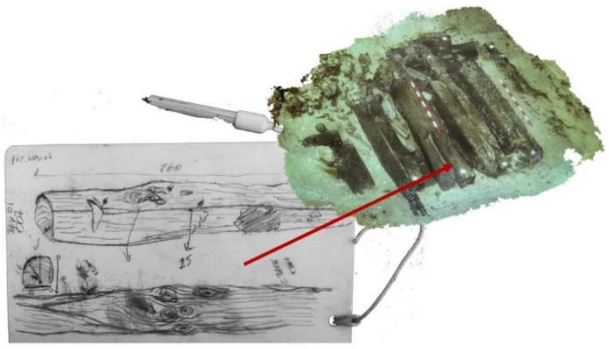


Figure 46 - The image illustrates the photogrammetry produced from the *Baynnaise*`s *Area 1* wreck site. This section of the hull was initially dredged and recorded using direct measurement and digital techniques. Samples were collected for wood identification and dendrochronological studies. The sketch illustrates

timber no. 007 recorded on the site where it possible to observe parts of the parent tree morphology (knots and natural edges). (photogrammetry and sketch by the author).

The working plan included the following stages:

a) The site was assessed to perform a visual survey to update the existing records about the sedimentation and erosion levels.
b) A significant area of the hull, known as *Area 1*, was dredged to expose the ship´s timbers allowing to perform an accurate recording.
c) Photographic record and sketch of the visible areas of the ship´s hull.
d) Timber recording included dimensions, evidence of shipbuilding techniques, wood characterisation and cataloguing. Photogrammetric of *Area 1* was also made at this point.
e) A visual assessment focus on the timbers allowed to collect information about wood features such as ring width average, wood anatomy, timber function, dimensions and other details to identify potential sampling candidates.
f) After completing the full recording and sampling process[135], the wooden structure was covered with sediment to avoid deterioration of the timbers and proliferation of microorganisms.

Based on the archival investigation undertaken on the available documentation:

a) Selected trees (growth patterns) had a direct correlation with the predesigned timbers.

[135] From this fieldwork were collected ten samples of unknown timber provenance is still remained unknown (Domínguez-Delmás et al. 2015, 1). However, the information collected *in situ* allowed performing wood morphologies and 3D tree reconstruction studies along with the existent information found in archives about *Bayonnaise*.

a. Standing trees having numerous knots\branches along the stem were disregarded to avoid weak point in the ship timbers.
b. Timber`s parent trees were felled, and their bark and sapwood immediately removed to avoid sap deterioration.
c. *Bayonnaise* ship timber was subject to seasoning to achieve higher hardened levels of durability.
d. The planking was subject to bending techniques by fire or steaming, allowing to provide the required shape to provide the predesigned profile to the hull.

a) Based on the archaeological evidence was possible to identify:
    a. Each set of double futtocks was placed at a distance of about 16 cm from the next.
    b. Each futtock has a width of approx. 21 cm, height of 20 cm, but the length is unknown due to the low level of preservation of the surviving timbers.
        i. Due to the low level of timbers preservation was not possible to identify the maximum length of each futtock. All framing timbers have been infested by *Teredo navalis* and therefore, despite keeping the original shape present various weak point caused by the worm.
    c. The pith location (first annual ring) on the recorded timbers is mostly located at the edge of one of the faces.
    d. Within the recorded timbers was possible to identify a fast-growing pattern.
    e. Several knots were identified along the futtocks.

f. The growth pattern is consistent with the timber shape orientation.

g. Parent trees natural edges were found in most of the recorded timbers which seemed to be correlated to the heartwood – sapwood boundary.

h. Frames were having 21 cm width and 20 cm in height (although, the length is still unknown).

i. Features such as thickness, length and height of the hull planks were not yet identified.

j. According to the dendrochronology report produced by Marta Dominguez-Delmas and Ignacio Garcia González (Domínguez-Delmás et al. 2015, 1), on the collected samples from the selected timbers was not possible to identify dendrochronological series neither consistent evidence of wood provenance.

The achieved knowledge acquired from the studies undertaken on the *Bayonnaise* ship timbers' parent tree morphology, and 3D tree reconstruction investigation offered a distinct perspective. It became clear that archival and archaeological information about the vessel is not sufficiently detailed to achieve a clear understanding of the timber`s parent trees morphology, even when performed an integrated study in which both classes of sources were combined.

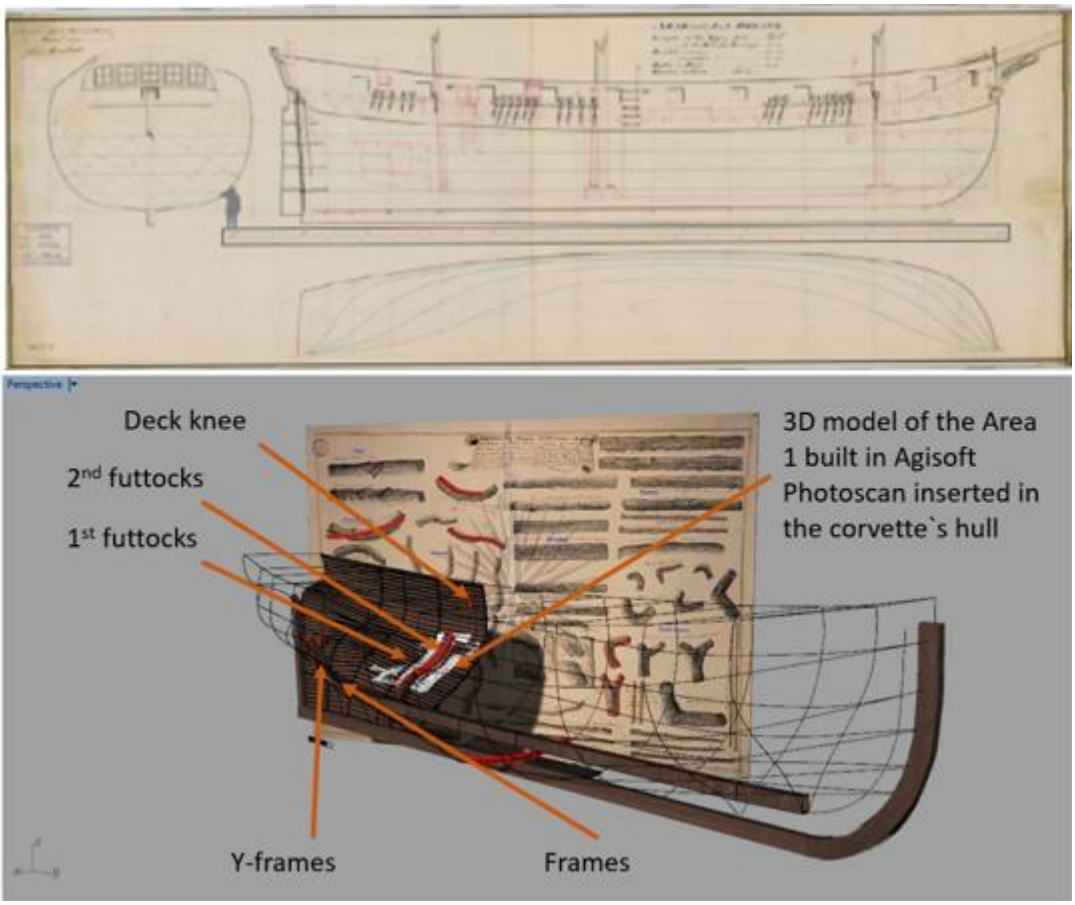


Figure 47 - Illustration of the performed exercise to identify the proposed of each timber referred in the album of the Marquis de Victoria (Navarro 1756) and the reconstructed section of the French corvette in which may be seen the suggested timber shape and their correlation with the predesigned hull timbers by (drawings by the author).

2ND CASE STUDY – THE BREMEN KOGGE, BREMERHAVEN, GERMANY.

The Bremen kogge (ship) was found in 1962 during dredging operations in the Weser river in Germany (Lahn 2000). The vessel built of oak timbers was dated by dendrochronology to winter 1378/79 (Daly 2007). The cog has 24 m in length, 8 m wide and an estimated 76-84 metric tonnes of load capacity. The cog was built using a mixture of carvel and clinker-built technology (Crumlin-Pedersen 2000, 231). The surviving timbers consist of the almost complete part of the starboard and approximately a third of the port side. The timber assemblage was preserved by saturation of PEG, which took almost 18 years to attain the required impregnation level of the timbers (Crumlin-Pedersen 2000, 230). All parts were then reassembled and put on display at the German Maritime Museum in

Bremerhaven since 2000. There, the Bremen kogge has a dedicated hall which provides the required controlled environment where the surviving reassembled timbers are being sustained by scaffolding. This approach has a shared propose in which conservators ensure the preservation of the remains while visitors can witness *live* heritage.

The Bremen kogge has been the subject of investigation focus on the surviving timbers by Aoife Daly (Daly 2009). This ongoing investigation was already able to establish an exact date for the felling trees and their provenance. However, the morphology of these timbers and the shape of the parent trees were still inconclusive. Therefore, it became pertinent to develop tree reconstruction studies based on the evidence extracted from a selection of planking timbers, in an attempt to identify parent trees morphology. Based on the produced reports and publications (Crumlin-Pedersen 2000; Castro, Fonseca, et al. 2010; Haneca et al. 2014) about the Bremen kogge complemented with the observation *in situ* of the port side of the vessel, strakes no. 7 to 10 were selected, due to their potential to reveal probable data about wood morphologies. These strakes are composed by an aft plank, the centre plank and the forward plank. On most of the planking from the port side of the vessel, it is possible to identify their morphology (growth-pattern, knots and the pith location).

TREE RECONSTRUCTION OF THE BREMEN KOGGE PLANKING PARENT TREES.

Despite the obstruction caused by the scaffolding, the centre plank from strake no. 8 presented the most relevant features to perform tree reconstruction. This timber has 743 cm in length and 56 cm sided and 4 cm moulded. It has a scarf on each end to accommodate the forward and aft plank. On the upper part overlaps on the outboard face to the strake no. 9 and on the bottom of the inboard face with the strake no. 7. This

also constitutes an obstacle for the digital recording due to the hidden parts (an area that overlaps with the upper and lower strakes). Strake no. 8 also accommodates some of the deck beams in which the scaffolding was fitted to maintain the integrity of the ships' hull (Figure 48).

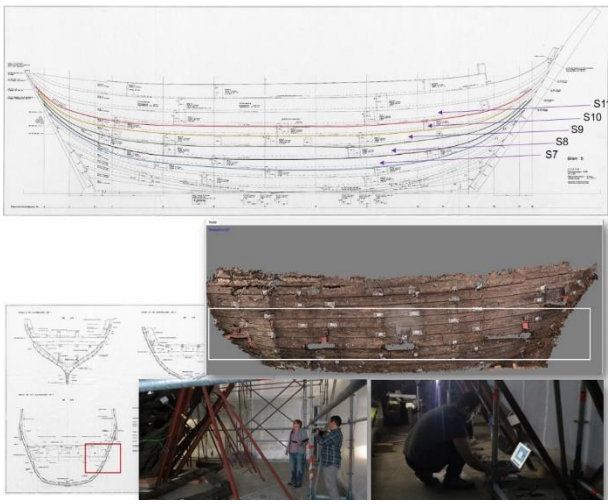


Figure 48 - (from top to bottom) Illustration of the ship plans produced by (Lahn 2000), working photogrammetry produced for initial studies (by the author), the image of the surrounding scaffolding and the support scaffolding in the Bremen kogge hall at the German Maritime Museum (photographs by Aoife Daly).

The present circumstances in which the Bremen kogge is on display increased the difficulty for the recording of the centre plank from strake no. 8. To maximise the available time for digital recording the strakes no. 7 to 10 were recorded in detail using digital technics, which included a FAROArm and computer vision photogrammetry. To conduct computer vision photogrammetry and to acquire precise measurements using a 3D digitizer arm, it was necessary to readjust the recording protocol and the techniques. The photogrammetry was built from 185 photographs having an overlap of more than 60% between each other. The first set of photographs captured the entire starboard and was used to acquire the shape of the hull on its full length. Then strake no. 7 to 9 was photographed in detailed having in which each photograph was taken having an overlap of more than 70% from the previous. They ensure the required capture of the wood

morphology and enough overlap to allow an accurate match between each photograph. The next stage was to use a 3D digitiser arm in conjunction with 3D Rhino to record in detail the selected plank. The 3D drawings were produced into three parts dues to the obstruction caused by the scaffolding. Equally, on these drawings, the area where the plank overlaps with the strake no. 9 the tracing was disrupted which generated a blank part. This allowed capturing the precise location of the grainlines, knots, cracks and other relevant wood features (Figure 49).

The information collected from centre plank on the strake no. 8 was then analysed, and files produced from the photogrammetry software *psz* exported to the 3D Rhino software as *obj* files. This method permitted analysing possible inaccurate measurements formed on the dense point cloud. Once the photogrammetric model merged onto the 3D drawing produced with the FAROArm, it was possible to have the timber to its full length and detail. The achieved 3D model at 1/1 scale, hand notes and direct measurements became at this moment essential to reconstruct the parent tree from timber no. 8.2. The location of the pith is the most relevant data in which relay the reconstruction sequence. Once identified the positioning of the first annual ring, was then possible to determine the maximum extent (edge) of the surviving timber. The next stage aimed to find the growth direction (canopy as opposed to the roots). The location of the knots determines the side branches and provides information about the type of forest (dense forest as opposed to isolated trees). The maximum length of the timber only ensures that the parent tree had at least the minimum of 743 cm in length. On the other hand, the inexistence of surviving sapwood on this timber made infeasible to establish the full wideness of the parent tree.

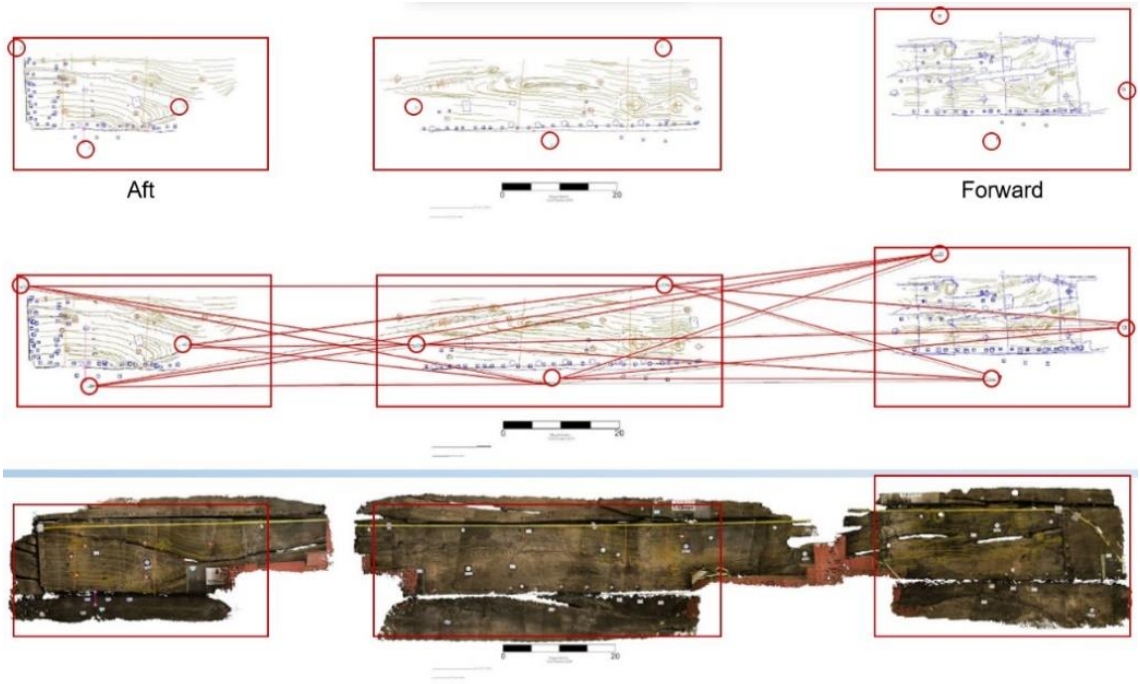


Figure 49 - Illustration of the recording process developed to obtain accurate dimension and data for wood morphology and tree reconstruction studies (FAROArm drawings and photogrammetry by the author).

After the completion of the positioning and scaling of each plank digital record in a 3D environment, the studies proceeded to the next stage of the investigation. To the tree reconstruction process was used the software Rhinoceros 3D 5.0 for the engineering and Simlab Composer 5 (Simlab Soft 2018) to the texturing.

The process comprised the following steps using Rhinoceros 3D:

a) As the vessel was displayed supported by a scaffolding system to avoid the hull to collapse, some areas are obstructed. This scaffolding generated two obstructed sections on the starboard side planking. Therefore 12 control points were used to accurately measure distances between each point. The solution was to record all the accessible section of the planks outer face. The record performed using a digitiser arm and photogrammetry technology produced two 3D digital models. This record included the collection of data about shipbuilding techniques and technology (timber edges, fastening, joinery, planking overlapping areas (clinker-

built ship)) and, the wood features such as the growth pattern, (grain), knots and their width and the natural cracking.

b) The end-product from the recording process using a digitiser arm and the Agisoft Photoscan/Metashape software was then imported into Rhinoceros 3D. In which, was produced an accurate 3D model in Agisoft Photoscan/Metashape from the photographs.

c) The drawing produced with the digitiser arm (FaroArm) consisted in a highly accurate digital model, and the 3D object produced in the Agisoft Photoscan/ Metashape had an error of less than one centimetre in the three-axis (x, y and Z).

d) The next step was to build a scale using the *Rectangle* tool with the dimensions 100 cm in length and 5 cm of height and repeated the process four times until reached an accurate colour scale bar. To differentiate each rectangle was used the *Hatch* tool to shadow two of the rectangles and marked the initial edge with the number *0* and the last edge with the Legend *3 meters* using the *TextBlock* tool.

e) To obtain the required accuracy of the group of objects using the *Scale* tool was recalibrated the photogrammetry model. The calibration between both objects was achieved by overlapping the corresponding control points and, to readjust the FaroArm drawing (angles) using the information provided from the photogrammetry object.

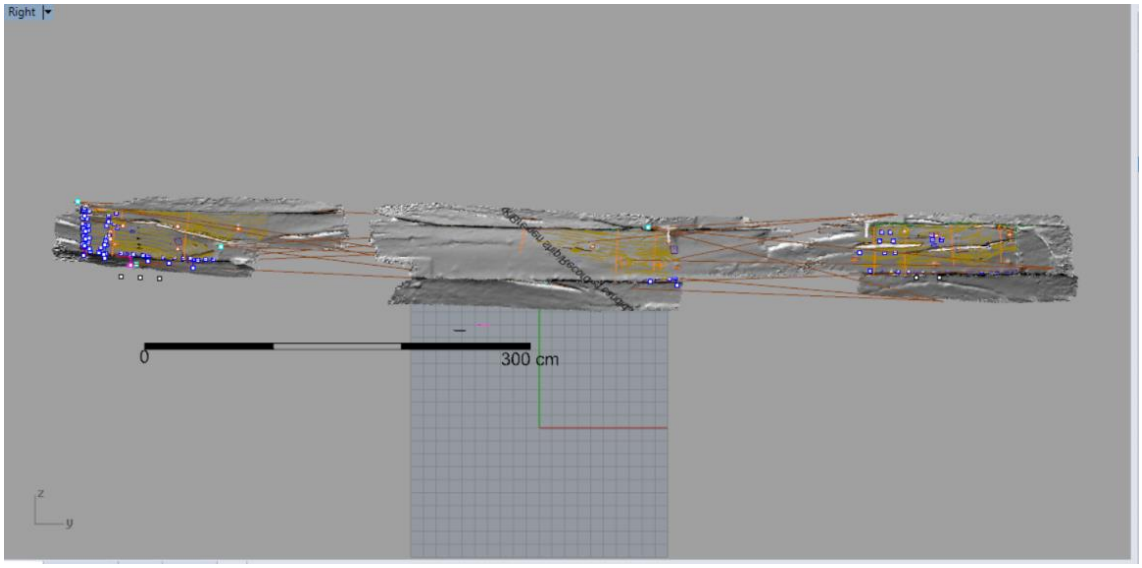


Figure 50 - Illustration of the steps a) to e) (drawings by the author).

f) Identifying the pith location on each timber record[136] (In the right view window). The first step was to draw a line using the tool *Control point curve* in a way to follow the maximum extent of the surviving first annual ring. In general, this part of the tree is highlighted by small cracks following the tangential medullary rays from the interior to the surface of the timber. Equally, the limits of the surviving timber should be highlighted using the tool *Control point curve* to these lines is recommended to use the colour red to the pith line and black to the edges of the surviving timber.

[136] This could only be achieved because the timber recording mentioned above integrated evidence of the tree´s growth pattern and other wood features.

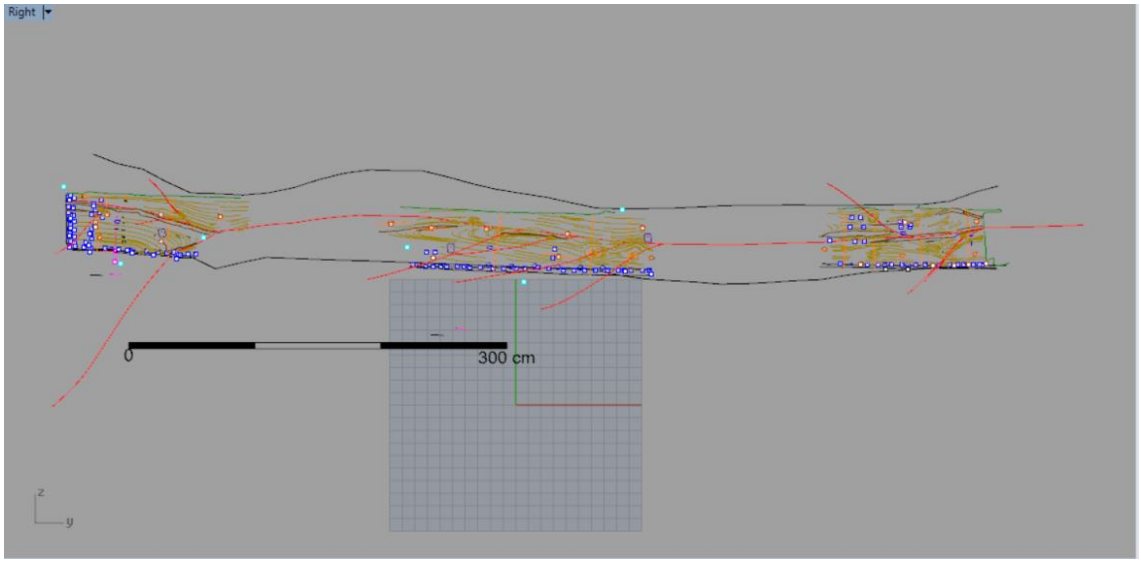


Figure 51 - Illustration of the steps f) (drawings by the author).

g) Using the tool *line*, a grid having between 15 cm to 20 cm between each line should be built over the timber´s wider surface, which will allow visualising the pith location and its correlation with the surviving limits of the timber. To this grid is recommended to use the colour black.

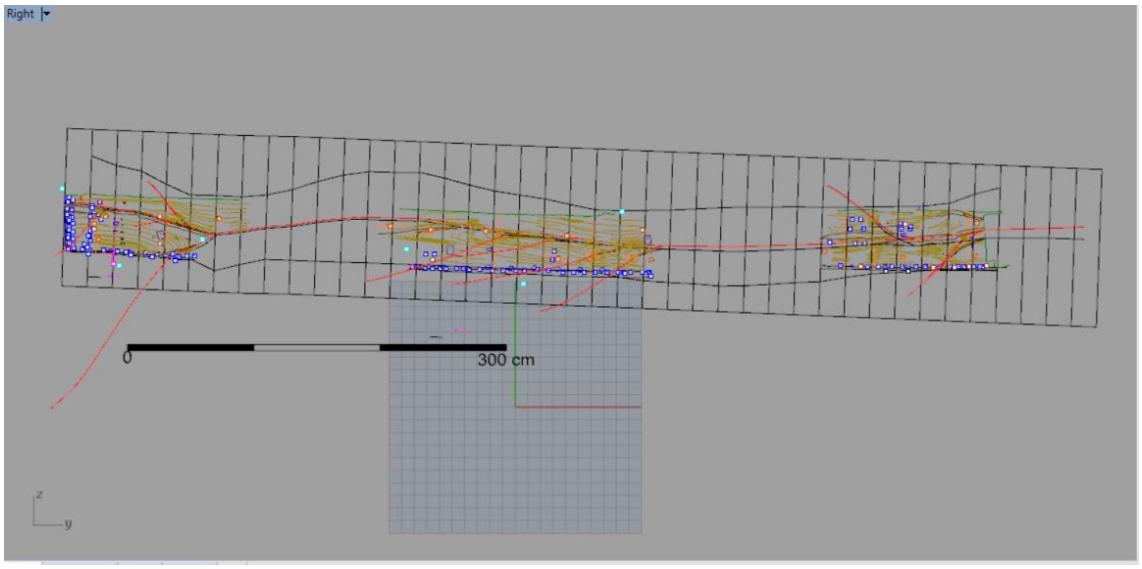


Figure 52 - Illustration of step g) (drawings by the author)..

h) Once the steps a) and b) are completed, it is recommended to hide the layers referring to the details recorded about ship timber features, such as fastening and

others[137]. This will allow to concentrate the attention in the study´s primary objective - Wood characterisation and tree reconstruction and to avoid misinterpretations or confusion in the colour attributes.

i) Using the tool P*oint*, each cross-section between the grid lines and the pith line should be marked. This will allow moving to the next step by ensuring an accurate correlation in a very methodical procedure.

j) From the point marked before, using the tool *circle,* a circumference should be built to the distant edge of the surviving timber. To this layer, it is recommended to use the colour red. This task will provide a direct interpretation of the outer part of the surviving timber. The reason why a circumference should be used to such task is tubular or cone shape formed by the trunk and branches[138].

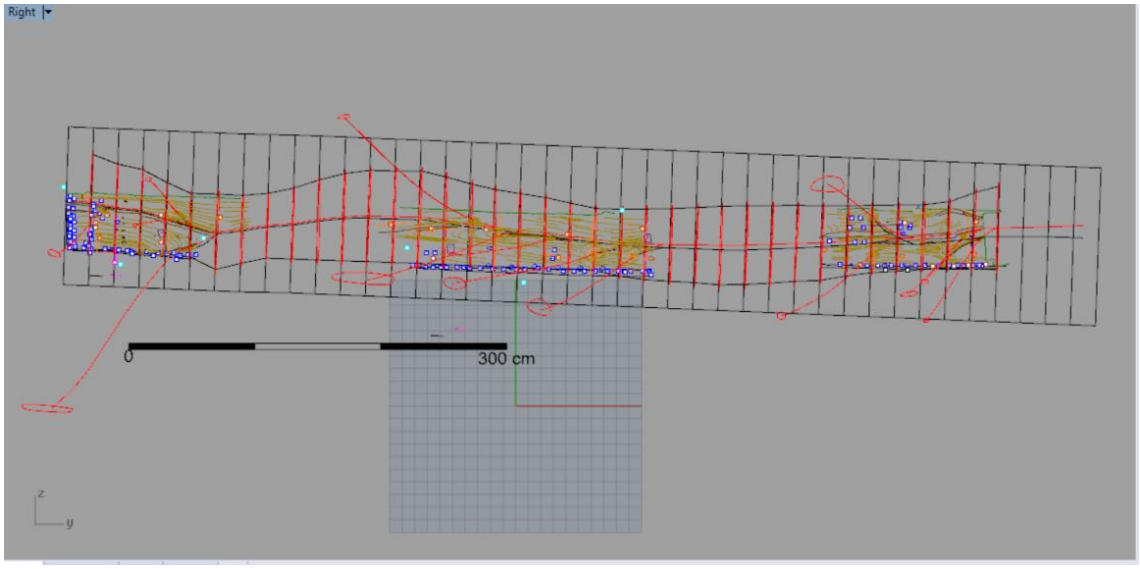


Figure 53 - Illustration of the steps h), i) and j) (drawings by the author).

k) Using the record growth pattern and the location of the knot, a line using tool *ControlPointCurve* should be drawn from a section below of the pith line to the

[137] At this stage, only should be visible the layers referring to the growth pattern, knots and cracks, plus pith, edges and the grid.
[138] If turning on the perspective view window and use the mouse to rotate it possible to visualise the tree shape, but more steps are required to complete the task.

centre of the knot in red colour. The angle of the branches is obtained from the recorded knot and its rings. It should be noted that the tree quest for solar energy make them grow vertically. The lower part of the knots has, in general, wider rings to provide the required strength to the branch to grow up.

l) Once completed the drawing of each annual branch ring should be applying the same procedure mentioned in step e).

m) In completion of the lines and circumferences to convert the pith lines (trunk and branches) into a three-dimensional object (tree), using the perspective view windows the produced drawings will provide a perception of the ship timber parent tree morphology. This 3D digital model should comprise multiple circumferences along the pith and the protruding branches.

n) The step to link the multiple circumferences should be divided into multiple sub-steps as the process may otherwise generate conflicts in the software. Therefore, it is recommended to perform one of the following steps.

    a. Use the tool *Surface1Rail* and then select the pith line and each of the circumferences in order up to bottom or the opposite an, then click enter to for the tubular/cone object shape representing the tree trunk/branches.
    b. Use tool *Loft* and then select in order up to bottom or the opposite each of the circumferences associated with the pith to convert into a 3D object.

o) The above option may trigger a slightly different surface shape of the 3D object. In the case of using the tool *Surface1Rail,* the obtained shape would be smoother and having fewer vertices as the conducting line, and the perimeter of the circumferences will determine the entire shape of the object. On the other hand,

using the *Loft* tool, the 3D object will be built circumference to circumference not establishing a direct link with the predecessor.

p) To the conversion of lines and circumferences associated with the branches should be followed the step i). The produced shape of each branch should be different from each of the other and the trunk shape. This variation is directly related to the branches of individual shape. Although, in the case of performing tree reconstruction based on timbers shaped from conifer trees such as Pinus sp. the variation is less significative as the orientation of the branches attend to be more horizontal rather than the broadleaf trees such as the oaks.

q) After completing the process, the grid should be hidden (tool: *Hide*) and the collection of 3D objected rotated[139] to the original tree growth pattern.

r) The result obtained by performing the above steps will generate a monochromatic 3D object build within an accurate methodical procedure. Although, the single grey colour reduces the perception of the tree morphology. Therefore, the 3D model should be textured. This involves obtaining a *tif* or *jpg* file from the bark of a tree of the same species to the ship timber in the analysis (e.g. *Quercus suber*, *Quercus rubber* or other).

s) The correct texture and texture mapping may be achieved by selecting each object at-the-time and change the material in the layer box:

    a. Then a new box will open and click in colour the corresponding picture may be inserted.

[139] All the irrelevant layers should be shown (tool. *Show*) and selected, then using the gumball tool rotate the entire collection of lines and 3D objects to the original tree position having the roots on the bottom and the verticality of the branches to the upper part of the 3D environment.

b. Select properties and select *Apply surface mapping* and confirm the option *Capped (Yes)* to allow the correct orientation of the texture in the 3D object.

c. In the *Properties* folder of the layer box, select the option *Show mapping*. This automatically will allow moving the textured surface in every direction to correspond to the required location of the properties illustrated in the picture used to the texture[140].

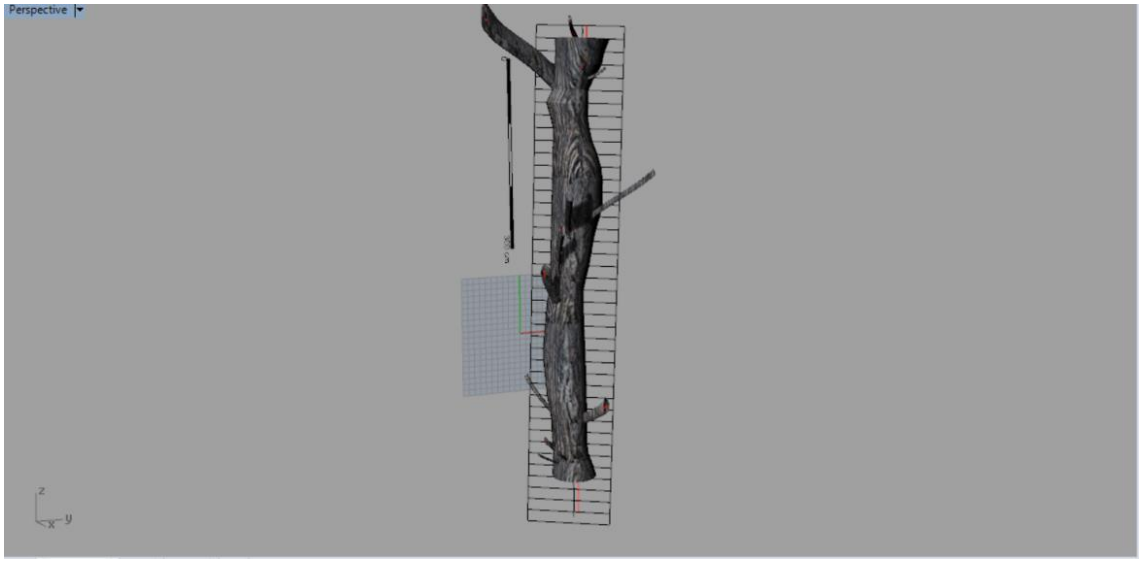


Figure 54 - Illustration of the textured 3D object (drawings by the author).

t) The next step is to save the entire workspace as a Rhinoceros 3D file (*.*3dm*) and to *Export selected* as an Object (*.*obj*). This can be achieved by selecting the collection of the 3D object in the workspace and *File*, *Export selected options* (maintain the default options), *Save texture* and then *Saved* the file in a desirable folder.

[140] If the picture does not correspond to the scale of the 3D object, correction can be made on the picture repetition implanted on the 3D object. In this case should be used return to the *Layer box*, select *Material* and in the box pressed the hyperlink of the selected picture. Then in the option mapping increase the number in the Repeat box until completed the adjustment.

u) The next step is to use the software SimLab Composer 5 or similar tool to obtain an accurate environment to the parent trees reconstructed.

Within the studies performed on the wood morphology and tree reconstruction focus on the plank no. 8.2, 10.2 and 11.2 of the Bremen kogge, was possible to characterise its parent trees as:

a) The plank was built from a standing tree having the minimum of 743 cm.
b) The tree stem was highly populated by side branches, by a minimum of 11 cm width. The branches identify during tree reconstruction grew along the stem, making it very knotty — two of which having 125 cm and 73.5 cm of diameter. One of the knots is located at a height of 418 cm and another one at 625 cm.
c) The tree stem growth pattern did not provide evidence of a straight trunk but of a curved stem.
d) The timber point from this stem was extended in 107 cm beyond it.
e) The sapwood was removed to shape the timber, but the heartwood seems to preserve its maximum extent.
f) The tangential cut of the plank show evidence of the pith along with its extent, but its location alternates from the outboard face (forward of the vessel) to the inboard face.
g) It seems that the solution found by carpenters to fill the holes made by the knots was the application of wooden patches.
h) Some cracks present evidence of stitches potentially made to avoid the timber to split in two or more pieces.

i) By analysing cross-sections taken from the tree reconstructed having planking in it, have shown that the timber was converted from the inner part of the stem (Figure 55).

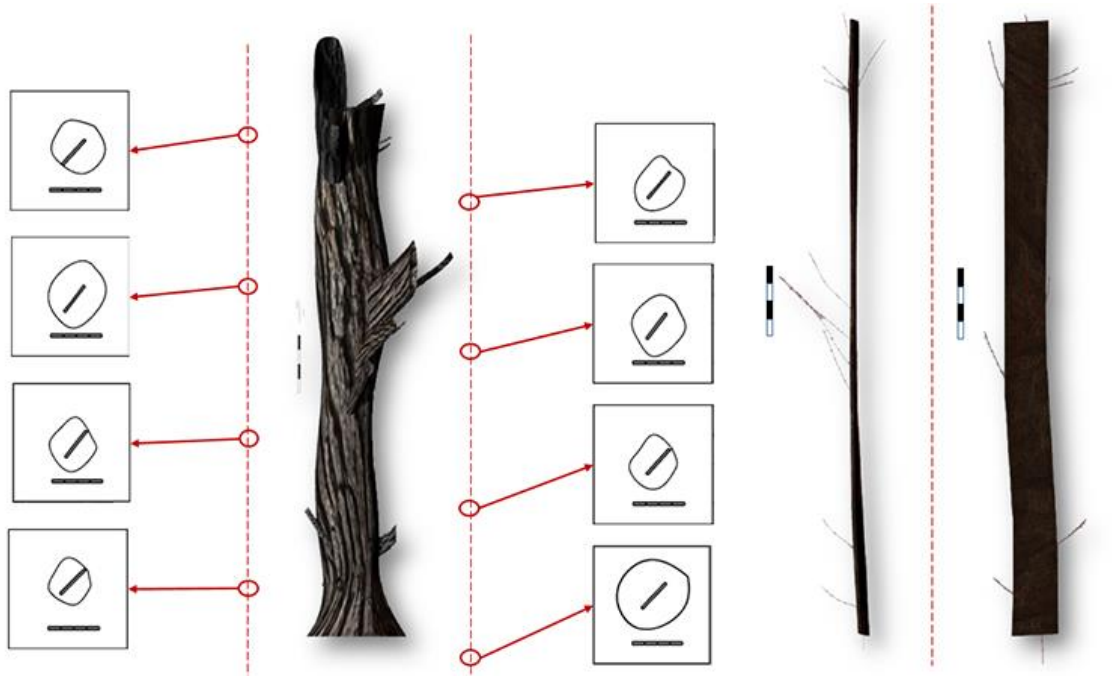


Figure 55 - Illustration of the method developed to identify the location of the planking no. 8.2 in regards to the tree`s stem (drawings by the author).

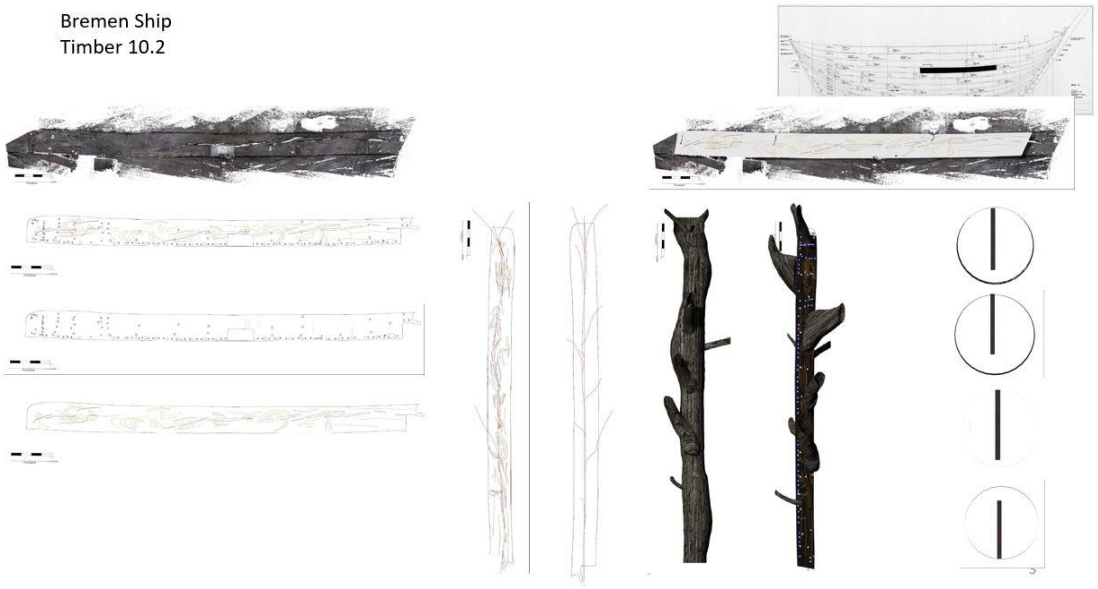


Figure 56 - Illustration of the method developed to identify the location of the planking no. 10.2 in regards to the tree`s stem (drawings by the author).



Figure 57 - Illustration of the method developed to identify the location of the planking no. 11.2 in regard to the tree`s stem (drawings by the author).

Despite the achieved results were also identified limitations of the tree reconstruction process:

a) The lack of information about side branches on one of the tree´s side limited the reconstruction of branches in that area.
b) Due to the limit space caused by scaffolding, there are unrecorded areas which could not be analysed for tree reconstruction (see picture below).
c) To establish a comparative study between the trees employed to build the Bremen kogge, further tree reconstruction studies will be required. However, the digital tree now presented have a consistent shape with the other selected planking.

The selected trees were far from being ideal for shipbuilding. A conclusion achieved after the performing of tree morphology reconstruction studies based on data collected from a selection of planks from the Bremen kogge. The tasks involved in this study allowed to

characterize the ship timber`s parent trees and to identify their specificities. Based on the evidence collected from the face of each selected plank, these trees possessed, in general, long trunks populated by a significant number of branches growing vertically in its full extent. Ingrown deadwood indicated by the dead, patched up or fallen out dead branches confirm that they received no maintenance to secure quality timber. A morphology that is consistent with the absence of adequate forest practices to the shipbuilding industry and with trees planted in an open landscape in which trees are not in competition with others for solar energy.

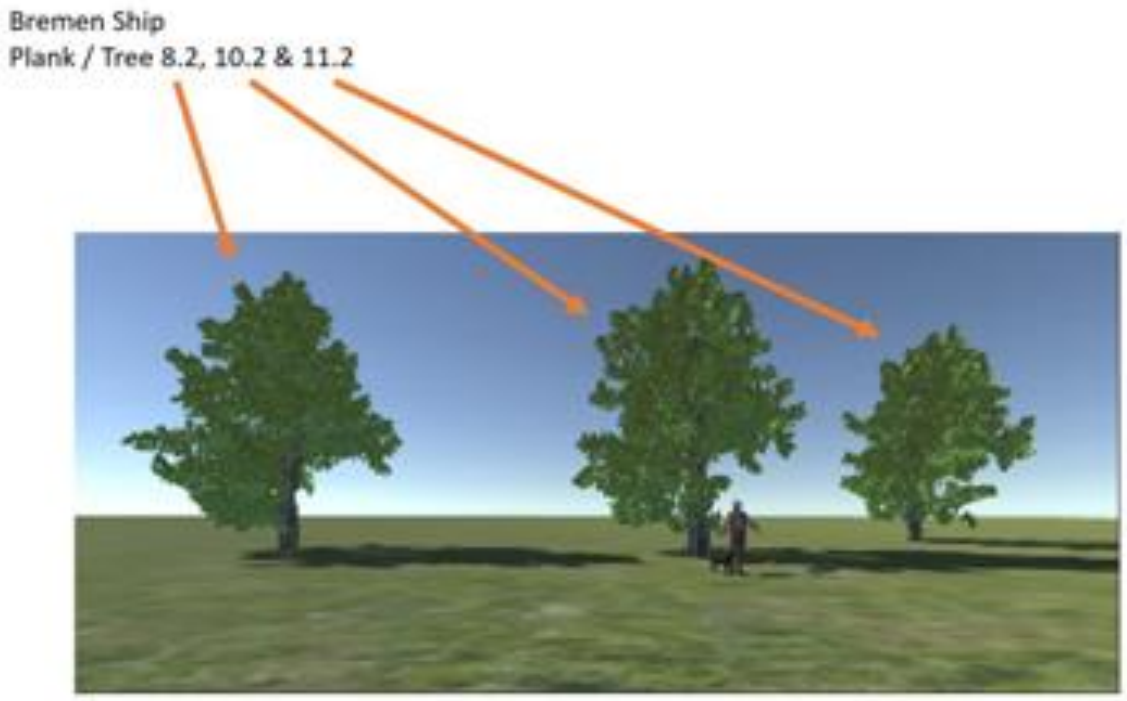


Figure 58 - Illustration of the overall tree reconstruction and wood morphology studies performed on the planking no. 8.2, 10.2 and 11.2 of the Bremen kogge (drawings by the author).

Another aspect observed during this study is the evidence of excessive use of the available timber since the analysed planks have in one extremity the upper part of the root system and on the other end derive into multiple branches. This indicated the attempt of a shipbuilder to employ these trees on its above its maximum advised length. The studies focus on the parent trees morphologies still require further investigation to

allow producing more in-depth analysis of the employed trees to build the Bremen kogge although, the surviving planks of this vessel presents similar specificities to the already analysed timbers.



Figure 59 - Illustration containing the correlation between the planted trees in the side of the River Weser and the timber used to build the Bremen kogge (drawings by the author).

Ingrown deadwood indicated by the dead, patched up or fallen out dead branches confirm that they received no maintenance to secure quality timber. A morphology that is consistent with the absence of adequate forest practices to the shipbuilding industry and with trees planted in an open landscape in which trees are not in competition with others for solar energy. Another aspect observed during this study is the evidence of excessive use of the available timber since the analysed planks have in one extremity the upper part of the root system and on the other end derive into multiple branches. This indicated the attempt of a shipbuilder to employ these trees on its above its maximum advised length. The studies focus on the parent trees morphologies still require further investigation to allow producing more in-depth analysis of the employed trees to build the Bremen kogge although, the surviving planks of this vessel presents similar specificities to the already analysed timbers.

In completion to study, in the illustration below contain the overall process performed on the Bremen kogge. The images identified as A1, B1 and C1 represent the drawing made with a 3D digitiser following a protocol to achieve the best possible level of detail, resolution and accuracy of the existing wood features. The process included the digital recording of the growth pattern (grain direction), the entire collection of knots and the natural cracking. The image identified as A4 and B4 illustrates the entire collection of knots protruding from the planks 10.2 and 11.2. Based on the evidence collected on each of planks (8.2, 10.2 and 11.2), the images identified as A3, B3 and C4 represent the maximum perimeter of each trunk and branch and, the cross-sections demonstrating from which position in the tree trunk the plan was obtained. Figure 57 illustrates the entire process conducted during the tree reconstruction study to obtain the shape of the plank 8.2 parent tree (from which it was extracted). Figure 60 represents the end-product of the tree reconstruction study conducted on the above-mentioned Bremen kogge planks and a visualisation of the landscape in which the trees have grown, in a way to complement the studies performed by Mike Belasus (Belasus 2012) and Aoife Daly (Daly 2007).

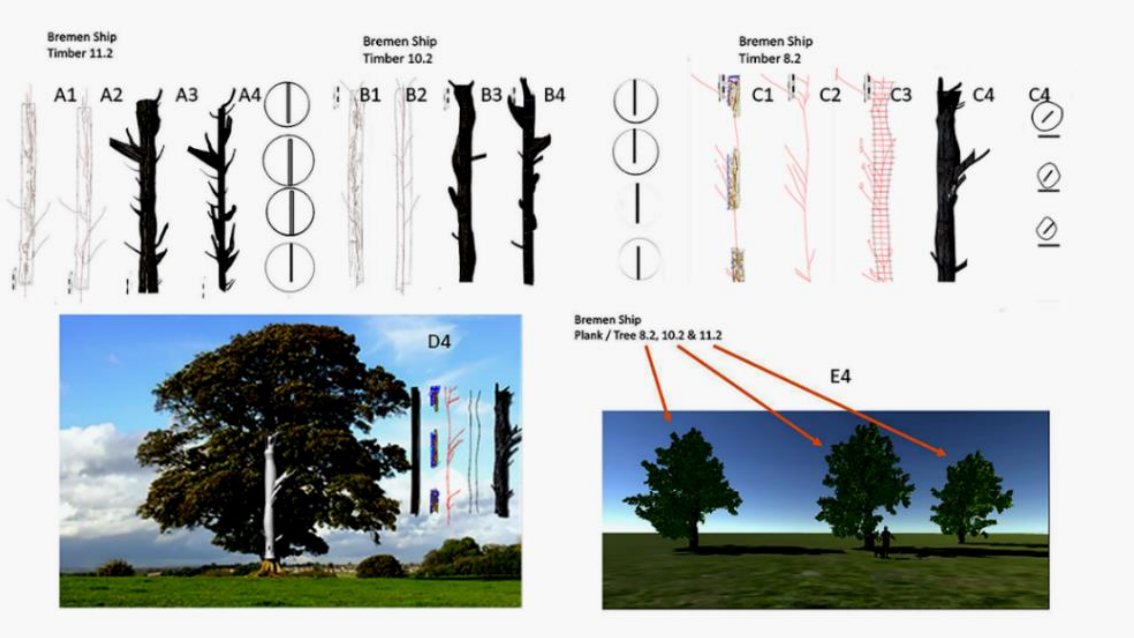


Figure 60 - The illustration represents a compilation of the step-by-step tree reconstruction studies focusing on the timbers 8.2, 10.2 and 11.2 (drawings by the author).

3RD CASE STUDY – THE *VOC BATAVIA*.

Built-in Amsterdam in 1628 for the Dutch East India Company, the *VOC Batavia*[141] had its last journey in the following year off the coast West of Australia. The remains of the 650 tonnes ship are on display at the *Shipwreck Museum* at Fremantle, Australia. The section in display on the *VOC Batavia Gallery* comprises the aft part of the vessel on its port side.

The recording, investigation and rescue of the surviving timbers were performed by Jeremy Green and his team during the 1970s (Baker et al. 1976). The employed method to the conservation of the surviving timbers by full saturation with polyethene glycol (PEG) took place over several years. Once the predefined levels of saturation were achieved the most representative hull timbers were reassembled and set on display on a permanent exhibition (Duivenvoorde 2009, 61).

[141] The *VOC Batavia* was built having 56 m in length and 10 m wide and a crew of 341 including the passengers.

MERGING DIGITAL RECORDING TECHNIQUES TO RECONSTRUCT TREES FROM SHIP TIMBERS.

Nowadays, the on-display surviving timber`s surface has a waxy appearance reflecting the level of impregnation by PEG. Which provides extra protection to the timbers in the display, but inhibits a clear visualisation of the wood features, such as the growth pattern, knots and other aspects of the tree morphology.

The first stage of this research was to carefully select a number of hull planks which would provide relevant information about wood morphology. A detailed inspection considered potential candidates for wood morphology and tree reconstruction studies to the available planking, the first three planks (aft to forwarding) of the first three strakes. The adopted criteria to the selection of these timbers had to count with the limited available timbers on display and the existence of relevant wood features on the outer surface of the timbers. These three planks are part of the hull, and their measurements comprehend a significant proportion of the aft. They start from the transom (stern post) and continue until the port side of the vessel.

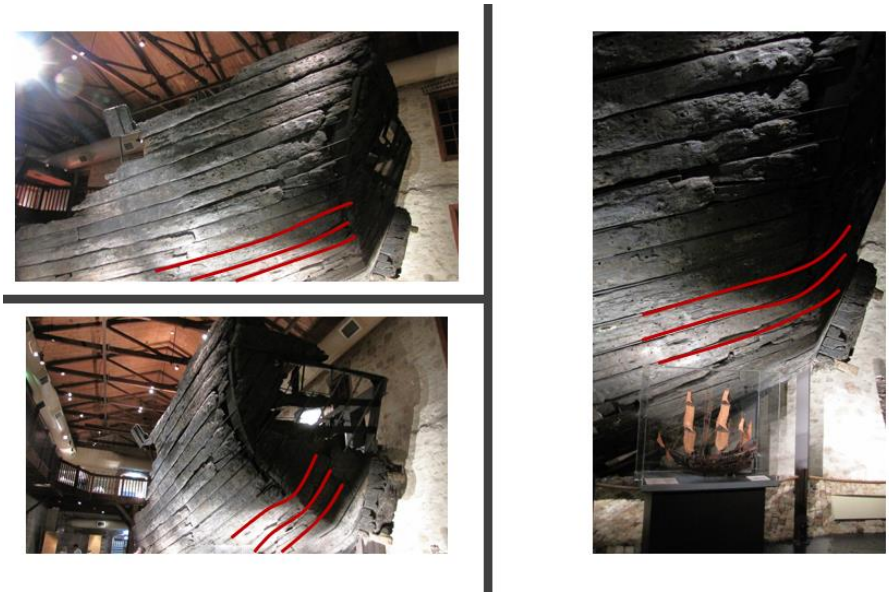


Figure 61 - Representation of the selected planks to the performing of wood morphology and tree reconstruction studies (drawings and photographs by the author).

The next step was to undertake a digital recording by taking photographs of the select timbers to produce a computer vision photogrammetry. Over than 600 hundred photographs were taken from the planking in the display. The 3D digital model produced from the photographs was then calibrated to a 1/1 scale using the control points and hand notes (having an error on the axis of 0.3 cm). From the primary model, three planks were then turned onto three individual planks. Using the 3D Rhino, several attempts were performed to identify potential crossmatch (growth-patterns, natural curvature) between planks. This process revealed to be ineffective due to the waxy surface of the timbers, which inhibit all the wood features essential for the present study.

The adopted procedure to obtain a three-dimensional digital model of the *VOC Batavia* selected timbers comprised the following tasks:

a) Taking photographs from the planking in multiple angles to cover the maximum of the timber`s faces.
b) Import the obtain photographs to the Agisoft Photoscan/Metashape.

c) In the tool *Workflow*, option *Align photos*, selected high *Accuracy*, generic *Pair selection*, 40000 *Keypoint limit* and 4000 *Tie point limit*. This method allowed to obtain the alignment of 143 from the 144 taken photographs.

d) The Dense cloud was built selecting Medium *Quality* and mild *Depth filtering*.

e) The Mesh was built by selecting the arbitrary *Surface type*, dense cloud as *Source data*, high *Face count*, disabled *Interpolation* and All *Point classes*.

f) The 3D digital model was then obtained by selecting *Build texture* in the *Workflow* menu using generic *Mapping mode*, mosaic *Blending mode*, 4096 x 4 *Texture size/count* and enabling colour correction.

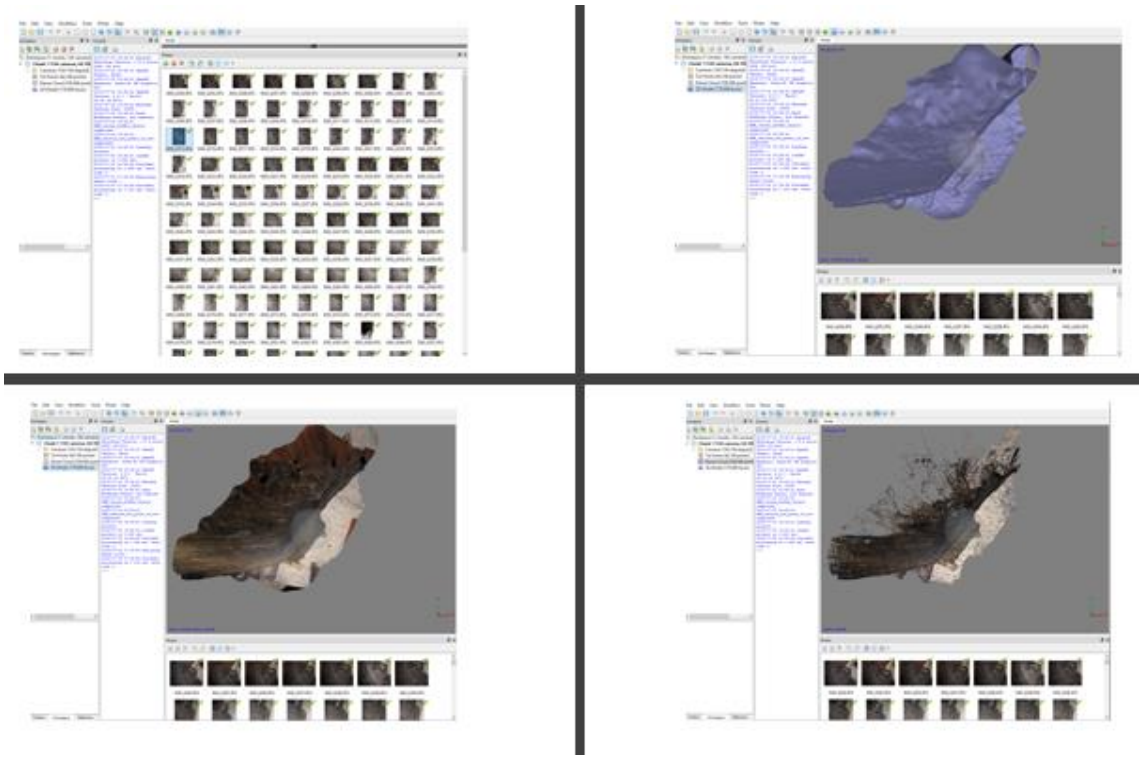


Figure 62 - Illustration of the procedure mentioned above to obtain the 3D digital model of the selected planking from the *VOC Batavia*`s hull (surfaces produced by the author).

After obtaining the 3D digital model of the area of interest, the calibration process was required to achieve a higher level of detail and accuracy to perform the tree reconstruction studies. Therefore, in the Agisoft Photoscan/Metashape software, were performed the following tasks:

a) All unnecessary parts of the mesh were removed using the tool *Free-form selection* and the keyboard key *Delete*. This allowed reducing time-consuming in the *Align photos* to process and to concentrate the attention in the selected planks.

b) Then using the hand notes taken on site the calibration of the model was performed by dropping *Markers* in the edge of the selected timbers following the recorded measurements. In the *Reference* bar, the distances were introduced between points:

    a. Point 1 – Point 2 = 0.37 m,

    b. Point 3 – Point 4 = 0.09 m,

    c. Point 5 – Point 6 = 0.43 m,

    d. Point 7 – Point 8 = 0.22 m,

    e. Point 9 – Point 10 = 0.22 m.

c) The next task was to redefine the area of interest in each picture by selecting *Tools* menu, option *Import* and select *Import mask* (*all cameras*).

d) Align the 143 photographs using the *Workflow*, option *Align photos*, high *Accuracy*, disabled *Pair selection*, 40000 *Keypoint limit* and 4000 *Tie point limit*.

e) The following process was to repeat lines d) to f) from the previous task.

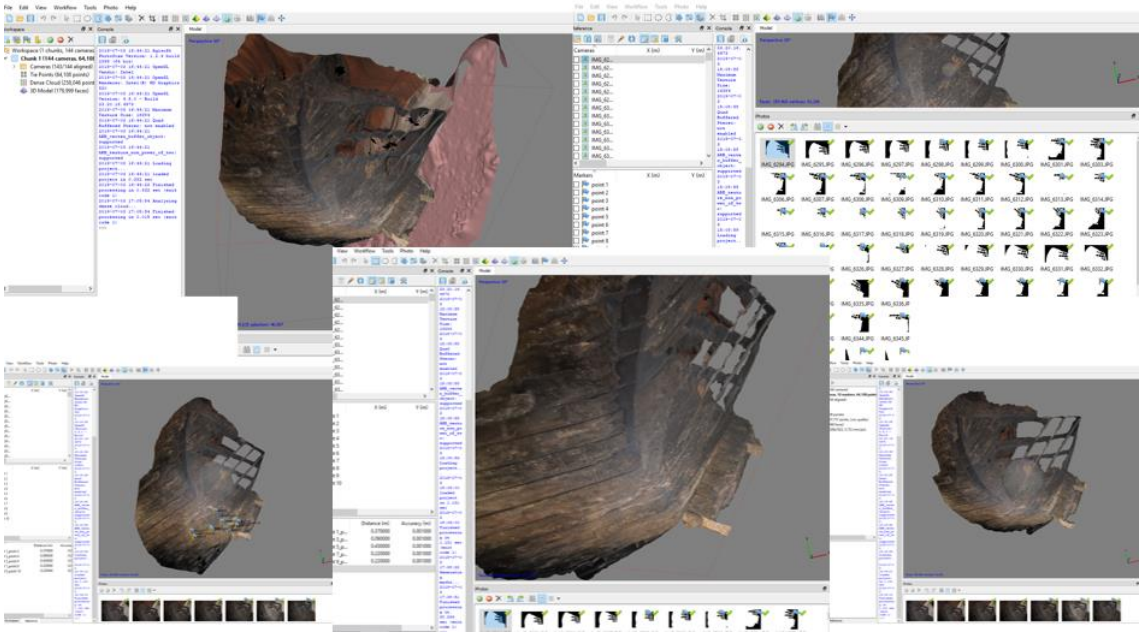


Figure 63 - Illustration of the above-mentioned developed process to obtain an accurate 3D digital model of the selected planks from the *VOC Batavia*`s hull (surfaces produced by the author).

This process allowed to obtain a high resolution and accurate 3D digital model to represent the morphology of each timber and their texture in which wood features could be observed.

The next task was to extract the selected planks from the overall 3D digital model. This task comprised the use of the following tools:

a) Identify and highlight the selected timbers from the 3D digital model, using the tool *Free-form selection* and the key *Delete* to erase unnecessary data.

b) To obtain the 3D digital model of the selected planks was used the tool *Import masks* from the *Tool* menu, option *Import*.

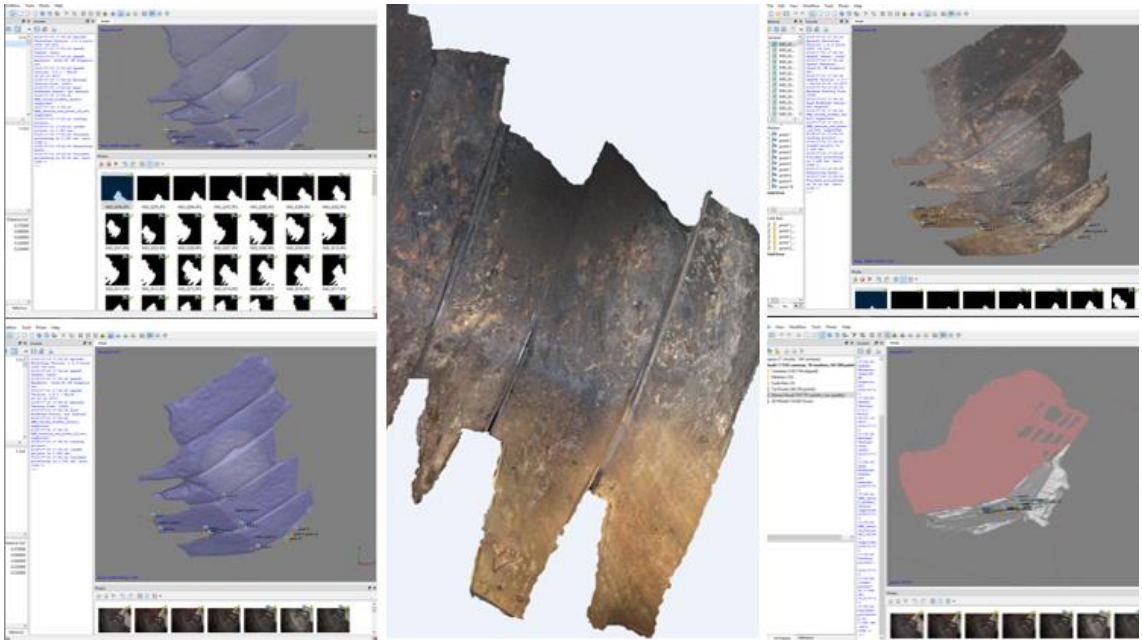


Figure 64 - Illustration of the process mentioned above to extract the selected timbers from the 3D digital model build from the photographs taken to the *VOC Batavia* hull (aft/portside) (surfaces produced by the author).

TREE RECONSTRUCTION OF THE *VOC BATAVIA* PLANKING.

The employed method to the accurate record the selected planking from the *VOC Batavia*`s hull was produced following computer vision photogrammetry techniques (Yamafune 2016b) and hand notes were taken following the published documentation by several authors (McKee 1978; Loewen 2000; Crumlin-Pedersen et al. 2002; Daly 2007; Nayling & Jones 2014; Nayling & Susperregi 2014). Although, the employed conservation method by oversaturation of the wood vessels with PEG inhibit the visual observation of timber`s natural features. The growth pattern, knots and cracks remain below the waxy surface. Therefore, another method was employed to extract data. This time, using an image processing software (Adobe Photoshop), photographs were processed and rendered by layers to highlight the grainlines (growth pattern), knots and other wood features. The process of converting the 3D digital model into an orthophoto (Yamafune 2016a) comprised the following tasks:

a) Using the produced 3D digital model (above described) in the *workflow* menu, option *Build orthomosaic* and maintain the default configuration. After completing the process, the orthomosaic has to be exported as a *tif* file, by selecting *Export jpg/tif/png*, from the *Export orthomosaic* in the *File* menu.
b) Using the software Photoshop CC, to convert the orthomosaic into an artefact drawing:
    a. Open the produced *tif* file (*File* menu, *Open* and select the *tif* file from the folder).
    b. Create a new layer (*Layer*, *New*, *Layer from background*).
    c. Duplicate layer (*Layer*, *Duplicate Layer*).
    d. Converted it into Black and White Image (*Image*, *Adjustments*, *Desaturate*).
    e. Duplicate the black and white layer.
    f. Invert the duplicated layer (*Image*, *Adjustments*, *Invert*).
    g. Change its blending mode from *Normal* to *Color Dodge*.
    h. Extract edges from the original orthophoto (*Filter*, *Blur*, *Gaussian Blur*).
    i. To extract more detailed edges.
        i. Black and white layer has to be duplicated again (*Layer*, *Duplicate Layer*). This duplicated layer has to move up to be a top in layer panels.
        ii. Applied *Glowing Edges* filter (*Filter*, *Filter Gallery*, *Stylize*, *Glowing Edges*).
        iii. Invert this *Glowing Edges* layer (*Image*, *Adjustments*, *Invert*),
        iv. Change the *Blending Mode* of this layer from *Normal* to *Multiply*.
        v. Merge Layers

j. Save the produced image.

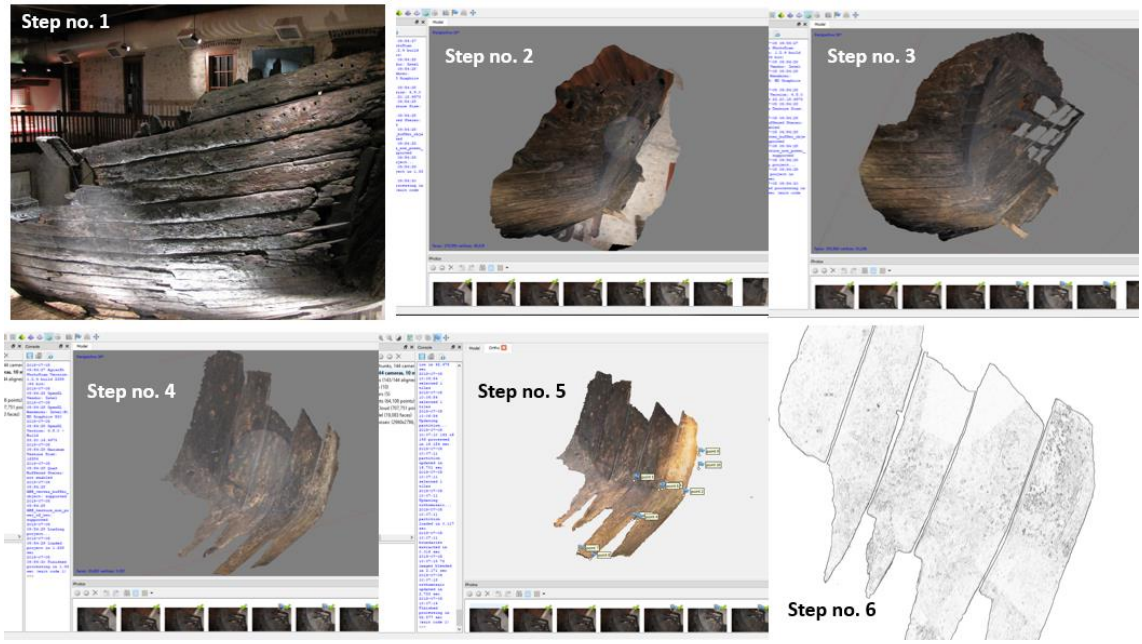


Figure 65 - Illustration of the task mentioned above to extract wood features from the select timber by using the method of converting an orthomosaic into an artefact drawing. (surfaces and drawings produced by the author).

The employed techniques revealed to be ineffective to extract and characterise the wood features from the *VOC Batavia*`s planking in the display.

PROVISIONAL CONCLUSIONS.

Within this chapter, three iconic vessels were examined under the theme of the present doctoral studies. This approach allowed to develop recording methodologies focusing on the collection of data, that latter were used in wood morphology and tree reconstruction studies. In addition, these methods were tested to identify potential limitations of the process by employing them in three different investigations. Adjustments were necessarily made on the recording methods due to the circumstances in which the vessels are located.

The *Bayonnaise* surviving timbers are still *in situ* which required diving operations, and therefore, the environment presented increased challenges caused by reflected light on the seabed and sediment. These conditions had a significative impact on the photographs taken and consequentially in the achieved results. During the Bremen kogge recording stage, the scaffolding that sustains the vessel created relevantly constraints during the FAROArm recording and impose blank sections on the photogrammetry. In the *VOC Batavia* case study, despite having a clear an unobstructed view of the selected timber, the waxy semblance of it generated a reflect on the photographs and inhibit evidence of wood morphology.

Either way, on the *Bayonnaise* investigation, the lack of information provided both by archival and archaeological data, revealed to be insufficient to perform tree reconstruction studies. However, by including other sources and comparative studies was possible to identify the potential ship timbers` parent tree within reasonable accuracy. The second case study revealed to be successful regarding wood morphology and tree reconstruction analysis, which provided an add-value to the investigation of the Bremen kogge. It is now possible to have an integrated knowledge about the felling date, provenance and shape of the trees employed to build the vessel. Finally, in the *VOC Batavia* case study proved that successful techniques used in other case studies such as in the Bremen kogge, may not be suitable in every case study.

CHAPTER 5 – METHODS FOR THE DEVELOPMENT OF TREES, SHIPS AND LANDSCAPE DIGITAL THREE-DIMENSIONAL RECONSTRUCTION: HOW CAN WE SEE TREES IN SHIP TIMBERS.

The fundamentals of archaeology reside on ethics, experience and resources. The major trends in archaeology (Willey et al. 1958; Trigger 1980; Hodder 1991) attend to develop a conceptual and efficient sequence of tasks to investigate human interaction with the environment. Since the late 1950s, profound transformations on the archaeologist's viewpoint triggered a complete reformulated perspective focus on the quest for answers about broader archaeological information. Contextualising the archaeological sites and the artefacts became archaeologist`s primary task. By the mid-20th-century, the study of objects and artefact collections was no longer an efficient way of investigating an archaeological site, as the surrounding (environmental) context assumed the higher relevance upon the *Material-Culture* (artefacts). Nowadays, the limitations imposed on an archaeological programme relies on technology and funding resources. Although, how far may we go on this process (Martins 2015b) and how sufficiently detailed will be the information collected to the contextualisation of artefacts. During the past decades, archaeologists have been investigating the relationship between the sites and the artefacts with the associated environmental, social and economic vicissitudes.

Along with this quest, technological advances have also been explored in archaeological research. Nowadays, it is not acceptable to partially investigate an artefact or an archaeological site without understanding the surrounding environment.

Using the study of boats and ship as an example, a shipwreck must be investigated by a multidisciplinary team of researchers and using efficient methods to obtain a deeper

understanding of the surrounding environment and the past events of the vessel such as routes, crew and cargo directly related to that vessel. Therefore, every year, new data is being published about recent findings and the revisited shipwrecks. Archaeologist`s adopted trend, is in most investigations, highlighted details that have been *invisible* in the past. The relevance of those details in some cases may be assumed as a turn-over in the knowledge. This does not mean that previous publications are wrong but rather incomplete as the archaeologists were not seeking to answer today`s research questions. Revisiting past reports may trigger enthusiasm, and a revival of ideas as the published words contain a specific level of knowledge. Documentation that reflects the *way of doing* in the past, to which new levels of knowledge were added over time by the scientific community. These moments comprise an evolution of science and the development of methods based on personal and collective experiences. As the most wanted new steps/level of knowledge is being added, the researcher`s resilience is fashioning the archaeological programmes. The outcome of an investigation must be published in technical and non-specialist language as the archaeologists are an obstinate public servant. The responsibility to published scientific results has been increasing within the past two decades. Dissemination is one of the major concerns in archaeology, but it comes with the demand of producing accurate and thorough results. As in other disciplines, in archaeology, a certain level of *controversy* is required in a way to challenge researchers to reach the next level of knowledge. Every year, new methods of approach are being placed in the discussion. Mainly through the form of doctoral and master thesis, which nowadays are gaining more notoriety since it is the most efficient agent to disseminate new ways of *doing* science.

Concerning the use of three-dimensional recording to capture and analyse archaeological data, some doctoral studies have provided advanced scholarship (Jones 2015; Yamafune 2016b; Dostal 2017). In the case of Doctor Toby Jones` thesis, a detailed and methodical procedure was developed to employ in 3D digital recording of ships timbers using 3D digitisers (FaroArm) and aiming to obtain an accurate registry of their surface and the application of those drawings to the analysis and reconstruction of vessels. In the thesis of Doctor Kotaro Yamafune, a systematic procedure was developed to ensure an accurate record of archaeological sites and artefacts within a high level of precision, using computer vision photogrammetry (Agisoft Photoscan/Metashape software). The studies performed by Doctor Christopher Dostal have demonstrated a method to achieve a thorough and accurate record of timber assemblages using 3D laser scanning equipment. Each of the thesis presented a method to obtain an accurate record of ship timbers, a collection of methods revealed to be of greater relevance to the present doctoral studies. The published techniques were followed in some cases but adapted ever since needed to the theme, aims and objectives of reconstructing trees from ship timber assemblages.

To the acquisition of data about ship timbers surfaces was partially followed information contained in the thesis mentioned above:

a) Described in the thesis *Three-Dimensional Digital Recording and Modelling Methodologies for Documentation and Reconstruction of the Newport Medieval* Ship by Toby Jones (Jones 2015), was considered the information about how to use a 3D digitiser arm (FaroArm technology), to acquire surviving information on

ship timbers surfaces[142]. The produced documentation suggested the methods of analysis of the surviving timbers based on the evidence found at the Newport Medieval Ship archaeological site. Although, as this ship was built following a tradition of clinker-built technology (Pomey et al. 2012), a few adaptations were made to the original manual. In a way to reflect the *reality* of the shipbuilding technology in focus on the present thesis which is in more significant quantity following the carvel-built shipbuilding tradition (e.g. Pepper wreck, Cais do Sodré wreck or others included in this thesis). The performed adaptations to the exiting manual had to be compulsory considering the requirements imposed during fieldwork to obtain an adequate Rhinoceros 3D collection of object layers:

a. As the ship timbers in the analysis contained different characteristics from the Newport Medieval Ship technology (as the used digitiser an older version to the employed in Newport investigation), the application of different a FaroArm probes was also subject to a variation.
b. The use of 3D drawings (line data) produced with the FaroArm and the associated printouts were mainly generated following the published recommendations (Jones 2013a). Although, more considerable attention in the digital record was given to the wood features, rather, the ship timber human-made shapes. This variation enabled the wood characterisation of the ship timbers by employing during the process an exhaustive record of

[142] *It specifically identified three levels or stages of recording in relation to ship finds, with level one encompassing the basic measuring, sketching and photography of a hull or hull remains. This minimal level of documentation should ideally contain enough information to make an educated interpretation of the vessel's form and function* (Jones 2015, 72).

the timber's growth pattern, the entire collection of knots, cracks and timbers natural edges.

b) From the thesis by Kotaro Yamafune - *Using Computer Vision Photogrammetry (Agisoft Photoscan) to Record and Analyse Underwater Shipwreck Sites*, was considered the information about how to produce 3D models (cloud data/mesh data) from the ship timbers in analysis using a photogrammetry technique. Computer vision photogrammetry enabled the record of precise and accurate models in which the wood features were digitally recorded. This method allowed to record a higher number of ship timbers reducing the costs in fieldwork, but also to test different techniques in the approach.

c) The method developed by Yamafune (Yamafune 2016b; Yamafune et al. 2017) allowed to obtain a clear and accurate 3D model of individual timbers[143] and then, to extract relevant wood features using Rhinoceros 3D. The studies developed by Yamafune also provided detailed information about how to capture images underwater to produce suitable 3D models to the purpose of tree reconstruction studies. Meaning, that the use of these techniques allowed to obtain accurate data in archaeological sites such as the case studies integrated into this thesis. This advanced technique allowed reaching the required accuracy even when dealing with surviving ship timbers located underwater to perform tree reconstruction studies.

d) The thesis by Christopher Dostal - *Laser Scanning as a Methodology for the 3-D Digitization of Archaeological Ship Timbers: A Case Study Using o the World Trade*

[143] *This proposed methodology allows archaeologists to skip time-consuming underwater measuring; what is more, it can provide more accurate data* (Yamafune 2016, 170).

Center Shipwreck, allowed to obtain detailed information about how to manage waterlogged timbers in a way to preserve its integrity and subtle surface details. In addition, the reflection made by Dostal[144] in turn of the accuracy and precision revealed to be essential to define the criteria to the development of fieldwork within the present doctoral thesis.

Taking the above-mentioned doctoral studies as references to the documentation of surviving ship timbers and waterlogged timber in general, it became essential to filter which techniques suit the purpose of tree reconstruction studies. In this way, sections of the thesis and numerous published papers[145] were used to produce a literature review capable of gathering information. Detailed and precise techniques were studied and tested to identify the current level of knowledge produced regarding the digital documentation of artefacts. Associated to this exercise, numerous documents[146] were read about:

a) Shipbuilding technology from the Iberian Golden Age of Discoveries (detailed information in chapter one and two).
b) The *good* timber, their provenance, forest practices and tree´s morphologies to employ in the Iberian shipyards (detailed information in chapter two and three).
c) Developed studies in the attempt to reconstruct trees from ship timber assemblages.

[144] *It is important to distinguish between accuracy and precision when it comes to the evaluation of archaeological documentation. Using a dart board as an example, accuracy is the ability to hit the bullseye, while precision is the ability to hit the same spot anywhere on the board over and over. Ideally, archaeological documentation will be both, but while precision is easy to determine, accuracy is sometimes less tangible* (Dostal 2017, 176).
[145] Referenced in the References and Bibliography section of this thesis.
[146] Referenced in the References and Bibliography section of this thesis.

The combination of such areas of science resulted in the implementation of a collaborative scholarship between maritime archaeology, land archaeology, wood sciences and computing which allowed reaching an innovative level of knowledge within the present doctoral studies.

Allied to the archaeology, digital humanities have proved that it is possible to recreate, and test theories based on evidence through a modelling process. Considering the fact that the digital *world* is virtually unlimited, the integration of such technology in an archaeological research programme will expand the desire of recreating sequences of human behaviour. A recreation in which the archaeological facts maximise the primitive scientific sense of *enquiring* about the past relationship between humans and the environment.

In general, maritime archaeologists focus their attention on the construction technology, ship`s profile and in the political and socioeconomic impact that vessels had in the past. However, as Richard Steffy stated (Steffy 1994) a ship is much more than an empty shell, a ship represents the will of humans and a tool to the human evolution. Meaning that its construction was initiated in the forest, perhaps generations before, if considering the required forest practices employed to obtain the *good* timber. The present chapter - *Methods for the development of trees, ships and landscape digital three-dimensional reconstruction: How can we see trees in ship timbers*, has the objective to provide an integrated study which culminates the achieved knowledge and experience obtained within the past five years of doctoral studies. Chapter five is also considered as the end-product of a long learning process in which its author had to:

a) Substantially improve skills in knowledge about shipbuilding technology from the 15th to the 18th-century.
b) Comprehensive knowledge about wood anatomy and trees morphology.
c) Also, to maximise three-dimensional computing skills in multiple software.

In a way to allow a theoretical descriptive presentation of the developed approach, a major case study will be at the centre of the present chapter. Providing a step-by-step workflow in which the advanced techniques will be described, discussed and presented the advantages and limitations in taking this approach. In addition, a correlation will be made between previous studies published about the attempted of reconstructing trees and the case studies presented in the previous chapters, with the primary case study - Belinho 1.

In maritime archaeology, it is highly relevant to investigate the technology of boats and ships, but also to obtain information about the used raw material. Therefore, it urges to obtain a substantial body of knowledge about the employed tree species, forest practices, felling particularities, forest renovation, timber trading routes and tree`s morphologies and their anatomy. In this way, the researcher will obtain a better understanding of the limitations imposed by trees in the shipbuilding industry and the pressure on the forests exerted by the shipyards. The study of tree`s morphology and their particularities represent innovative and original research, through advanced scholarship, capable of providing to the forefront of archaeology a new method to be followed by other researchers in the quest for knowledge. The application of the developed methods within the present thesis may be employed in maritime archaeology, land archaeology and other disciplines which may consider crucial to obtain information about the data mentioned

above. The systematic acquisition of data by the implementation of the useful and tested methods and techniques developed during the present doctoral studies allowed to adjust and readjust a methodology. Which, as its limitations but at the same time, places it at the forefront of the discipline by its integrity, quality, the capability to lighting unforeseen challenges and by offering a user-friendly procedure/methodology. The developed methodology was generated by obtaining knowledge from three sciences: Maritime Archaeology, Wood Sciences and Digital Humanities. From these disciplines, knowledge-based criteria were imposed to extract and highlight the most relevant methods in use in each of the research areas. The adopted criteria was not to acquire an *absolute* and *more in-depth* understanding of each of the disciplines but to develop a method in which it is possible to combine strategies from different sciences to extract relevant information:

a) Dendrochronology may provide the tree`s felling date.
b) Wood anatomy may provide the identification of the ship timber.
c) Maritime archaeology may provide information about the employed construction techniques.

To enable the reconstruction of ship timber`s parent trees and the landscape in which those trees were planted and managed. Also, it enabled a method to identify forest practice techniques and the limitations in the raw material to the purpose of shipbuilding. In this way, it is now possible (in most cases) to accurately reconstruct the trees from archaeological evidence such as ship timbers or timber logs from buildings. Although, why to perform such effort and to employ a substantial time-consuming in reconstructing trees? The answer to such a challenging question relies on the fact that in archaeology, the attention has been given to the shape of ship timbers and its place in the ship`s hull,

rather than to the preceding tasks to obtain the *good* timber. As mentioned in chapter two of the present thesis, the Iberian shipyards during the Golden Age of Discoveries required the continued supply of timber in such quantity and quality. Thus, the highly demanding industry could only be supported by a workflow through generations of carpenters following precise methods to manage the forest. This included the use of pollarding/coppiced techniques, forest regeneration techniques and the maintenance of established supply routes to shipyards.

Having performed a theoretical exercise about the value of the present doctoral studies, it has been reached the moment to present the developed methods within a detailed description. Each method will be presented using a step-by-step demonstration in a way to successfully reconstructs ship timbers parent trees. The fulfilment of such ambition will provide an innovative methodological approach to employ in archaeology, considering that it will extend the forefront of the discipline. The conceptualisation, design and implementation of the developed methodological approach and associated techniques were tested in multiple variables and environments. This approach is now able to generate new knowledge and its application for research and advance the academic enquiry.

Belinho 1 shipwreck will be used this thesis major case study in a way to demystify the complex task of reconstructing trees from ship timber assemblages. From which, disarticulated ship timbers were randomly washed ashore during storms. During the investigations of the surviving timbers, multiple recording methods were employed. The team of researchers comprised experts in wood sciences, archaeologists and other

disciplines. Fieldwork and the publication of results were mainly funded by the ForSEAdiscovery project and partially funded by the council of Esposende (Portugal).

INTRODUCTION TO THE CASE STUDY - BELINHO 1 SHIPWRECK.

During the winter of 2013/4 exceptionally, ferocious storms hit the Portuguese Atlantic coast. Records in temperature variations were abnormally in comparison with previous years. Tornados were recorded in January of 2014 across the country while the coastline was buffeted by extremely high waves and fierce winds. This dangerous environment was particularly severe in the northern area of the country, causing significant damage to the town's buildings and substantial erosion to the landscape.

Hidden for an unknown extent of time, the remains of a vessel were randomly washed ashore. A collection of disarticulated ship timbers along with other artefacts were dragged through the seabed to the beach of Belinho. This new find designated by the Portuguese heritage agency[147] as Belinho 1 comprises a vast number of timbers, pewter plates and stone cannonballs. The discovery of such heritage triggered the immediate rescue of the surviving artefacts in the remote beach of Belinho by a team comprising archaeologists, national authorities and local citizens.

As the collection of artefacts was rapidly increasing in number, was initiated the process of cataloguing the undifferentiated timbers, ship timbers, pewter plates and ceramics.

[147] Direção Geral do Património Cultural (DGPC) – Directorate-General for Cultural Heritage (Portugal).

Based on the visual assessment made on site, it became apparent the existence of two different chronologies - Roman ceramics and the Post Mediaeval multiple artefacts

The cataloguing process recorded more than two hundred pewter plates (made in tin and copper and some with high or low relief), several stone cannonballs, personal artefacts and a significant amount of ship timbers[148].

Based on drawings to illustrate the catalogue, became clear that dimensions and joinery present in this assemblage have consistent similarities within each other. In fact, those timbers were shaped and joined in accordance with a specific shipbuilding tradition. Evidence that made expert`s focus their attention on the collection of surviving ship timbers which maximised its scientific interest.

PREVIOUS INVESTIGATIONS ON THE BELINHO 1 WRECKAGE.

Led by the enthusiasm, the established team began gradually to initiate the investigation on the post-medieval Belinho 1 associated artefacts. The wide range of artefacts and their particular features triggered the need to invite experts in different areas. The team was then increased in number with the collaboration of researchers from the Instituto de Arqueologia e Paleociências (IAP/FCSH- UNL)[149] to record and analyse pewter plates. The researchers Helena Granja was invited to contribute to the paleoenvironmental analysis (Farrel et al. 2009), Carlos Almeida contributed to the cultural and archaeological contextualization of the artefacts and, José Bettencourt to the study of the ship timbers (Bettencourt et al. 2015). Later the historian Amândio Barros also offered his contribution

[148] At that stage (May 2014) the Belinho artefacts consisted of 78 ship timbers, 280 plates, platters and a mug (?) made in tin alloy, 73 copper alloy plates, 3 candlesticks in copper alloy, 1 musket lead bullet, 78 lead bars, 1 set of casket hoops, 1 copper bolt, 1 copper.
[149] Insituto de Arqueologia e Paleociências from the Universidade Nova de Lisboa, Portugal.

by investigating in archives for documentation potentially correlated with the provisional archaeological conclusions (Barros 2016).

Regarding the archaeological viewpoint, the archaeologist Jose Bettencourt supervised the team from the Centro de História d`Aquém e d`Além-Mar[150] (CHAM - UNL). The study aimed to identify the shipbuilding tradition and chronology of the wooden artefacts (Bettencourt et al. 2015). The objectives focus on the development of an inventory of the ship timbers and the analysis of a select segment of it. Bettencourt`s team recorded the keel, the stern knee and one of the hull planks along with other nine timbers as representatives of the shipbuilding employed techniques. The adopted methodology (Bettencourt et al. 2015, 7) for the inventory included labelling the artefacts with the archaeological site acronym (Praia do Belinho - PB), year (2014) of their inventory and, systematic numbering (example: PB14-001). Also, part of the catalogue, included measurements (height, length, width), typology and function of each recorded timber (keel, sternpost, frame, other) and conservation details.

The recording process was initialised by cleaning the selected timbers with fresh water to remove seabed sediment wedged on each surface. Once concluded this process, empty cavities originated by the fastening were marked with spikes allowing to record of the insertion angles made by treenails, nails and bolts.

The next stage comprehended the usage of two recording techniques. Two-dimensions 1/1 scale drawings of the transversal and longitudinal timbers were produced using the non-contact tracing technique. While drawings from the planking (tangential timbers)

[150] See more information on: http://www.cham.fcsh.unl.pt/

were performed implementing the contact tracing technique (McKee 1978). The first set of timbers included the Y-frames and floor timbers over which a translucent acrylic board was set up (no contact tracing with the timber was made in any point of the process) and transparent plastic sheets on top of it. Over these sheets, a laser beam was calibrated at an exact 90º angle perpendicular to the timber surface to be recorded. Then a series of dots were pinpointed on the plastic sheets in the exact perpendicular of the feature to be recorded.

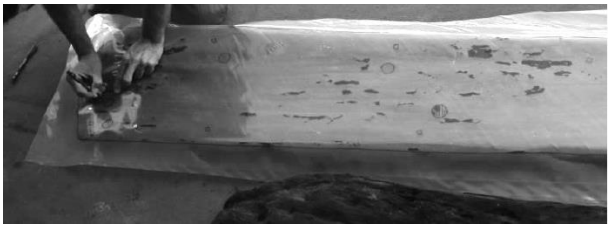


Figure 66 - Traditional contact tracing to the recording of ship timber features (Bettencourt et al. 2015, 9).

The contact tracing technique to produce drawings (a similar technique employed to record the Graveney boat timbers (Fenwick 1978; McKee 1978, 41-42) from the tangential timbers consisted of in setting up transparent plastic sheets over each timber surface and then outlining relevant timber features with a marker (Figure 66).

The usage of both techniques allowed to record important observed details which would contribute to identify the employed shipbuilding techniques. Final drawings performed on those transparent plastic sheets comprehended particular features such as the keel rabbet, scarves, fastening location, cross-sections and timber shapes.

In addition to the drawings, the archaeology team from CHAM also captured those details with a digital camera to produce a photomosaic of selected timbers. The method consisted of in taking pictures with a camera fixed on a tripod facing each timber surface.

The produced image files were then assembled in order to generate a photomosaic of each timber recorded surface (Bettencourt et al. 2015, 10).

After completion of the drawings and analysed the data produced and published[151] a fieldwork report (Bettencourt et al. 2015). Based on this document, Bettencourt`s team concluded that:

a) The 63 catalogued timbers were by far the most difficult to re-assemble on a ship`s hull;
b) Within the known collection of timbers (at the time) was identified one section of the keel, a fragment of the sternpost and another from the stern knee, several timber frames, futtocks, hull planks and the mast step.
    a. The section of the keel (PB14-007) as eroded surface and apparently incomplete on both ends. Its length is approx. 884 cm, width 23 cm on top and 24.5/25 cm of average. This ship timber was built by using a tree trunk after the sapwood had been removed. Presumably, the carpenter has only shaped the rabbet and inboard sides, leaving the tree´s original shape on the outboard side. Driven by the analysis of the rabbet angles, the researcher assumed that those were built by using the *tábua de resbordo*[152]. There are no traces of where the bottom frames were assembled, besides the large bolt holes (7 cm diameter). Furthermore, there is evidence of iron nails that should be used for fastening the *tábua de resbordo* (Bettencourt et al. 2015, 12).

[151] Fieldwork report was published in Portuguese language.
[152] The plating next to the flat keel, or what is known as strake A, / The strake of planking next to the keel; the lowest plank. Also, the lowest side strake of a flat-bottomed hull, / The first strake, against each side of the keel,

b. The sternpost (PB14-001): as a square section with 290 cm of length. There is evidence of the iron straps location to attach the rudder. It has circular ringed iron bolts with 2.8 cm of diameter, presumably associated with the location where frames were attached. On the rabbet, there is also evidence of where the hull planks were assembled. On the outboard face are shown traces of holes which could be associated with lead sheeting.
c. Stern knee (PB14-009): as a trapezoidal section with a length of 360 cm. Since it comprises a very specific shape with 21.5 cm forward end thickness and, 23.5 cm on the centre and 21 cm on the upper side, regarding the width on the forward end, this was 16.5 cm, 16 cm on the curvature and 17.5 cm on the upper side. According to Bettencourt (Bettencourt et al. 2015, 13), the timber used to be linked to the stern knee and reinforced by round section iron bolts of 2.7 cm to 2.9 cm inserted on hollows with 6.2 cm to 4.2 cm width. Furthermore, on the edge of the upper side and the outside face as a scarf to presumably linked to a Y-frame (26 cm length, 14 cm high and 4.7 cm of depth).
d. Timber frames (PB14-003, PB14-010 and PB14-011) (Figure 67): according to CHAM team`s conclusions, three frames should belong to the central part of the ship. All of it has the eroded scupper with approx. 6 cm of width, 4 cm high and traces of iron and treenails. The PB14-003 frame with 311 cm of length, between 16.4 cm and 15.5 cm of width and within 18 cm and 16.5 cm high. It reveals evidence of *rabo de andorinha* scarfs[153] on the side which used to link with the futtocks which, measure between 16 cm

[153] Dovetail scarf.

and 24 cm in width (larger on the bottom side). This evidence was also spotted on a fragment of a futtock (PB14-006) with 119 cm length, 16 cm in width on the scarf and between 17.5 cm and 13.5 cm high. The *rabo de andorinha* scarf has a depth of 1.5 cm, and it would be linked to a bottom frame. To reinforce these joints, the shipbuilder used a square-shaped iron nail and round treenail with 3 cm diameter. The last frame to be recorded was the catalogue number of PB14-012 which, represents the Y-frames in the after side and It has 1765 cm in length and 17.5/16 cm thickness. According to the researcher (Bettencourt et al. 2015, 14), this timber does not link with the stern knee but shows evidence of linkage with the hull planks.



Figure 67- 2D drawings of PB14-003 after CHAM (Bettencourt et al. 2015, 22).

e. Mast step (PB14-008): this timber has lost the forward and after ends and at the time measured 200 cm long, the maximum width of 27 cm on the ends and 42 cm on the central area, 21 cm high and 6.5 cm where it linked with the bottom frames. This linkage was reinforced by round iron bolts with 2.9 cm diameters. The area where the mast step linked with the mast has 83 cm of length, 21 cm of width and 11 cm of depth. Presumably, the

orifice with a diameter of 3.5 cm and 4 cm would be used to dredge water and not reinforce the structure with a bolt or treenail (Bettencourt et al. 2015, 14).

f. Hull planks (PB14-002, PB14-004, PB14-005): has from 24 cm to 37 cm width and from 4.5 cm and 5.5 cm thickness. The joinery was built by using two round treenails (2.7 cm and 2.8 cm) and between two and three iron square nails of 1 cm to 1.2 cm. Those nails were inserted through hollows with approx. — 3.5 cm in diameter. Much of the fasteners were caulked on the outboard face. Evidence was shown that caulking was also used to repair cracks on the planks in particular on the outer face.

g. Fastening (no catalogue numbers known): appears to have a mixture of fastening in iron with a square shape and 1 cm diameter to reinforce the joints between the frames and futtocks and, for the stringers, hull planks and the frames. Traces of iron nails and bolt with approx. 2.8 cm and 3 cm diameters were found to presumably join the keelson to the keel, through the frames or the sternpost. The team from CHAM also found little holes made by nails to assemble the lead sheet on the lower side of the hull.

c) According to the produced report (Bettencourt et al. 2015), the reached conclusions pointed to a traditional shipbuilding method known on the Atlantic coast of the Iberian Peninsula between the 16th and the 17th-centuries. These conclusions were based in terms of known archaeological evidence. In particular, after the researcher found scarfs similar to *rabo de andorinha* for the joint between the bottom frames and the futtocks. The presence of a stern knee to link the keel to the sternpost and usage of Y-frames embedded on the stern knee and

> a keelson that comprises the step mast were also evidence of the same shipbuilding tradition. The researcher also strengthens his conclusions based on the existent evidence of a lead sheet to protect the ship hull from sea life. The report finishes concluding: the ship timbers that were washed ashore on the beach of Belinho presumably have their place on a ship representative of an Iberian shipbuilding tradition, which sunk in the 16th or 17th-centuries. He also states that the ship remains to hold a significant value in terms of heritage and knowledge.

The CHAM`s Belinho 1 report constituted the first report made it through a high detailed timber observation. The research team invited in the first place by the local council developed their studies throughout a five days' fieldwork. Although, Bettencourt suggested that there was much more information to collect and investigate. Nonetheless, it was essential at that moment to interpret the ship remains and to find out more about the provenance of the unknown artefacts. Likewise, it had the intention to find possible correlations within the known artefact features and, presumed chronologies. Has the researcher stated (Bettencourt et al. 2015, 15-16) the known evidence shown that the ship remains to represent an Iberian shipbuilding tradition. Supporting its conclusions upon the existent scarfs on the bottom frames and futtocks called by *rabo de andorinha*. The usage of a technology that consists of adding a stern knee with embedded Y-frames to reinforce the linkage between the sternpost and the keel. Also, compliant with the Iberian (Atlantic) shipbuilding tradition (Oertling 2001) is the mast step included on the keelson and carvel-built hull with a lead sheet tacked on the outside face.

Considering the fieldwork report produced by CHAM´s team, the historian Amândio Barros[154] developed his research aiming to find documentation about sunk ships occurred during the late 16th-century on the coast of Esposende. The studies reveal that on the winter of 1577 widows of three sailors from the *Nossa Senhora da Rosa* signup for notary attorney, in order to claims their husbands' properties. The archival investigation revealed this claim on the 14th of March, the same day that villagers, went to the beach of Belinho to collect everything they could from *a sunk ship* (Barros 2016, 53). Although, researchers have not yet found consistent information to correlate the Belinho 1 with the *Nossa Senhora da Rosa*.



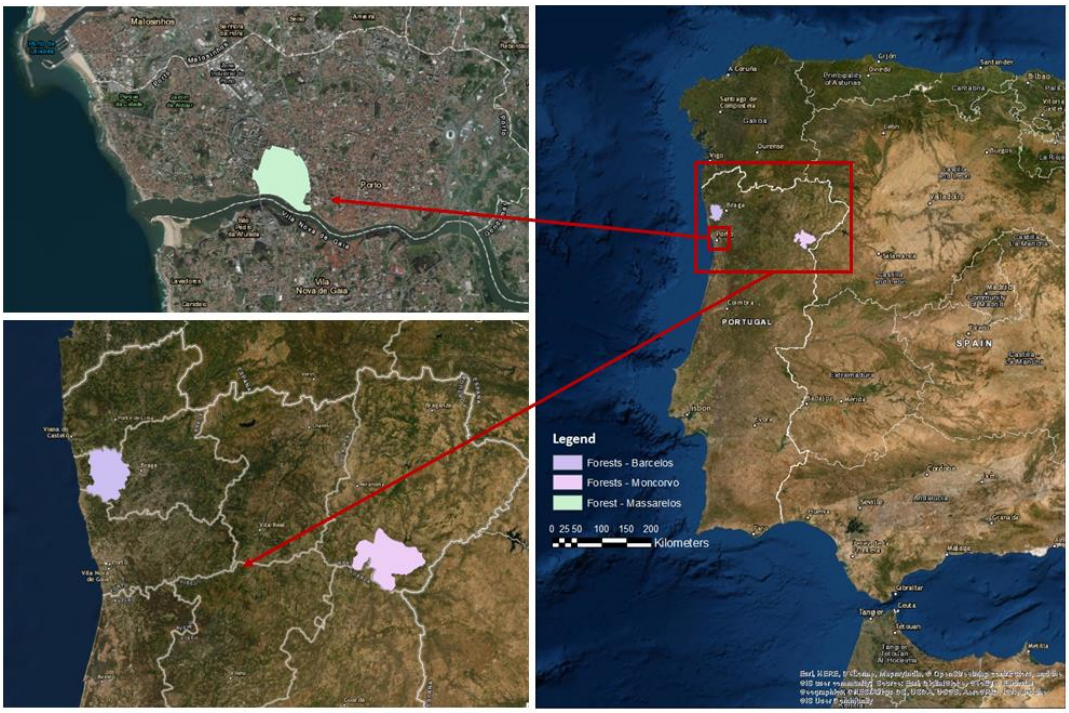
Map 2 - Nautical chart from Lucas Jan Waghenaer 1583, a cognitive map which, represent the cities (from left to right) of Viana do Castelo, Esposende, Vila do Conde and Porto.

Moreover, Barros (Barros 2016) argues that the *Nossa Senhora da Rosa* loaded with Madeira wine, and tar, sunk on its returning journey[155] from the Canary Islands heading to the port of Vila do Conde (located south of Esposende). Which, according to the author, was a well-known route by sailors to transport cereals, wine and dye plants. Another relevant documentation was found by Barros referring to the construction of the

[154] Established researcher from the University of Porto, Portugal https://sigarra.up.pt/flup/pt/func_geral.formview?P_CODIGO=425265

[155] During the Golden Age of Sail, these islands along with the Azores and Madeira Islands were used to restock of water and food by ships coming from India, China and South America. The researcher states that according to the archives, these Atlantic routes were considered regular during the 16th-century.

vessel. Archival investigation yields that Fernão D´Aires built the *Nossa Senhora da Rosa*, and António Eanes using trees harvested Massarelos[156] and had between 70 to 80 tonnes. This information revealed to be of greater relevance once it provided clues about shipbuilding industry located in the vicinity of Porto, using tree harvest in the near town of Massarelos following the guidelines of Portuguese shipbuilders/contractors (Map 3). Thus, this investigation significantly contributed to valuable knowledge about local timber supply and the considering the employed technology in the construction of the (Iberian ship) *Nossa Senhora da Rosa*, implied the timber requirements in quality, quantity and tree`s morphologies.



Map 3 - Map representing the information contained in the archives (by author designed following the publication by Amandio Barros (Barros 2016).

[156] The dedicated forests for shipbuilding of Barcelos, S. Martinho de Mouros and Torre de Moncorvo.

BELINHO 1 PROJECT: TIMBER RECORDING AND SAMPLING – PROJECT DESIGN.

Considering the relevance of the Belinho 1 collection of artefacts, it became imperative to conduct further investigation as required by the Council of Esposende[157]. To study this heritage were gather experts from different areas of science, such as maritime archaeology, conservation and wood scientists, but also with the collaboration of students and local citizens.

The aim of the project[158] consisted of characterising the nature of the shipwreck material (Martins 2015). The project design (Martins 2015a) included the development of a methodology based on several publications to obtain an accurate record of the surviving timbers. The recording process followed the methods employed during the excavation of the Graveney Boat (Fenwick 1978b; McKee 1978), the recording of the Newport Medieval ship (Jones 2013a; Jones 2013b) and the methods developed by Yamafune (Yamafune 2016b; Yamafune 2017; Luís Filipe Monteiro Vieira de Castro et al. 2017).

The expected end-product of the recording campaign was to achieve an accurate record from each of the surviving timber. In a way to be used in tree reconstruction studies and ship recognition to fully characterise the ship timbers parent trees and the technology employed to build the vessel. Regarding the theme of the present doctoral studies, this project substantially contributed to finding answers about wood features (anatomy, morphologies). Within this ambition, four objectives were determined:

[157] This led to the invitation addressed to the ForSEAdiscovery Project researchers in order to develop a summer school from the 2nd to the 23rd of August of 2015.
[158] The project design flowed the guidelines published by Historic England - M.O.R.P.H.E. - Management of Research Projects in the Historic Environment: The MoRPHE Project Managers' Guide (Historic England 2015).

a) To enhance understanding of the Belinho 1 shipwreck through recording of its surviving timbers.
b) To enhance understanding of the Belinho 1 timbers through the implementation of wood science studies. Including microscopic wood anatomy, dendrochronological analysis and geochemical analyses.
c) To develop and test a methodological approach to gain a better understanding of:
    a. Timber´s morphologies employed during the Iberian Golden Age of Discoveries.
    b. Trace evidence of forest management.
    c. Timber supply and wood provenance particularities
    d. Moreover, the dedicated forest and landscape to supply the Iberian shipbuilding industry.
d) To develop 3D digital ship reconstruction studies to identify the shipbuilding tradition and to obtain the ship´s profile (dimensions and tonnage).

BELINHO 1 PROJECT: TIMBER RECORDING AND SAMPLING – RECORDING STAGES AND EMPLOYED METHODS.

The employed method to define the fieldwork workflow was partially based on the guidelines produced during the recording of the Newport Medieval Ship (Jones 2013a; Jones 2013b; Nayling & Jones 2014; Nayling & Susperregi 2014). However, adjustments have been made to those guidelines in order to adequate to the reality of Belinho 1 artefacts.

Within the predefined objectives, a methodical and systematic workflow (Table 7) was designed to the definition of the recording criteria.

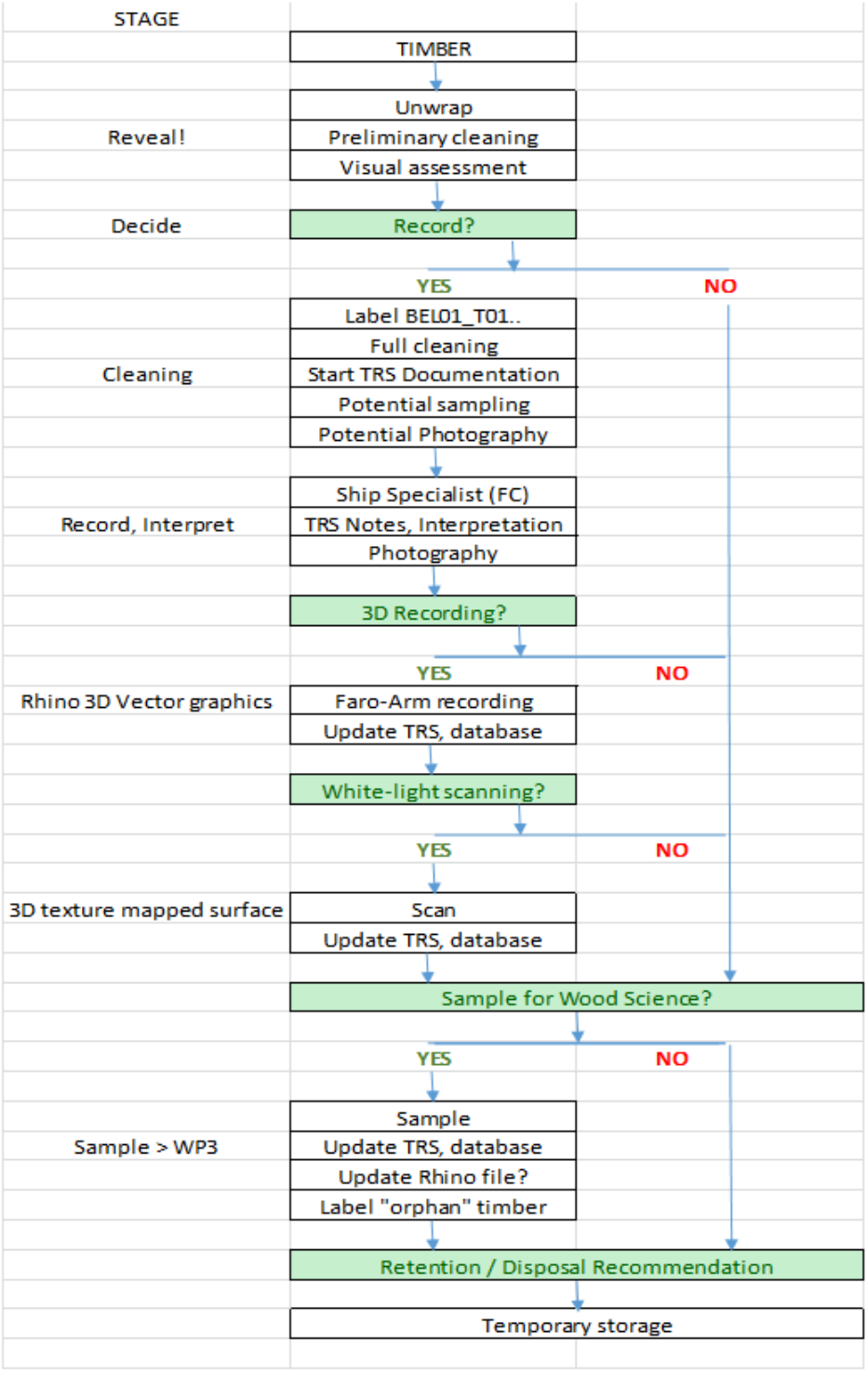


Table 7 - Table produced to illustrate the workflow decision and the organisation of the working stations (Martins 2015a).

Aiming to achieve successful accomplish objective c), the workflow consisted of:

a) As the timbers were randomly recovered and stored in a freshwater tank wrapped in plastic film, the first task was to separate them by their specificities. This task

involved gathering similar timbers in a separated location inside the tank (Figure 68). More considerable attention was given to the potentially best-preserved timbers. This task involved the selection of floor timbers, stern knee, sternpost, a section of the keel and the Y-frames (for catalogue numbers see APPENDICES 1 – PUBLISHED PAPERS WITHIN THE PRESENT THESIS.).



Figure 68 - Photograph representing the task of organising timbers inside the tank (photograph by Ana Almeida).

b) The workflow was designed to comprise six working stations in which decisions had to be made, as some of the timbers were not moved to in accordance with the workstations sequence (table above). The adopted criteria was based on the relevance of each timber to the achievement of the predefined objectives. Meaning that after the completion of the designated tasks in each workstation the team decided to which station the timber would be transferred.

c) Each timber (one-by-one) was then transferred to the Cleaning station. To achieve a safe method to transfer the timbers, two techniques were employed: using a rolling tray and by crane. After unwrapping the film using freshwater, the remaining sediment and small stones were carefully removed and collected (if any) traces of caulking material for analysis. From the treenail's holes was removed the sediment and sea life in it (Figure 69). During the cleaning process was also performed a visual assessment while the Timber Recording Sheet (TRS)

was filled with detailed information about surviving wood and ship architecture features and a hand sketch.



Figure 69 - illustration of the cleaning task and timber features identification (photograph by the author).

d) The next stage involved labelling the timbers within a numeral sequence. Each timber was labelled with an inventory number (e.g. BEL01-001W[159]) accompanied by a TRS (Figure 70). This initial assessment of the individual timbers allowed the definition of conservation procedures and to refine the selection of timbers possessing relevant information to the purpose of tree reconstruction studies. The culmination of this stage ended by taking a general photograph and closeup photographs of timber´s most relevant evidence.

[159] BEL01-001W stands for Belinho 1-timbers number Wood.



Figure 70 - Illustration of the cleaning, labelling, initial recording dimensions by hand notes (photograph by the author, TRS filled by Filipe Castro).

e) Based on the workflow table, if the decision made was to continue recording, an expert in shipbuilding continue the acquisition of information about the ship timber. In this stage was employed the method developed by McKee (McKee 1978) with adaptations. A panel in which a grid was marked was placed bellow the timber to provide a scale and references to produce of 1/10 scale hand drawings. Direct measurements (McKee 1978) were also taken and written on the TRS.

f) If the timber comprised relevant information to the performing of trees reconstruction studies, was then transferred to the Rhinoceros 3D Vector Graphis Station. Timbers included in this stage were then prepared and recorded following the next steps:

a. The Rhinoceros 3D layer system developed during the Newport Medieval Ship digital recording was adapted to the circumstance of the Belinho 1 surviving timbers before the installation of this station

   i. The Rhinoceros 3D layer collection was adapted from the manual produced by Jones (Jones 2013a). These modifications included the use of two sets of templates: 1st set containing the adequate layers to the transversal timbers four faces (port, starboard, forward and aft faces), and the 2nd set of templates to the longitudinal timbers (inboard and outboard faces). Each of the templates comprised sublayers grouped by faces. Sublayers allowed recording of the full range of archaeological features edges a and wood features.

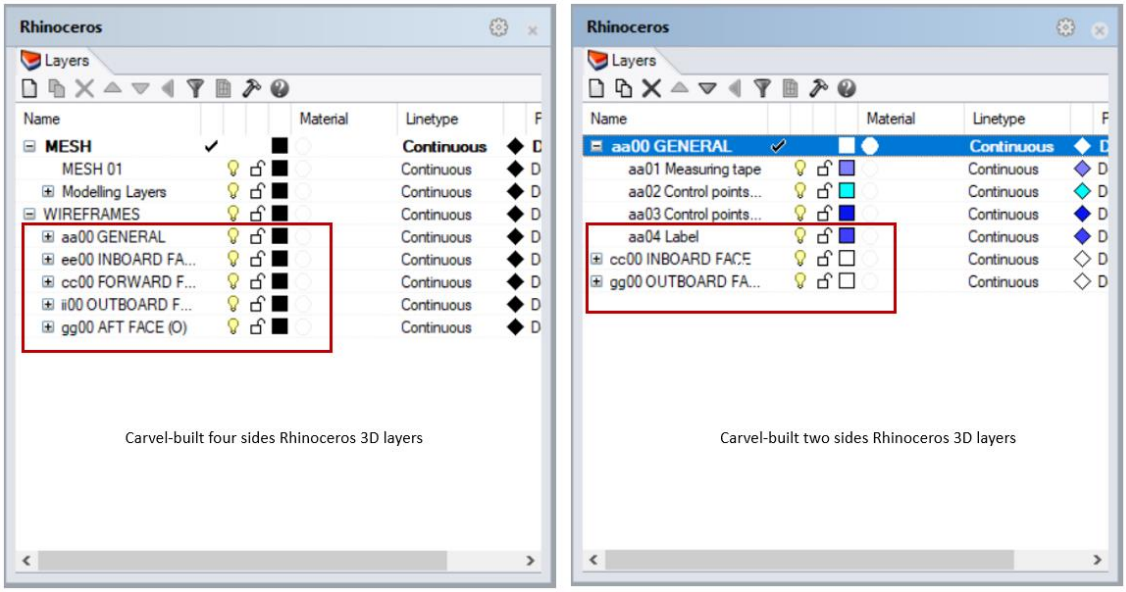


Figure 71 - Illustration representing the two sets of adequate layers to record carvel-built vessels.

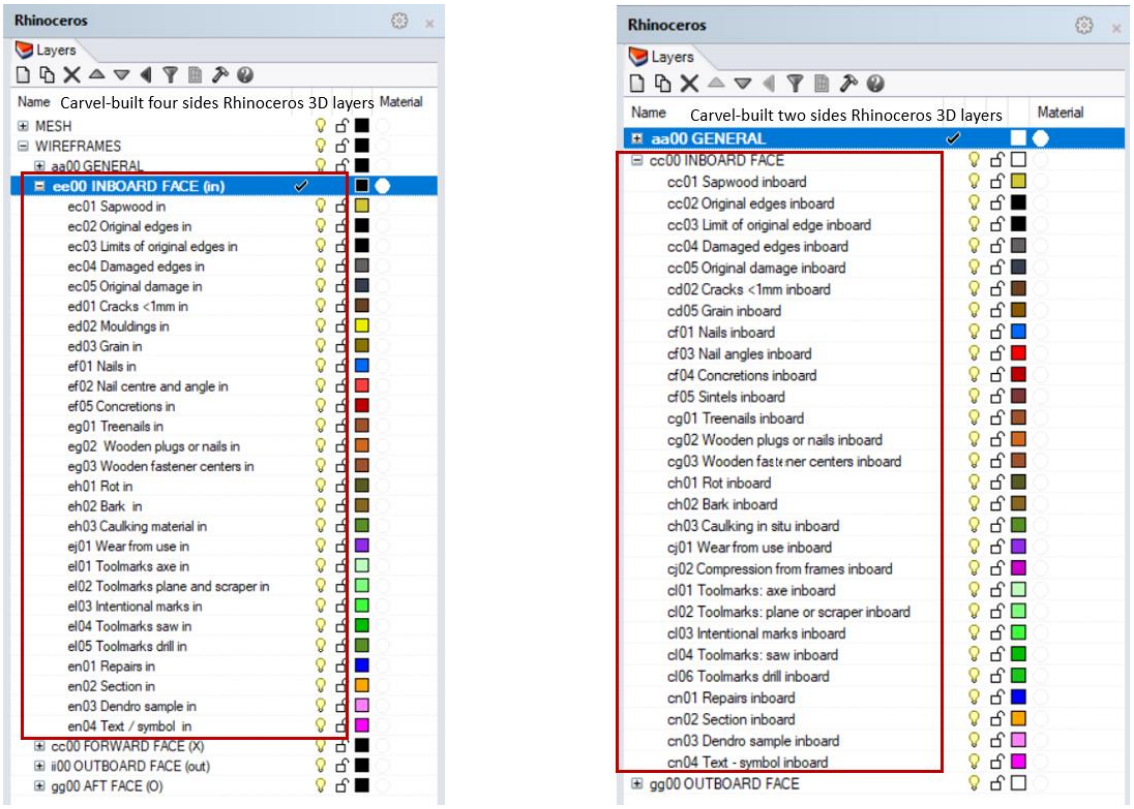


Figure 72 - Illustration of the predesigned sublayers to record carvel-built ship timbers.

ii. The first task was to set a working station comprising a widescreen television of 42 inches (to use as a desktop monitor), a wireless keyboard and mouse, the laptop with Rhinoceros 3D 4.0 installed and a table sufficiently robust and long in which each timber could be placed on the display. The option to use rhinoceros 3D version 4.0 resides on the requirements in compatibility imposed to use the available FaroArm a Gold Arm version. The next task was to calibrate the 3D digitiser arm following the constructor guidelines and requirements. Using the manufacturing software Calliper 3D. Once FaroArm had been calibrated, the link between the FaroArm and the Rhinoceros 3D software was established using RS232 serial port the only compatible connection wire to the Gold Arm. Thus, obliged

to work with the Rhinoceros 3D 4.0 since the only way to work with the available 3D digitiser arm.

iii. A procedure was used to check that the FaroArm was generating correct information in the Rhinoceros software environment. This was achieved by marking in the table´s side three points (using the *General layer* - *measuring tape*) at a precise distance of 20 cm from each other. Allowing to double-check the exact correlation between the measurements in the *real world* with the digital environment. To record these three points in Rhinoceros 3D was used the tool *Point* and pressed the *green button* on the digitiser. These points should be recorded by placing the arm ´s probe directly on top of the marked point in the table in a perpendicular (straight) alignment with the table´s surface. To compare the distance between the three points in Rhinoceros 3D window, should be select one of the four views: *top*, *bottom*, *left* or *right*[160]. Then using the tool *Distance*, selected the option *Point* in *Osnap* and placed the cursor on top of the first point and pressed the mouse *left button* dragging the line until the next point and then pressing the mouse´s left button agai*n*. This will allow to observe in the command line the distance between points and to cross-check if the digitiser arm is calibrated with the Rhinoceros 3D software. A

[160] The View: Perspective should be avoided to reduce measuring errors and excessive time-consuming to find the following point.

sequence of measuring distances between the first to the second point and the first to the third point should be applied.

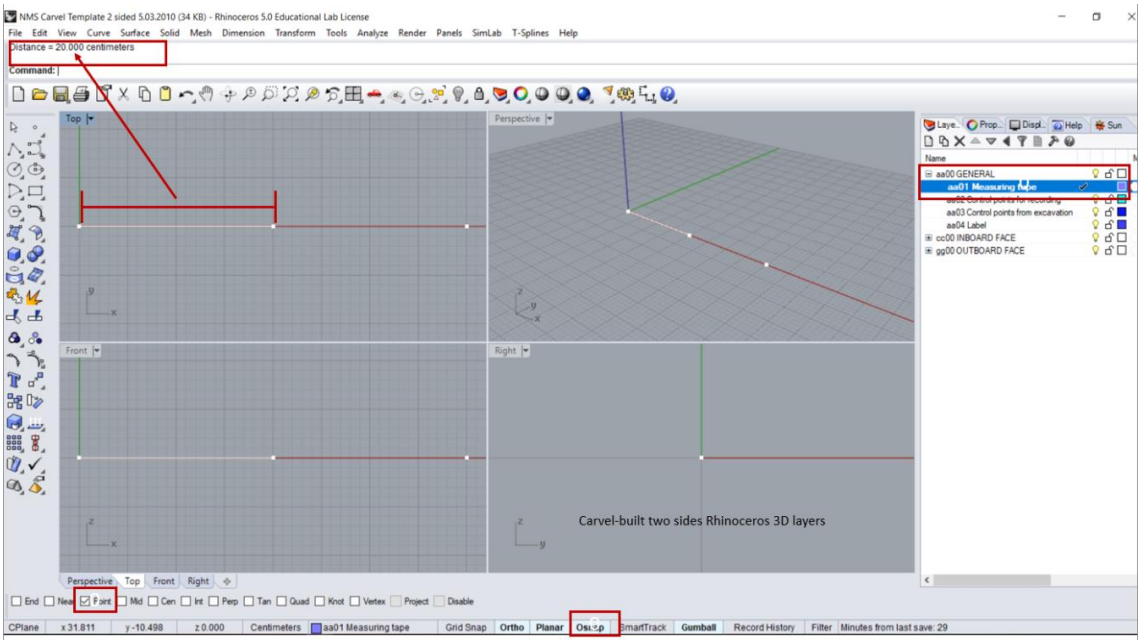


Figure 73 - Illustration containing the adequate options in Rhinoceros 3D software to calibrate the recorded points (marked on the working table) with the digital environment.

iv. Completed the calibration, a smooth material such as carpet should be used to cover the table to provide a soft bed to the timber and to retain the water drained from the waterlogged timber. The ship timber should be placed on top of that carpet in its full extent to avoid damaging the timber´s surface and consequently the loss of evidence. It should be noticed that some of the wood features such as visible annual rings, some softened knots by degradation, part of the grain flow (growth pattern), may be lost during the management of waterlogged timbers. Therefore, maximum caution was addressed during the timber´s transferring between workstations. Also, before placing the timber on the table, in a way that the FaroArm operator could be able to use the arm at its

maximum extent to avoid unnecessary use of leapfrogging (Jones 2013a).

v. Physical control points such as screw nails were attached perpendicularly embedded in the ship timber surfaces. This task will allow performing leapfrogging when needed and to *Orient* the digitiser arm when resuming the digital recording after swapping from the top surface to the bottom surface (see detail information in the publication by Toby Jones (Jones 2013a, 10).

vi. The next stage included a visual assessment and definition of the path to be recorded using the digitiser arm. In this particular stage, greater attention was given to the integrity of each timber surface. The operator could only record one surface at the time. This operation involved placing pins to be used as reference guides during the digital recording.



Figure 74 - Illustration of the method to identify the digitiser probe`s path to accurate record each timber surface (photograph by Ana Almeida).

vii. After defining the digitiser path, in Rhinoceros 3D was selected the tool Sketch curve[161], and with the correspondent, layer initiated the recording. Collect line data for each of the successive layers for each of the faces available for recording (Figure 71 and Figure 72)[162].

viii. Once the recording has been completed on accessible faces the timber was then turned over to provide the digitiser to remain face or faces.

In completion of the recommendations provided above, more considerable attention will be given now to the recording of wood features and the required accuracy. As stated before, waterlogged timbers should be managed with extreme caution to avoid the loss of natural wood features. This can be achieved by adopting slow movements and prepare the way between workstations, using gloves if needed and by avoiding abrasive materials during the transference and deposit of the timbers. In the following pages will be addressed and described the process of digitally record the surviving wood features based on the attained knowledge and experienced.

[161] Correct path: Tools menu / 3D – digitiser / Sketch curve (drawing lines from a number of recorded points) or Polyline curve (a polyline consists of a line segment that are joined end to end).
[162] The Rhinoceros 3D set of layers should defined before initiating the digital record of the artefact. This does not mean that new layer cannot be added if necessary, but waterlogged timber should be stored in wet of humid place which is not compatible with computing hardware. Therefore, every minute that a waterlogged timber is place outside of a wet zone the degradation a loss of information accelerates the degradation of the artefact.

THE RECORDING OF WOOD MORPHOLOGIES: A STEP-BY-STEP DEVELOPED METHODOLOGY.

During the development of this doctoral studies, many hours were spent in fieldwork seasons and post-excavation (laboratory tasks) in which the following methods were developed, refined and tested. Some of the addressed techniques were adopted and adapted from the previously mention thesis (Jones 2015; Yamafune 2016b; Dostal 2017).

The developed methodological approach widely discussed within this doctoral thesis aimed to:

a) Record surviving ship timbers within an efficient and effective way.
b) Demystify the complexity of gathering multiple areas of science in one efficient method.
c) Allow performing a visual assessment on the timber's surfaces, to enable researchers to divide timbers into three groups: morphologies, anatomy and collective particularities.
d) Produce a detailed catalogue of timber based on their morphology rather than *just* on their functionality in the ships or building structures.

There a number of ways of recording archaeological timbers including traditional and digital method such as hand-notes, 3D digitiser/laser scan and photogrammetric techniques. In some cases, the conjunction of two or three techniques may be the employed. In particular, when the timbers are on display in complex locations or on a more aggressive environment. As mentioned in chapter four of the present thesis, previous conservation techniques (TREE RECONSTRUCTION OF THE VOC BATAVIA

PLANKING.) or obstructed and still assembled timbers (timber recording of the Bremen Ship) may require a substantial adaptation of the established recording techniques (McKee 1978; Jones 2015; Yamafune 2016b; Dostal 2017). Therefore, a combination of procedures will be provided as a solution to the most challenging conditions to obtain accurate data from wood morphologies. The relevance of this thesis section relies on the fact that accurate data must be obtained to perform tree and landscape reconstructions. Otherwise, the end-product will distort the reality of the archaeological evidence and potentially conduct to a misinterpretation of the archaeological context. The method was designed based on attained knowledge and experience-based in a way to provide the route to that knowledge and also the smooth path to the achievement of successful and accurate end-results.

Within the above discussion, there are two environments in which the surviving timber may be located: underwater which includes the intertidal zone and water tanks; and, the dry areas, including storage facilities, museums exhibitions, reserves or open areas. At the first impression, it may seem obvious this separation of environments, but the conditions in which timbers are located are of greater relevance to determine which techniques should be employed for its recording.

RECORDING WOOD FEATURES USING A FAROARM 3D DIGITISER.

The acquisition of wood features from archaeological timbers using a FaroArm 3D digitiser implies setting up a workstation as mention in the above section (Line f). The first step is to conduct a critical visual assessment of the surviving wood features to identify the particularities in each face. This included identifying the location of knots, natural cracks, the grain flow (growth pattern) and the natural edges (the edge between the

heartwood and sapwood). To achieve a successful result, a few aspects must be considered:

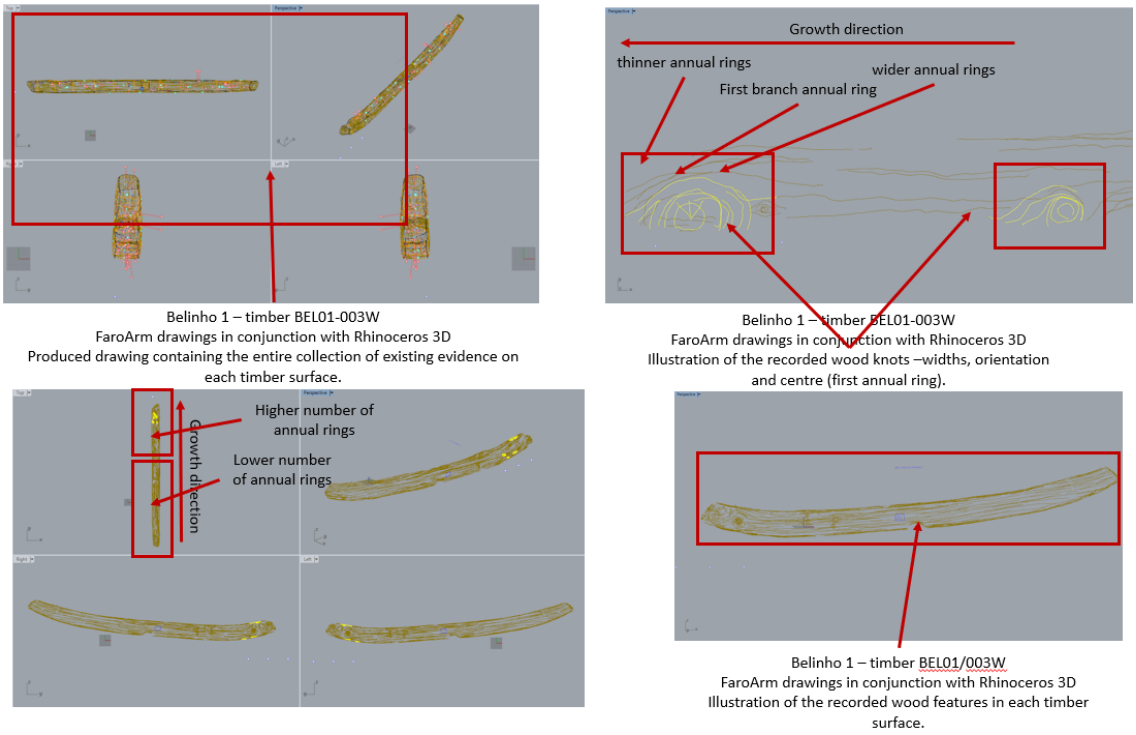
a) Knots:

   a. Close inspection will identify the maximum and minimum width of the knots and, will provide information about the orientation of the remove brunch. This will also provide information about the orientation of the timber in relationship with the parent tree. In the oak trees (*Quercus sp*.) as in other broadleaf trees, the branches attempt to grow up to obtain as must solar energy as possible. Therefore, the upper part of the knot should possess annual rings having a small distance between each other. As opposed to the lower part in which the annual rings must be wider to provide a robustness to the branch in a way to support its weight. In most of the observed oak family specimens, the knots have an almost oval shape in which the upper part has narrow annual rings compared to the lower part. Thus, knots provide consistent information about several morphology features related to the shape and angle, size and position of branches:

      i. Can provide relevant information about the tree`s growth direction. In other words which end of the timber is nearest to the bottom of the tree and which is near to the top of the tree.

      ii. Can provide relevant information about the type of woodland/forest characterization – dense forest as opposed to the open landscape. A low number of knots are in general a synonym of dense forest as the tree grow higher to compete with others to capture solar energy. A higher number of knots in tree growing in

open landscape (see more information in chapter two (***Chapter 2 - The Iberian shipbuilding tradition and the morphologies of trees woodlands, shipyards and treatises***) for detailed information.



Belinho 1 – timber BEL01-003W
FaroArm drawings in conjunction with Rhinoceros 3D
Produced drawing containing the entire collection of existing evidence on each timber surface.

Belinho 1 – timber BEL01-003W
FaroArm drawings in conjunction with Rhinoceros 3D
Illustration of the recorded wood knots –widths, orientation and centre (first annual ring).

Belinho 1 – timber BEL01/003W
FaroArm drawings in conjunction with Rhinoceros 3D
Illustration of the recorded wood features in each timber surface.

Figure 75 - Illustration of a record from a timber (BEL01-003W – floor timber) containing the data acquired from wood features – wood morphology, annual rings, knots, crack and grain lines (drawing by the author).

b) Natural cracks:

   a. Cracks can be observed across the timber surface, although they might be interrupted by other wood features or human-made shape.

   b. Their location may not be coincident with the centre axis of the timber, as its location is directly related to the conversion of the timber from the parent tree.

   c. The angle of the crack may provide relevant information about from which side of the tree the timber was obtained. In some planks (e.g. Bremen Ship and Belinho 1) the natural crack angle provides information about the location of the tree pith in relation to the plank face.

d. Natural cracks commonly provide relevant information about the location of the tree´s first annual ring (the pith). The orientation of the natural cracks is coincident with the grain flow (growth pattern) apart from the deviations caused by the branches which have a pith linked to the trunk pith.

e. The natural cracks may not be visible or differentiated from other cracks. However, a close visual inspection will bring to attention as these cracks are always following the grain direction.



Belinho 1 – timber BEL01/071W (stern knee)
FaroArm drawings in conjunction with Rhinoceros 3D
Produced drawing containing evidence of the pith location
after identifying the natural cracks.

Figure 76 - Illustration of from a timber (BEL01-071W – stern knee) containing information about the trunk and branch`s pith location.

c) Grain lines (growth Pattern):

a. The recording is considered as essential as other wood feature. It provides relevant information about the growth pattern direction and orientation.

b. The recording of detailed information about the grain lines will provide the surviving shape of the parent tree.

c. The recording of grain should only contain the visible grain lines, curvatures and be interrupted ever since it is not visible or reaching missing parts in the timber´s faces (e.g. fastening, wood degradation caused by sea life (*Teredo navalis* (shipworm) or other animals/vegetable).
d. Grain should be recorded from each of the timber´s faces, including the bottom/aft and upper/forward faces. This includes the recording of the pattern generated by the annual rings and the multistoried rays (in the case of the oak family). The recording of the direction of the radial rays will provide relevant information about the pith location and therefore, clues about timber conversion technique[163] and from which sector of the tree´s trunk or branch the timber was obtained.
e. Detailed recording of the grain lines will also provide information about timber selection. The analysis based on the recorded grain flow will allow identifying if the ship timber was obtained from a tree having a compliant shape to the predesigned timber. For instance, where the curvature of the grain is closely aligned with the curvature of the timber.
f. The recording of grain lines in conjunction with the pith location may equally provide relevant information about the landscape in which the parent tree was planted (e.g. flat landscape or slop). A noncentral pith in the trunk of a tree often related to that tree growth on a slop as against tan horizontal landscape.

[163] Quarter, half, eights.



Figure 77 - Illustration of from a timber (BEL01-036W – Y-frame) containing information about the patterns recorded from the annual rings and medullar tangential rays.

RECORDING TIMBERS USING THE PHOTOGRAMMETRIC TECHNIQUE.

The recording of wood artefacts can be successfully achieved by using computer vision photogrammetry techniques (Yamafune 2016b). As mentioned to the recording of wood features using a 3D digitiser, tree reconstruction studies imply a thorough and detailed recording of wood features. Meaning that a comprehensive recording of the grain lines, natural cracks and knots should be included during on excavations and laboratory fieldwork. The use of this technique will provide data to the reconstruction of timbers parent trees if the added photographs have sufficient quality and capable of providing sufficient detail to the produced 3D model:

a) The end-product will not comprise the relevant data if the captured photographs revealed to be blurred or taken from a distance.

a) Several aspects must be considered, such as:

a. Quality of the 3D model: calibrated on the three-axis (X, Y, Z), fine texture, integrated scale, greater attention given to the wood features while photographs are being taken, photographs cover a 100% of the surviving timber.

b. The software used to produce the 3D model based on the taken photographs (e.g. Agisoft Photoscan/Metashape) must provide the user with compatible exporting tools[164].

c. To obtain an accurate 3D model of a timber to perform tree reconstruction studies, it is suggested to employ a protocol similar to the developed within the techniques developed by Kotaro Yamafune (Yamafune 2016b).

d. Considerable attention has to be given to the limitations imposed by the environment in which photographs are being taken.

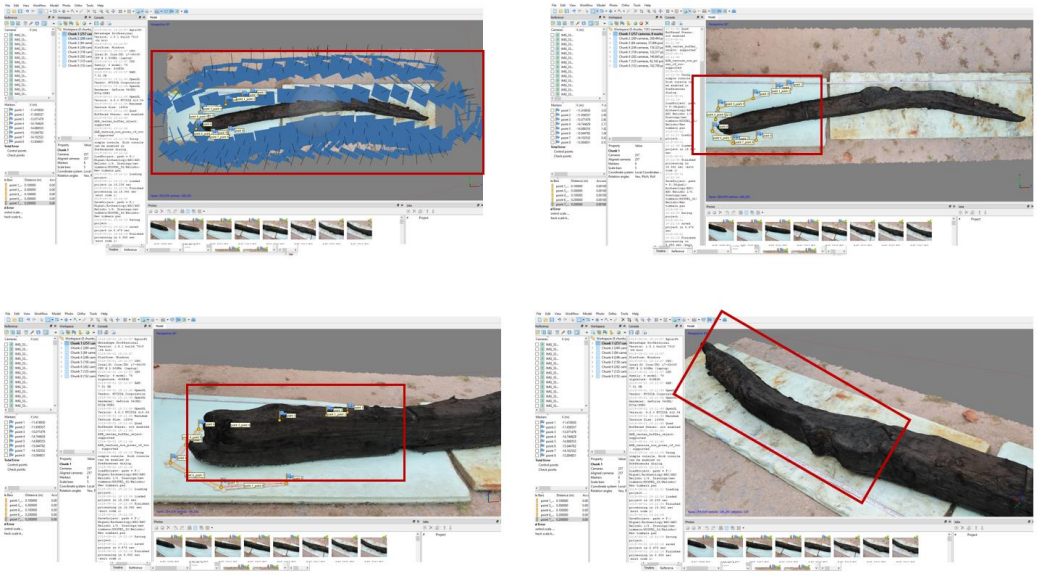


Figure 78 - Illustration of the adopted method to the recording of archaeological timbers using computer vision photogrammetry techniques (screen captures and performed Agisoft Photoscan processes by the author).

[164] Most of the developed 3D software have on its exporting the option obj (3D Object) which is the most reliable and compatible file extension to export / import between software. However, some software offers the tool of exporting as fbx (Filmbox) which saves the produced data in one file rather than the option of exporting as obj which comprises a file containing the 3D object and multiple jpg (Joint Photographic Experts Group) files containing the mapping texture.

RECORDING TIMBERS USING HAND SCALE DRAWINGS TECHNIQUE.

The use of hand scale drawings represents the most challenging techniques and perhaps the lowest level of success to the performing of tree reconstruction studies. Although, if the drawings included the above-mentioned wood features, it is possible to achieve some results and therefore, clues about the timber`s parent tree morphologies. The technique involves converting the hand drawings into digital documentation and to import the *jpg* files into the Rhinoceros 3D software. The success of this technique is directly related to the adopted protocol by the hand drawings author. As it might seem obvious, if the author does not introduce in its drawing the wood aspects such as grain lines (growth pattern), knots, cracks and the lines representing the natural edges – the drawings do not suit the purpose of tree reconstruction studies. Another relevant aspect that should be considered the line thickness to obtain a representation of an archaeological timber. The scale drawings must not be produced from multiple lines to draw a unique line. Meaning that sketching thin lines will generate indecisions about the location of the reproduced aspects/features. Therefore, hand scale drawings should be produced using sharped pencils of thin markers in a way to draw straight and unique lines to illustrate the archaeological timber`s edges, particularities and wood features.

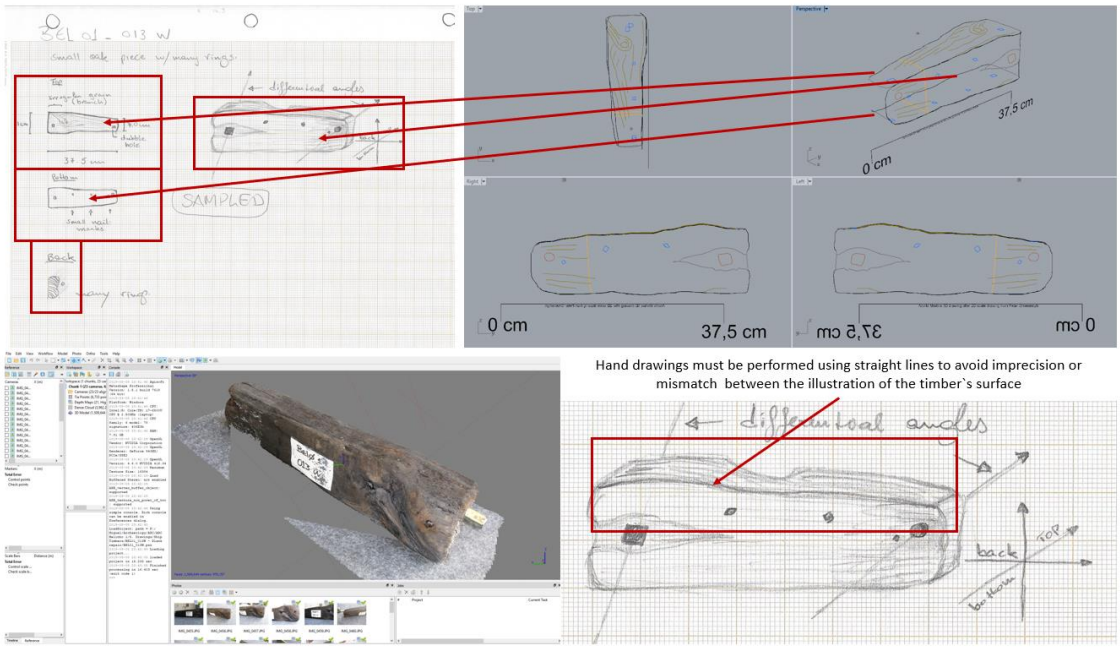


Figure 79 - Illustration a scaled hand drawing to reproduce timber BEL01-013W (structural fragment). The illustration represents different stages of the converting method from a scaled 2D drawing into a 3D digital drawings using the recorded dimensions to calibrate the Rhinoceros 3D file and the use of computer vision photogrammetry to obtain the timber`s surface texture (hand drawings by Filipe Castro and digital models by the author).

The method to obtain a 3D digital model from a hand scale drawing may vary from technique to technique. Although, to the purpose of tree reconstruction studies, the employed method to the present doctoral studies followed the next stages:

a) Drawings must be scanned into *pdf*[165] or *jpg* files.

b) The next stage is to import the image file into the Rhinoceros 3D software:

   a. In the folder in which the *jpg* file is stored – select and drag the file into the Rhinoceros 3D window (the drop windows should correspond to the same view illustrated in the drawing).

   b. Select option *Grid snap* and press in the coordinates *0* from the X, Y and Z axis to insert the drawing in the centre and then select a point in distance

[165] If the drawings were converted into pdf file, must be export in a pdf software into image file preferably into *jpg* file.

from the first to allow the insertion of the image. Then using the tool Polyline must draw a line in direct correspondence to the 2D hand scale drawing. This line should possess the same length as the scale in the drawing.

c. Using the tool *Scale,* the drawing has to be dimensioned in a way to correspond the included scale in the hand scale drawing to the produced line in Rhinoceros 3D. Once completed the scaling, the drawing must be included in a layer named 2D drawing (to change the layer name or move the object from a layer to another see (Jones 2013a; Jones 2015).
d. After selecting the layer *Scale,* a scale must be drawn using tools *Rectangle*, *Hatch*, *Text box* and Group (see further information in (Jones 2013a).
e. Using the tool *Control point curve* lines should be drawn in accordance with the information contained in the drawing. These lines must represent the surviving *Original edges*, *damage edges*, *grain*, *cracks* and *knots*[166]. This process must be performed to every timber`s faces represented in the hand scale drawing.
f. The next step is to use the hand notes to obtain the thickness of the timber. To achieve a digital representation, the starboard side surface must be turned clockwise and dragged to the position of the port side surface. Then the thickness may be measured using the tool *Line*. The method consists of drain a short horizontal line and in the vertical direction

[166] To obtain a complete digital record from the scale hand drawing may be included the layers and lines illustrating the treenails, tool marks, iron nails and nail`s centre.

and correspond the height of this line with the hand notes to the same dimension. This line should be finished with another horizontal line. In this way, the horizontal lines may be used to the positioning of the recorded timber surfaces previously transformed in Rhinoceros 3D.

g. The next step consists of in the production of a 3D object from the converted scale hand drawing. This may be achieved by joining the correspondent lines from both 1/1 scale drawings. Thus, using the tool *Line*, all similar lines must be connected. Meaning that the original edges and damaged edges should form a face. Using the tool *Surface2rail* select the rails, and the curves and then solid faces will be integrated with the drawing. This process will transform 2D lines into an accurate 3D object.

h. Unfortunately, no cross-sections were recorded during the hand drawing. Therefore, it is more difficult to reconstruct the parent tree and show the conversion of the timber.

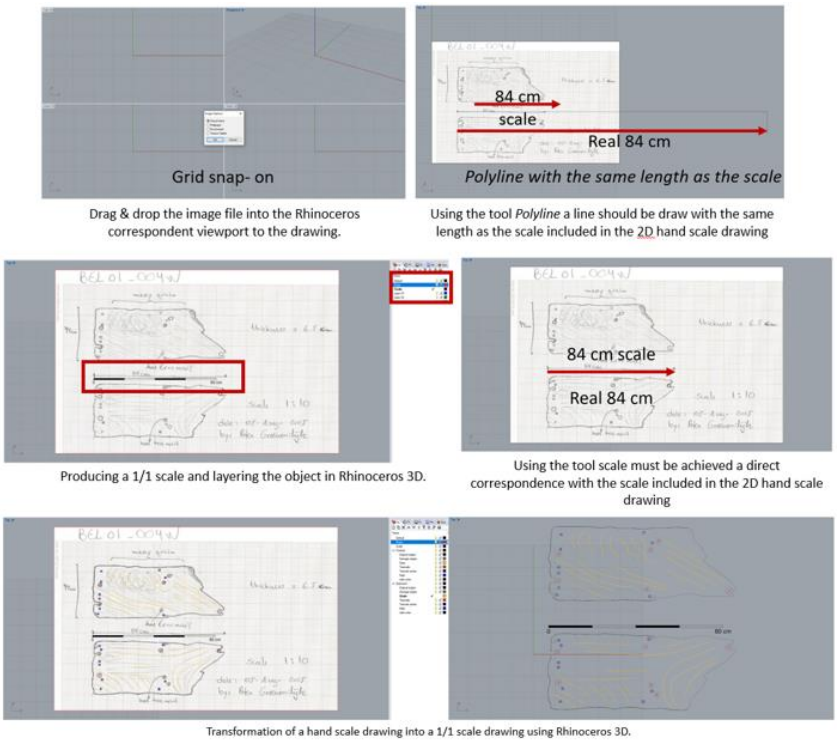


Figure 80 - Developed method to convert a 1/10 scale hand drawing (timber BEL01-004W) into a 3D object using specific tools in rhinoceros 3D (screen captures and produced a 3D model by the author).

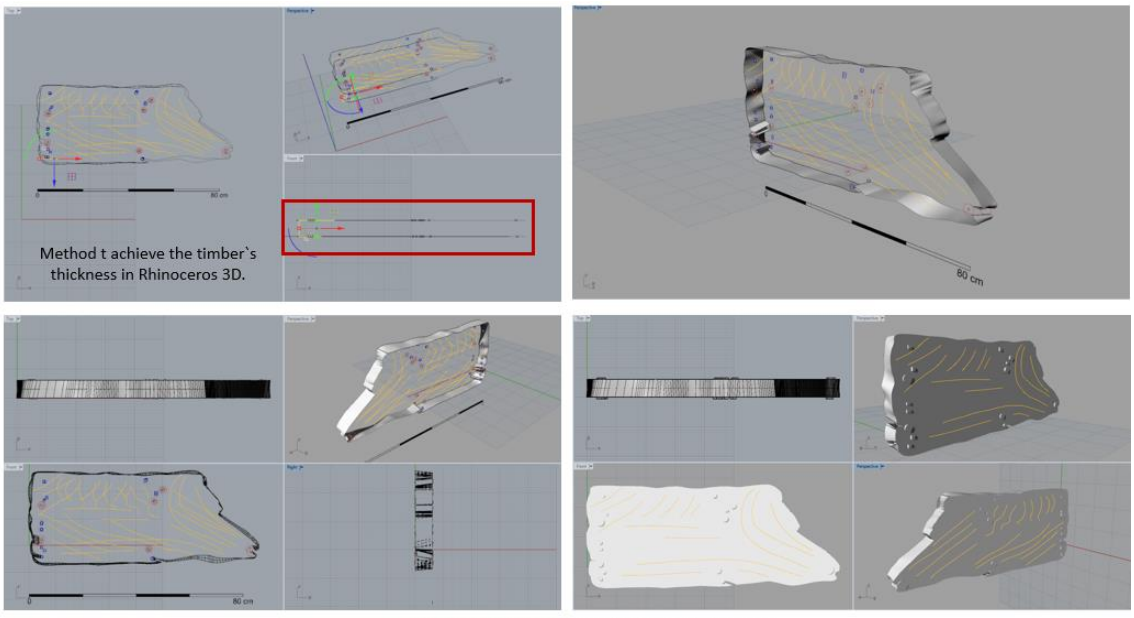


Figure 81 - Illustration of the developed process to convert 1/10 scale drawings into 1/1 scale 3D digital objects (by the author).

THE DEVELOPED METHOD TO RECONSTRUCT ARCHAEOLOGICAL TIMBER`S PARENT TREES BASED ON SURVIVING EVIDENCE.

The developed approach aiming to perform archaeological timber`s parent trees reconstruction involves a group of tasks prior to the method itself. As mentioned in the previous paragraphs, it is highly recommended to obtain a wider understanding of trees morphologies and their particularities. Several studies have tried to develop a mathematic logarithm to predict or analyse the tree`s growth parent (e.g. Cheraghalipour et al. 2018). However, many environmental and external agents may interfere with tree natural growth. These agents gather a combination of events which in some cases are triggered by humans. During the Iberian Golden Age of Discoveries, foresters dedicated their life to the development of suitable techniques to obtain *good timber* for the shipbuilding industry. In such cases, this *good* timber could only be achieved within a minimum of two generations. In which the first planted the tree and started its management, and the following generation obtains the required shapes/morphologies. To obtain a suitable tree from which floor timbers, futtocks, keels and mast steps where extracted required the management of parent trees having at about 38 to 65 years old. In this way and considering that European life expectancy during the 16th to 18th-centuries was between 35 to 40 years old; a suitable parent tree could only be achieved within two to three generations. This process had to clearly be based on knowledge transfer. On the other hand, also considering the political instability deeply established in Europe during the Medieval and Post-Medieval Age it was highly uncertain to ensure that dedicated woodlands/forest to the shipbuilding industry could provide the required *good* timber. Therefore, the Portuguese and Spanish crowns have developed policies to the effective protection of such woodlands (further information in the Introduction of the present thesis). In addition, the archaeological surviving material in analysis nowadays on represent a highly reduced testimony of the demanding shipbuilding industry. Apart from the Baltic Sea, Medieval and Post-Medieval shipwrecks represent a scarce testimony of the past shipbuilding technology and construction techniques; and, an even reduced demonstration of the

complex and intense system to obtain, provide and employ trees growing to the purpose of this industry. Therefore, it urged to develop a thorough, precise and efficient approach and associated methods to reconstruct those parent trees to obtain a better understanding of the human decisions made prior to the construction of naos, caravels and other ship types employed during the discovery of the overseas territories. In this way and associated with the ship reconstruction techniques it became possible to trace back the construction of vessels on its entire theorisation, conceptualisation and framework. Tree reconstructions studies offer an innovative opportunity to reconstruct maritime landscapes on its maximum exponent:

a) Woodland/forest reconstruction – parent trees reconstruction based on archaeological and wood evidence.
b) Parent tree reconstruction – identification of the criteria adopted to obtain good timber to shipyards.
c) Archaeological timber – understanding of the pressure exerted by the shipyards on the woodlands/forest to have them providing suitable timber.
d) Surviving timbers – a better understanding of the limitations imposed by the wood/trees on the shipbuilding technology.
e) Ship timber – identification of the adopted techniques to obtain suitable timbers despite the shortage of adequate timber.

In a way to present the developed approach and associated methods, five types of structural timbers from the Belinho 1 shipwreck will be used as representatives of different parent trees. Each of the timber will be presented and described focusing on:

a) Its functionality on the ship`s hull.
b) A comparison with other similar timbers also identified in other shipwrecks.

And, then followed by an individual:

c) Reconstruction of each parent tree profile.

d) The reconstruction of the landscape in which the parent tree was planted.

The selected timber from the Belinho 1 shipwreck comprises the Y-frame BEL01-001W, Floor timber BEL01-003W, the plank BEL01-054W, the section of the keel BEL01-071W and the stern knee BEL01-072W.

RECONSTRUCTION OF THE Y-FRAME BEL01-001W.

BEL01-001W was the first recorded surviving timber from the Belinho 1 shipwreck. In terms of its functionality in the ship`s hull, this type of timber allowed to reduce the thickness of the hull[167].

In the Iberian shipbuilding tradition from the 15th to early 17th-centuries, the Y-frames were displayed on top of the stern knee. Its name was given by its shape *Y*. Essential for achieving the desired hull shape both ends had to be sharp at the bow and stern within a skeleton-first shipbuilding architecture. These timbers were secure by copper alloy or iron bolts nailed from the outer side or outboard. Outer planks were secure with a combination of treenails and iron nails. The length (vertical size) is directly related to the height of the stern. Alves (Alves, Reith, et al. 2001, 415) made a comparison between the Corpo Santo and the Aveiro A wrecks in terms of the hull shape and the purpose of the ship - shallow water or deep sea, cargo or war vessel. The *Y* shape timbers were also recorded during the excavation of the Angra D[168] (Garcia et al. 1999). Oertling included on his table (Oertling

[167] In the Iberian vessels from the 16th to 18th-centuries, the hull`s profile was thinner in the aft part of the hull to allow better buoyancy and larger in the forward part to allow cutting water.
[168] Angra D is an underwater archaeological site that is part of the Underwater Archaeological Park of Angra do Heroísmo Bay, on Terceira Island, in the Azores. The site corresponds to the sinking of a vessel in the bay of Angra do Heroísmo, identified in 1996, during the development of prospecting work for the Archaeological Impact Assessment, for the construction project of the Angra do Heroísmo Marina.

2001, 234) this frames as part of the commonly seen timber and shipbuilding features for the Iberian technology.

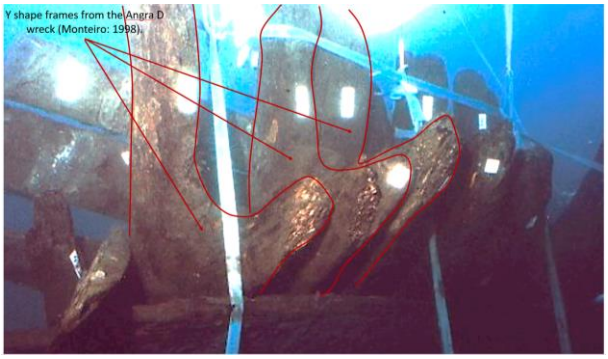


Figure 82 - Y shape frames from the Angra D wreck (Garcia et al. 1999, 210).

Y-frames may indicate transformation in shape – angle, opening of the upper part, height and arms dimension. The angle of the upper part surface is directly related to the angle required to allow a smooth contact with the keelson. The position of these timber type is made by direct contact through scarfs of a variety of shapes, wood and iron fastening and compression by the pressure exerted by other timbers on top of each Y-frame.

The vertical angle of each Y-frame may vary depending on its positioning. It may be straight vertical on the first set of Y-frames (forward to aft, in the aft of the vessel) and then gaining a lower angle to aft part when closed to the sternpost. This variation may be observed on the bottom of each Y-frame: lower angle to higher angle from forward to aft of the ship`s hull.

The requirements in wood to shape these Y-frames demand a tree growing straight and on its upper part to be divided in (at least) two big branches. In most of the observed surviving Y-frames from the Belinho 1 shipwreck there a consistency in the lack of knots along the trunk and then in the separation into two/three main branches (BEL01-001W, BEL01-032W, BEL01-036W, BEL01-037W, BEL01-039W, BEL01-040W and BEL01-043W). Most of

these timbers are also lacking in sapwood (exception made to a small trace of sapwood in BEL01-001W). The widening of these timbers is also consistent with the requirements imposed by the shipbuilders as the Y-frames grow in height in a opposite relation to the widening from the forward to the aft part of the vessel (based on the collection of known surviving timbers from the Belinho 1 shipwreck).

The surviving maximum dimensions of the Y-frame BEL01-001W were 210.8 cm vertical and fore and aft dimension of 18.5 cm, width of 21.5 cm on the lower part. The existing evidence of fastening indicates the use of treenails (2.7 cm and 2.2 cm) and iron nails (1.1 cm) on both faces Portside and starboard side). The assemblage technique comprised a linkage to the stern knee through a scarf on the bottom face and reinforced with a bolt. The connection to the tangential timber (planks) was fasten to the framing system by treenails and iron nails. This timber was obtained from a trunk of a tree and lower part of two branches.

The BEL01-001W was recorded using multiple methods such as hand sketches, hand notes, photography, computer vision photogrammetry and FaroArm drawings.

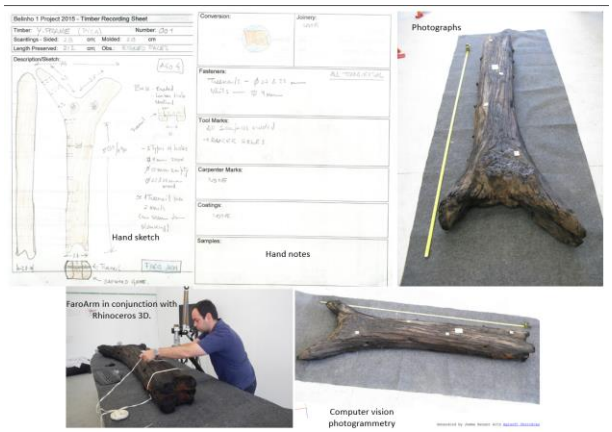


Figure 83 - Illustration of the employed methods to record timber BEL01-001W (Y-frame) (hand sketch by Filipe Castro, Hand notes by Nigel Nayling, photographs by Antonio Santos, Photogrammetry by the author).

In accordance with ship reconstruction studies performed during the Marie Curie Actions, ITN ForSEAdiscovery Project, the positioning of BEL01-001W proceed BEL01-039W and follows BEL01-037W.

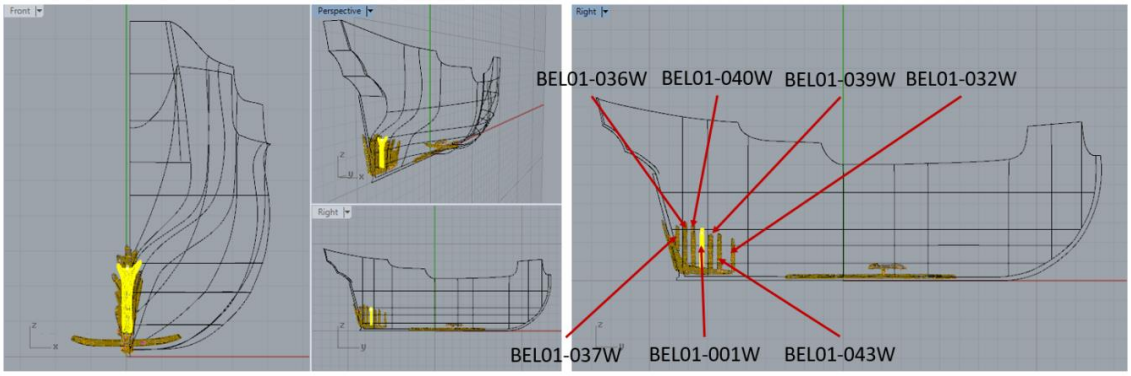


Figure 84 - Illustration of the BEL01-001W positioning and function in relation to the ship`s hull.

The positioning of the timber BEL01-001W and the other Y-frames was achieved by identifying the bottom angle in each Y timber and its relationship with the existing angle in the stern knee. The vertical angle was then achieved by identifying a direct relationship between the Y timbers fastening and the exiting fastening in the surviving planking. In this way, was possible to identify several consistencies between the Belinho 1 surviving archaeological evidence and the Portuguese treatises from Oliveira and Lavanha (Oliveira 1580; Lavanha 1618). Allowing to draw the ship`s profile and indicative measurements using a 3D digital environment (Suarez et al. 2019). The similarities identified between archaeological facts and archival documentation also allowed to establish a direct correlation between the Belinho 1 shipwreck and the table published by Thomas Oertling (Oertling 2001, 234).

	RYE	SJ	PI	HCW	MRW	CW	STB	EPW	RAA	WLW	SJB	AGD	NSM	CDS	CST	BEL01
1. Pre-assembled central frames, dove-tailed mortices, transverse treenails	–	Y	–	Y	Y	Y	Y¹	Y	Y	Y	–	Y	Y¹	Y	–	Y
2. Planking nails: treenails per plank/frame join at midship	0/?	2/2	stern 2/3/0	–	2/–2	2/2	2/2-2	2/2	2/2	?	3/2	?	2/0	2/0	stern 2/2	02/02
3. Sternpost scarphed to upper arm of keel knee	–	Y	Y	–	–	–	Y	N	Y	Y	–	?	–	–	Y	Y
4. Single stern deadwood knee	–	Y	Y	–	–	–	Y	Y	Y	Y	–	?	–	–	Y	Y
5. Y-timbers tabled to deadwood	–	Y	Y	–	–	–	N	Y	N²	Y	N	Y	–	–	N²	Y
6. Keelson notched over floor timbers	Y	Y	–	Y	–	Y	?	Y	Y	Y	–	Y	–	–	–	Y
7. Mast step is expanded part of the keelson	Y	Y	–	Y	–	Y	?	Y	Y	Y	–	Y	–	–	–	Y
8. Butresses and stringers	Y	Y	–	Y	–	N	?	Y³	Y³	Y³	–	Y	–	Y	–	-
9. Ceiling and filler planks	Y	Y	–	Y	Y	Y	Y	Y	N	Y/?	–	Y	–	Y	–	-
10. Rigging chain assemblies	–	Y	Y	Y	Y	–	Y	?	N	?	Y	–	N	N	–	-
11. Flat transom, sternpost proud of transom	–	Y	Y	–	Y	–	Y/?	N	N	Y	–	Y	–	–	N	Y
12. Carved garboard	–	Y⁵	Y	–	–	N	N	–	N	?	–	?	N	–	Y⁵	Y

IDENTIFICATION KEY:

– Information not available. That portion of the wreck was either not found or not preserved.
? Information was not recorded, but could be recovered at a later time.
RYE Vessel A, Rye, Sussex, England.
SJ The *San Juan*, Basque whaler at Red Bay, Labrador, Canada.
PI The *San Stephen* of the 1554 New Spain Fleet, Padre Island, Texas.
HCW The Highborn Cay wreck, Exumas Islands, Bahamas, BWI.
MRW The Molasses Reef wreck, Turks & Caicos Islands
CW The Cattewater wreck, Plymouth, England.
STB The Studland Bay wreck, Poole, England.
EPW The Emanuel Point wreck, Pensacola Bay, Fla.
RAA The Ria de Aveiro wreck, Portugal.
WLW The Western Ledge wreck, Bermuda
SJB The St. John's Bahamas wreck, Bahamas, BWI.
AGD The Angra D wreck, Azores.
NSM The *Nossa Senhora dos Mártires*
CDS The Cais do Sodré wreck, Lisbon, Portugal
CST The Corpo Santo wreck, Lisbon, Portugal

1 Although not dowelled, the floor and futtock are scarphed together and fastened transversely.
2 The San Juan possessed an unusual curved keel which was "T"-shaped at midship and "Y"-shaped at its ends (Waddell, 1986: 135) obviating the need for a garboard.
3 The mortices in this case are not dowelled, but square with male and female on each timber.
4 There are no tabs. The floors are tie-nailed into the deadwood.
5 In these cases the buttresses do not touch the stringers.
6 The garboard has a curved top internal edge (Francisco Alves, pers. com. 2/10/92).

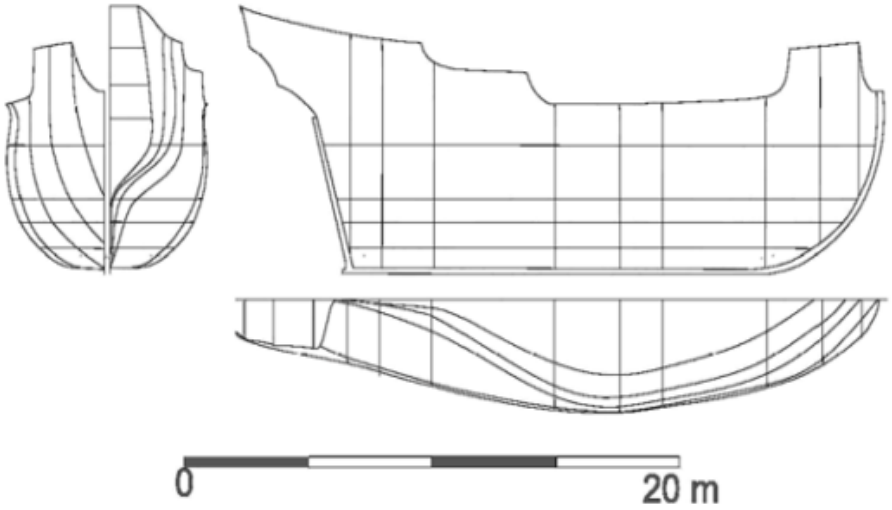


Figure 85 - Included data from the Belinho 1 shipwreck in Oertling`s table (Oertling 2001, 234) and the produced line drawings of the vessels based on the archaeological evidence and archival documentation (lines drawings designed by the author following the guidelines by Filipe Castro).

The produced 3D digital representation of the BEL01-001W included:

a) FaroArm drawing (following the above-mentioned techniques).

b) FaroArm edited drawings – a reviewed drawing from the first in which the entire sort of objects was verified in a way to obtain a *clean* drawing to be used during data analysis and publications.

c) Extruded trunk and branches – this drawing allowed to obtain a preview from the BEL01-001W parent tree.

d) FaroArm printout drawing – following the edited drawing each surface was separated from the original drawing and displayed under the suggestions published by Jones (Jones 2013a, 25) to obtain a 2D illustration of each timber surface. These drawings were produced to allow their publication in articles.

e) Photogrammetry – each timber surface was photographed following the above-mention technique (in this chapter) and produced a 3D model for the timber.

f) Extruded fastening drawing – to highlight the fastening locations, angles and particularities to identify the correlation with the other timbers. This drawing was produced to embed good practices, allowing parallel studies to tree reconstruction studies.

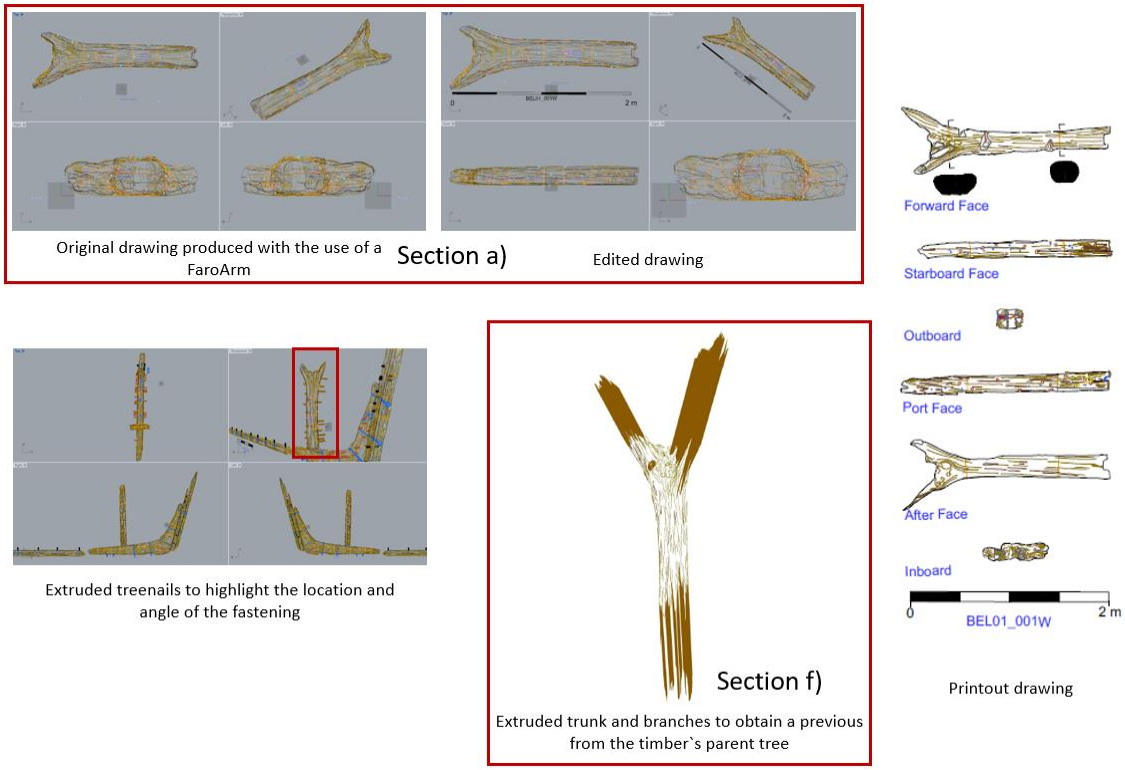


Figure 86 - Illustration of each drawing produced from the original FaroArm drawing (drawings by the author).

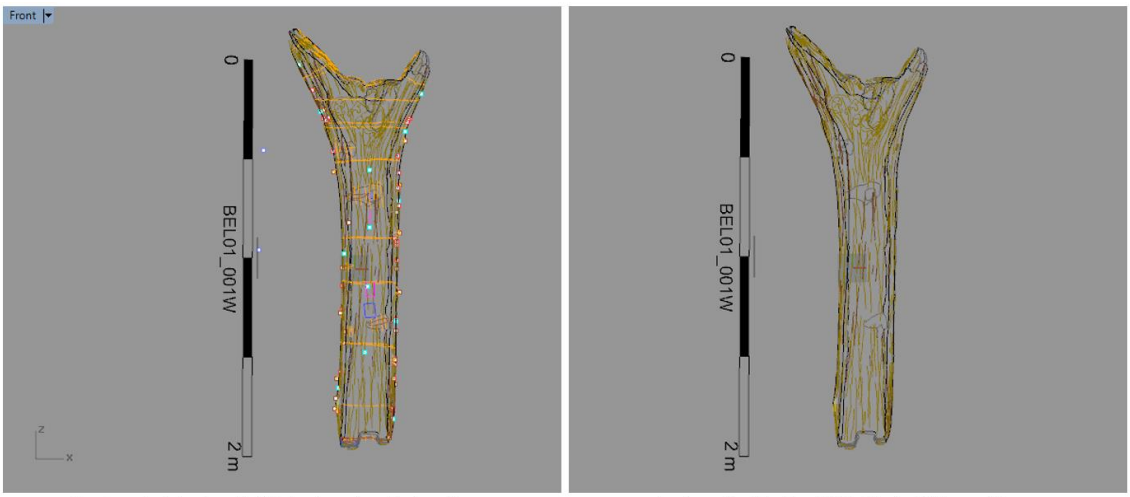
After obtaining the above-mentioned group of drawings was then conducted the analysis of the surviving wood features and developed the reconstruction of the BEL01-001W

parent tree. The method employed to reconstruct the parent tree from the archaeological timber followed most of the techniques employed during the tree reconstruction of the Bremen Ship selected planks (further information in chapter 4 – section: **TREE RECONSTRUCTION OF THE BREMEN KOGGE PLANKING PARENT TREES.**). Although, a few variations[169] had to be adopted since the record of BEL01-001W comprised the complete record of the six timber`s surface. Allowing to obtain a comprehensive record of the surviving wood features. In addition, it allowed identifying an entire collection of data about the parent tree such as the maximum surviving perimeter of the trunk, positioning of the branches in relation to the trunk and their perimeter.

The developed method of reconstructing Y-frames comprised the following tasks (step-by-step process):

a) Using the FaroArm edited, drawing all irrelevant Rhinoceros 3D layer were hidden. This allows to highlight the wood features such as grain (growth pattern), cracks, natural edges and, also original and damaged edges.

[169] The adopted variations are directly correlated to the existing data – in the Bremen kogge the recording of selected planks only comprised the outer face of each timber, as opposed to the recording of Belinho 1 timbers which comprised a full record of each surface.



FaroArm edited drawing – highlighting the entire collection of layers

FaroArm edited drawing – highlighting (only) the wood features

Figure 87 - Illustration of the differences between the FaroArm edited drawing having the entire collection of recorded data and the highlining of (only) wood features (drawings by the author).

b) Then using the grain (growth pattern) to obtain the direction of the tree growth and the current information in the upper surface of the branches allowed to draw a line representing the trunk and branches first annual ring – the pith. The decisions on the position of pith in the trunk were achieved on a variety of perspectives (side view, top view and a perspective view in rhinoceros 3D). Further information will be addressed in the reconstruction of the BEL01-072W (keel) (**RECONSTRUCTION OF THE KEEL SECTION BEL01-071W.**).

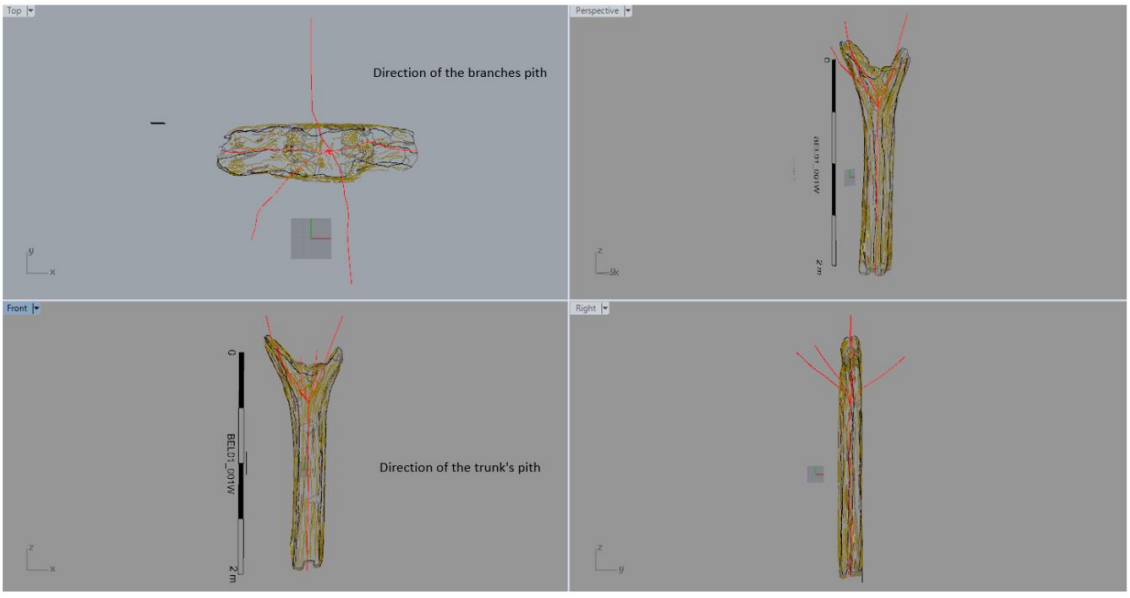


Figure 88 - identifying the trunk`s and branches pith (first annual ring) location (drawings by the author).

c) Using the recorded data about the annual rings, allowed to draw circles on each observed ring to identify the growth pattern and the orientation of the branches. Regarding the branches, the record of the observed annual rings revealed to be of the highest importance since it provides information about their orientation[170]. The following figure (Figure 89 - *Illustration of the observed/recorded annual rings and tangential medullar rays on the upper and bottom part of timber BEL01-001W. (drawings by the author).* represents an early version of the attempt to reconstruct the timber parent tree, and as it may be seen in the drawing, the circles are placed horizontally.

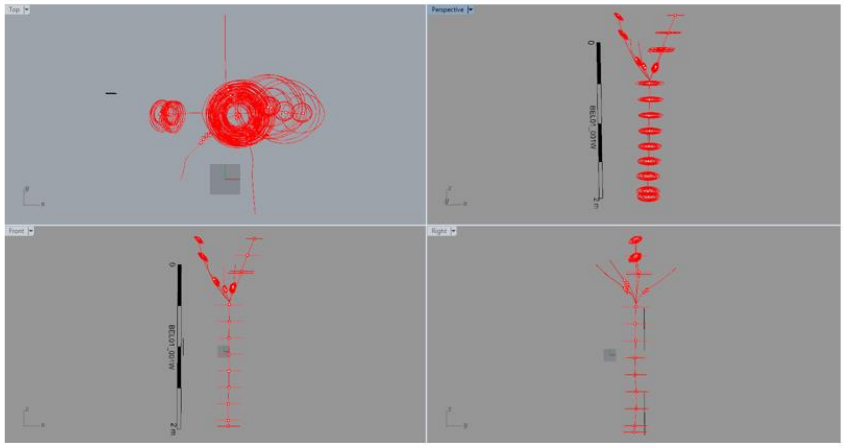


Figure 89 - Illustration of the observed/recorded annual rings and tangential medullar rays on the upper and bottom part of timber BEL01-001W. (drawings by the author).

[170] The permanent demand of capturing solar energy have a direct relation to the *insisting* vertical tendency of a tree (further information in chapter 2). In the case of trunk, it is notorious its verticality but in the case of branches the annual rings attend to wider in the lower part of the branch and thinner on the upper part. This allows to strengthen the branch where gravity has a higher influence.

d) The next step consisted in determine the trunk and branches maximum surviving width. Each perimeter was determined by generating a circle centred in the pith line and then preferably by the natural edges or alternatively by the original edges of timber`s surface. To successfully achieve a smooth shape from the record surviving timber it is recommended to draw a grid have a bigger dimension than the recorded timber and divide it in equal part of 20 cm each[171]. This grid will also allow an accurate reconstruction of the parent tree and the digital original morphology representation. Although, despite not being the case of timber BEL01-001W, in the case, archaeological timbers having accentuated variation in morphology every section must be referenced by sufficient circumferences.

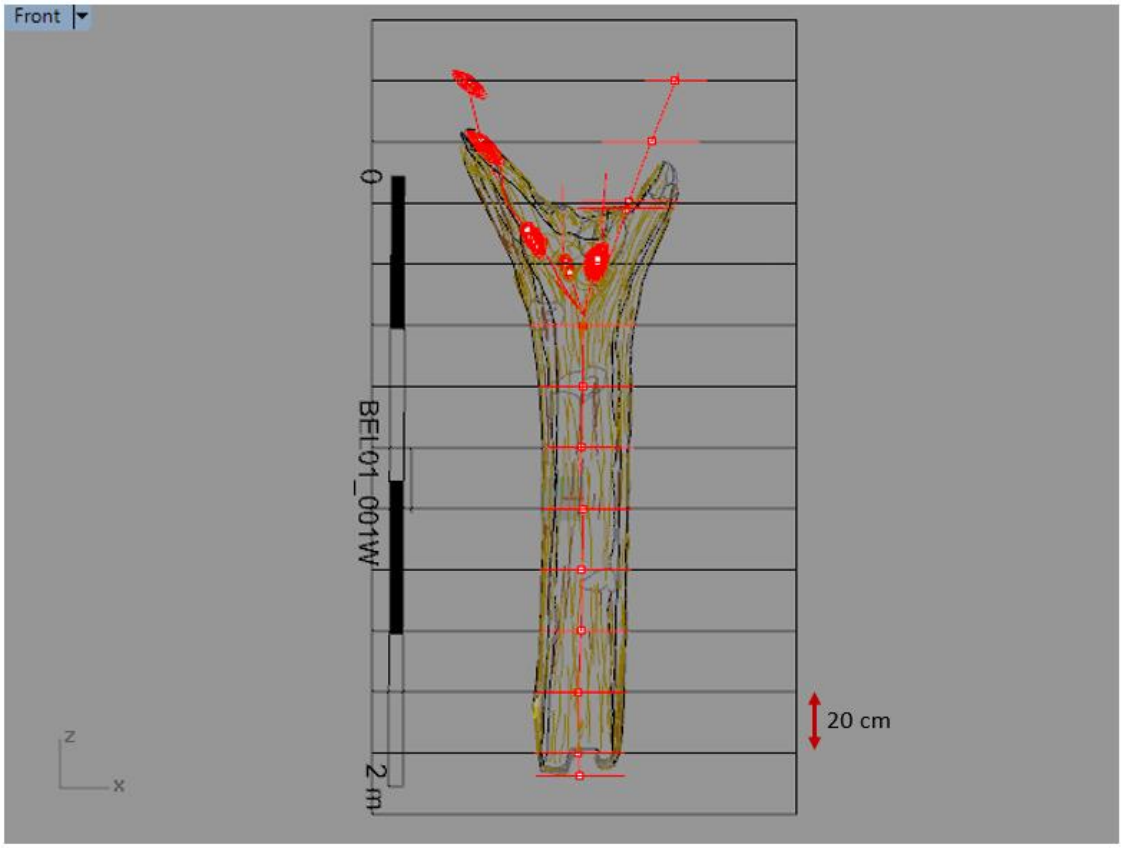


Figure 90 - Illustration of the prepared grid having 20 cm between each horizontal line in way to provide a an accurate and smooth shape to the construction of the BEL01-001W parent tree (drawings by the author).

[171] In the case of performing tree reconstruction studies in smaller timber the distance between horizontal lines in the integrated grid may reduce to 10 cm from the following line.

e) The next step was to obtain a preview from the BEL01-001W parent tree. This process consisted in drawing lines along the overall extension of the trunk and branches. The guidelines to obtain an accurate representation will be found by switching the Rhinoceros 3D window to *Front* and then using tool *Control point curve* to draw (using the associated layer) the limits of the surviving timber. In the case of possessing information[172] about the sapwood and bark average number of rings, the distance between the sapwood and bark layers may be refined in a way to provide accurate width between each layer.

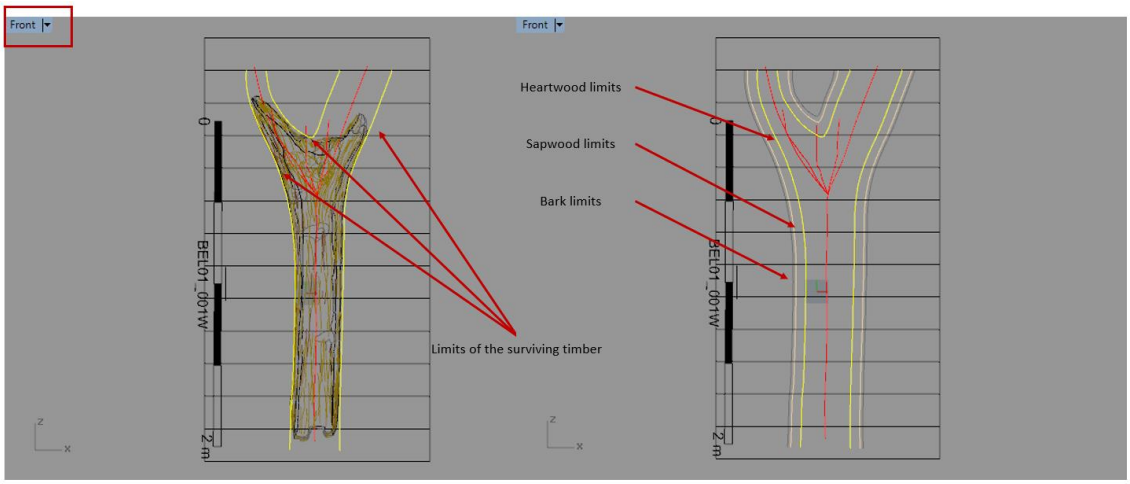


Figure 91 - Illustration of the obtained preview based on the evidence captured from timber BEL01-001W in a way to provide information about its parent tree morphology (drawings by the author).

f) To obtain the visual representation of the BEL01-001W parent tree exception made to the layers – pith and ring width, all other layer must be hidden. Then selecting the outer circumferences in order (from the bottom to the top of the drawing) using the tool *Surface 1 rail* will generate an accurate representation of the BEL01-001W parent tree.

[172] At the present stage Dendrochronologists have not yet determined the BEL01-001W timber provenance information (Domínguez-Delmás, Groenendijk, et al. 2015), therefore, the distance between heartwood to sapwood and the thickness of the bark was estimated to a reasonable width: 7.4 cm sapwood thickness and 2.5 cm bark thickness.

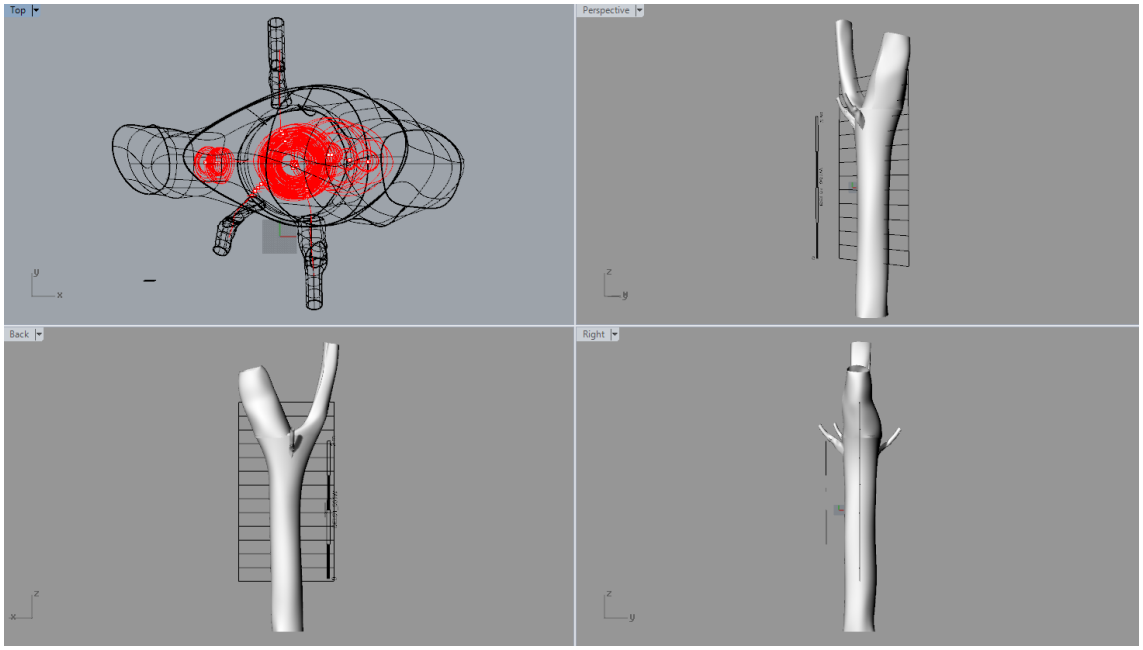


Figure 92 - Illustration of the developed approached and associated methods to reconstruct an archaeological timber (BEL01-001W) parent tree (drawings by the author).

The following knowledge produce about the ship timber BEL01-001W (Y-frame) represents the added-value achieved by implementing the develop approach:

a) Specific V-shape of the canopy required to the construction of the Belinho 1 ship.
b) Long-standing trunk suggests the use of a tree possibly planted on relatively open woodland forest.
c) Wider annual rings (fast-growing tree) suggests a location to the planted close to waterlines or rainy places.
d) The use of a specific V-shape tree is directly correlated to the carpenter's requirement to the used natural curvatures/morphologies to obtain the good timber (strength, durability and compliant tree shape to the predesigned timber).
e) Width of the stem is consistent with the other timbers in the ship´s stern.
f) The pith, growth pattern and the split of the stem into two branches provided the shape required for ship construction.

g) The use of timber such as BEL01-001W suggest an implementation of dedicated trees to the shipbuilding industry from the late-15th to the 17th-centuries. This chronology was obtained in association to the investigation undertaken on the Belinho 1 cargo rather than by dendrochronology due to the lack of know dendrochronological sequences to the recorded ring widths.

Reconstruction of the Floor timber BEL01-003W.

The timber BEL01-003W is a potentially predesigned floor timber. The concave shape, fastening location and dimensions places this timber closed to an amidship.

The floor timber`s shape, angles and size were directly related to the drawings produced by the shipwright using the *graminhos (see further information on* **CHAPTER 1 – TO BE OR NOT TO BE AN IBERIAN SHIP:***)*. The master frame and the *almogamas* were essential to find the turn of the bilge. After the aft *almogama* the hull started to sharp to the stern and the forward *almogama* the same for the bow (Martins 1998, 92). This, according to Steffy (Steffy 1994, 10) also represents the box or container that could carry whatever required transportation. From the *almogamas* towards the ends (stem and stern), the empty area was filled with the *Y* shape frames. The floor timbers displayed from the mainframe to the *almogamas (see further information on chapter one* - **IBERIAN SHIPBUILDING, TREATISES, SHIP`S GEOMETRIC PLANS AND PROFILE.***)* has every each of it different length, angle and rotation according to the ship plans. This technique was also essential for the planking in way that the hull was built with a smooth shape (Martins 1998, 92). Furthermore, Oliveira in (Oliveira 1580) explained that hull ovoid shape should be larger on the bow than on the stern *because the bow does not divide a narrowband both sufficiently water or opens the path without the bowl. The following part of the hull*

follows an example of nature, as both the fish and the birds go sliding, so the earlier parts of their bodies more or less thick. The fish heads are thicker, in general, the tails and breasts of birds thicker than the back (Barata 1965).



Figure 93 - Example of a dove-tail scarf from Aveiro A wreck (Alves, Reith, et al. 2001, 323).

BEL01-003W is a floor timber made of *Quercus sp.* on which would be observed the grain flow along the frame. Its assemblage in relation to the keel was assured by a central scarf on the outboard face and reinforced by an iron bolt. On the linkage, with the futtocks, the employed technology consisted of on a scarf with dovetail shape. This technique was also observed on the Aveiro A, Angra D and Western Ledge Reef wrecks ship timbers.

Within the collection of Belinho 1 shipwreck surviving timber other floor timbers were identified and recorded. From the first set of rescued timber in the beach of Belinho: BEL01-041W, BEL01-042W, BEL01-044W and more recently (2017) the BEL01-076W.

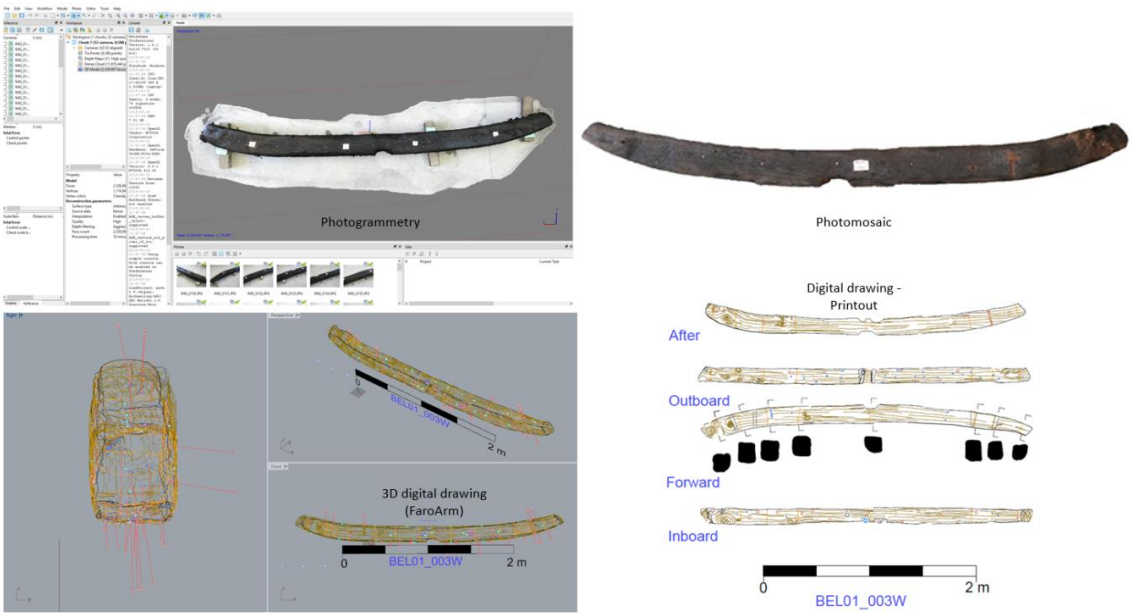


Figure 94 - Representation of the timber BEL01-003W (drawings by the author).

The BEL01-003W[173] surviving maximum dimensions of the floor timber were 300 cm in length moulded 15.5 cm and sided of 16.8 cm. The recorded fastening comprised a connection to the keel using iron bolts and, the connection to the planks with treenails (2.7 cm and 2.2 cm) and two iron nail per treenail (1-1.1 cm). There is no pronounced reduction of the section on the ends, although the slope and are longer on the face that contacts with the futtocks. In regard to wood anatomy, BEL01-003W has 30 annual rings and an average ring-width 7.2 mm average ring width (fast-growing parent tree).

The ship timber characterisation made to the BEL01-003W places this floor timber at amidship. A conclusion based on the existing fastening which directly finds correlation with the existing fastening holes and scarfs (at the upper face) on the mast step (BEL01-051W) and (at the bottom face) on the section of the keel (BEL01-071W).

[173] Previous investigation undertaken by CHAM/FCSH-UNL recorded the floor timber with the catalogue number PB14-003 (Bettencourt et al. 2015).

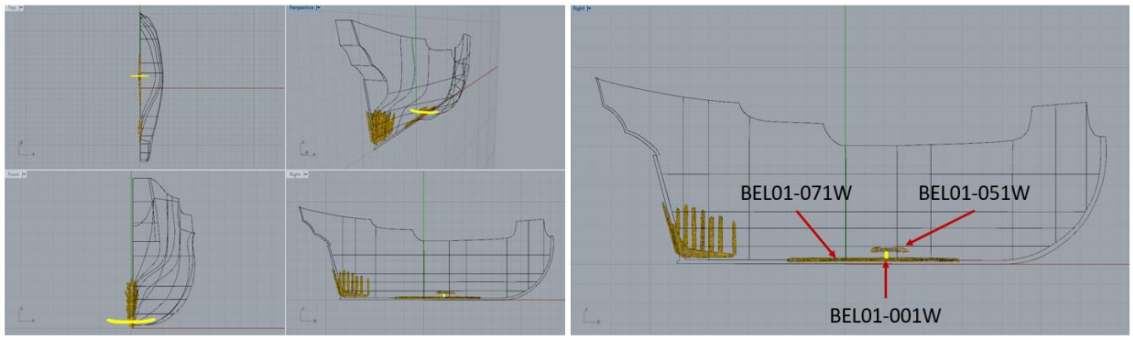


Figure 95 - Illustration of the BEL01-003W positioning and function in relation to the ship`s hull (drawings by the author).

a) The recording methods employed to capture information from the BEL01-003W timber face followed the same criteria applied to the Y-frame BEL01-001W. This included the FaroArm drawing (following the above-mentioned techniques), FaroArm edited drawings, FaroArm printout drawing, photogrammetry, extruded fastening drawing and the extruded trunk and branches.

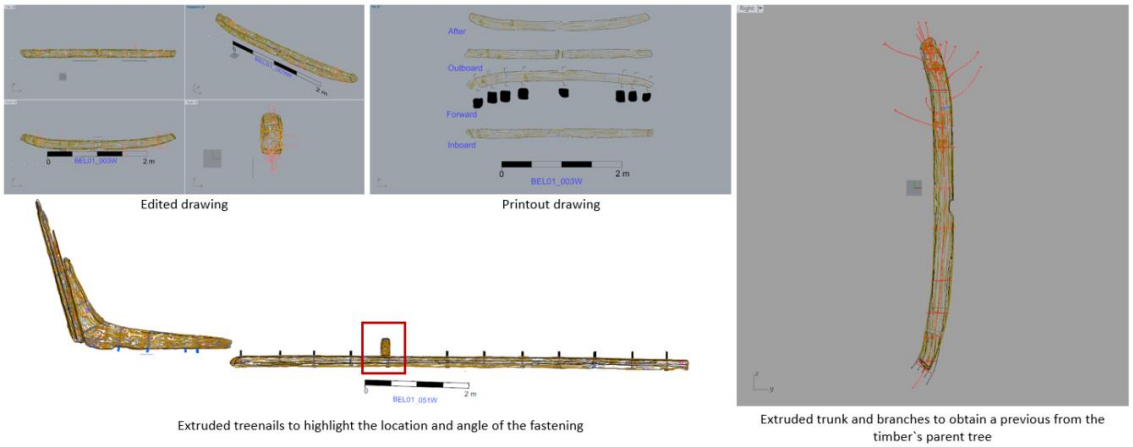


Figure 96 - Illustration of each drawing produced from the original FaroArm drawing (drawings by the author).

The produced digital drawings focusing on the recording of BEL01-003W wood features also allowed to conduct tree reconstruction studies.

In the case of BEL01-003W, the reconstruction of its parent tree revealed to required variation of previously explain methods. The parent trees reconstructed from the Bremen

Ship planking had it base on the recording of the outer face of each timber and limited by obstacles (attached scaffolding). This demanded a configuration setting in which the three recorded sections of each plank had to be joined using the produced models from the photogrammetry and FaroArm drawings. In the case of BEL01-001W Y-frame the limitations/obstacles were reduced to a minimum. This allowed to fully record the surviving timber and to obtain a clear understanding its parent tree profile/morphology. Although, neither the planks from the Bremen Ship neither the Y-frames from the Belinho 1 shipwreck were considered as not being part of a tree`s branch. A conclusion that arose from the tree reconstruction studies focusing the floor timber BEL01-003W. The methods employed to obtain a clear understanding of its parent tree will be described on the following step-by-step process:

a) Using the edited drawings produced during the recording fieldwork:
    a. All non-related to Rhinoceros 3D wood features layers (such as *snit*, *nails* or *treenails*) were hidden in a way to obtain the clear view of the grain (growth pattern), cracks, original edges, damage edges and natural edges.

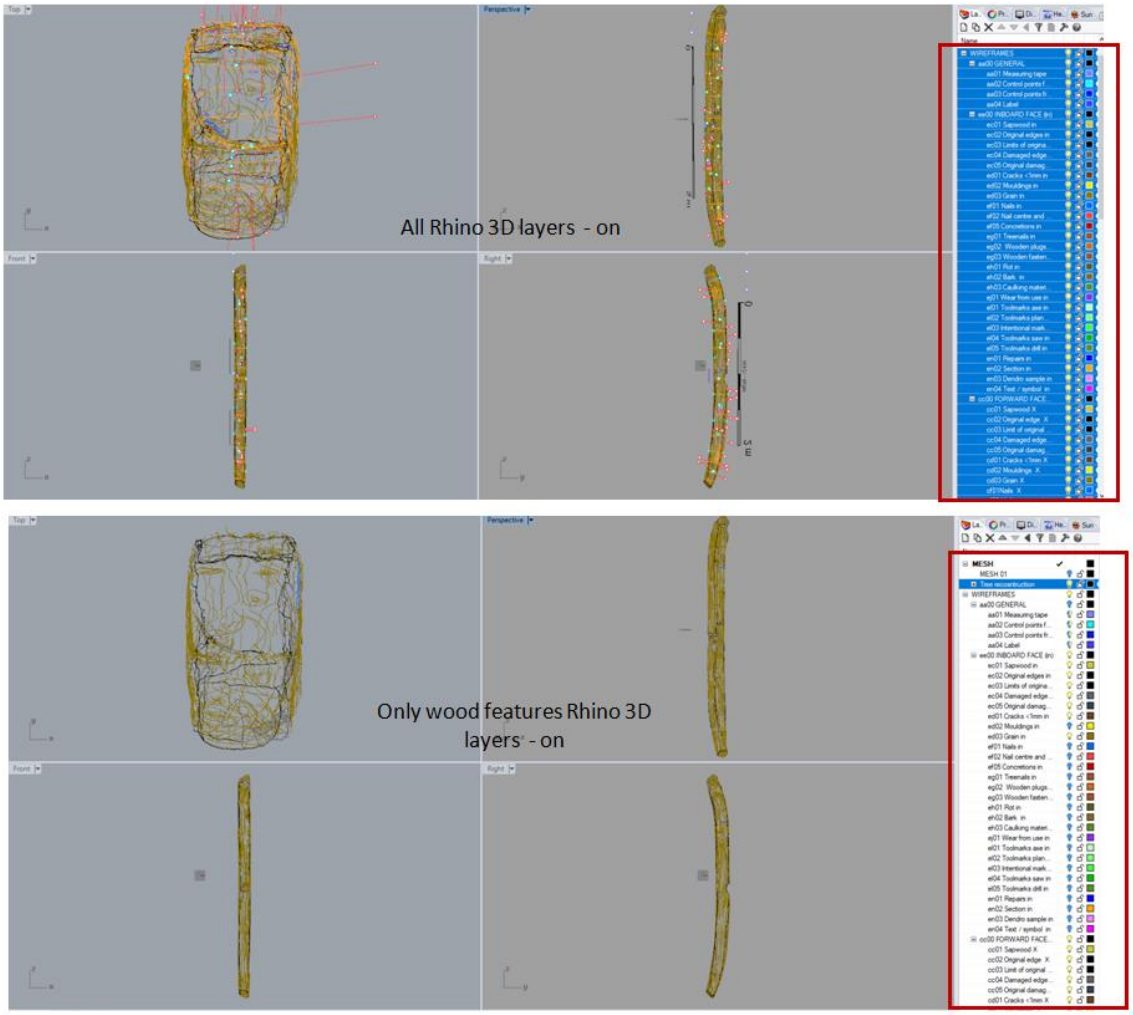


Figure 97 - Illustration of the differences between having the visible the Rhinoceros 3D entire group of layer and, the selection of layers related to the wood features (drawings by the author).

b. Special attention was given to the lines representing the grain (growth pattern). These lines are significantly dissimilar on each of the surviving timber extremities. Thus, allowed to identify the side of the roots and the canopy.

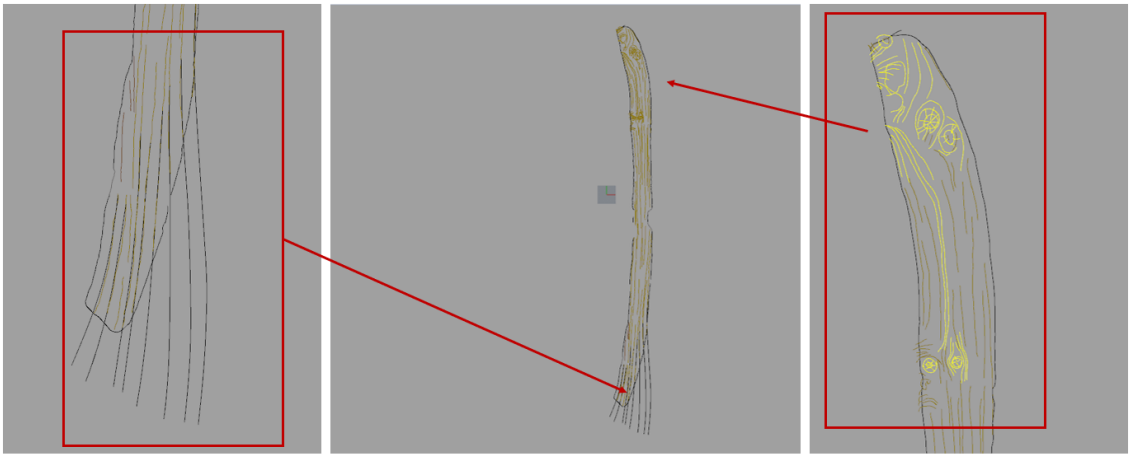


Figure 98 - Illustration of the analysed information about the direction of the growth pattern (roots as opposed to the canopy) (drawings by the author).

c. The next step was to identify the pith location and its direction, as well as the branches` pith and width.

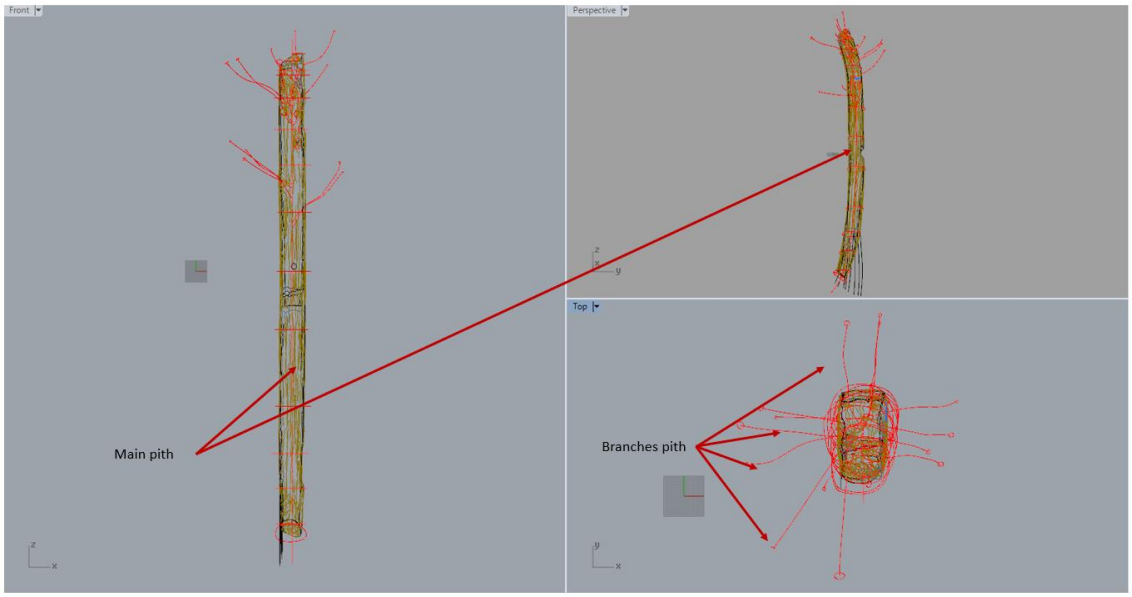


Figure 99 - Illustration of the achieved conclusions regarding the location of the main pith and smaller branches` pith (drawings by the author).

d. Once identified the pith, points were placed along the grid (similar method to the employed in BEL01-001W) draw circumferences from each point to the edges of the digital representation of the BEL01-003W. Differences in the construction of the grid between the tree reconstruction studies performed on BEL01-001W and BEL01-003W vary because of the

dissimilarities in the morphology of the ship timber. In the case of BEL01-003W, despite an apparent consistency in shape, the grid horizontal lines vary from 49 cm to 2.9 cm distant from the following line. This variation allowed to raise the accuracy level of the parent tree model by reducing the lines were observed the lower number of detail and increasing where detailed information was in greater number.

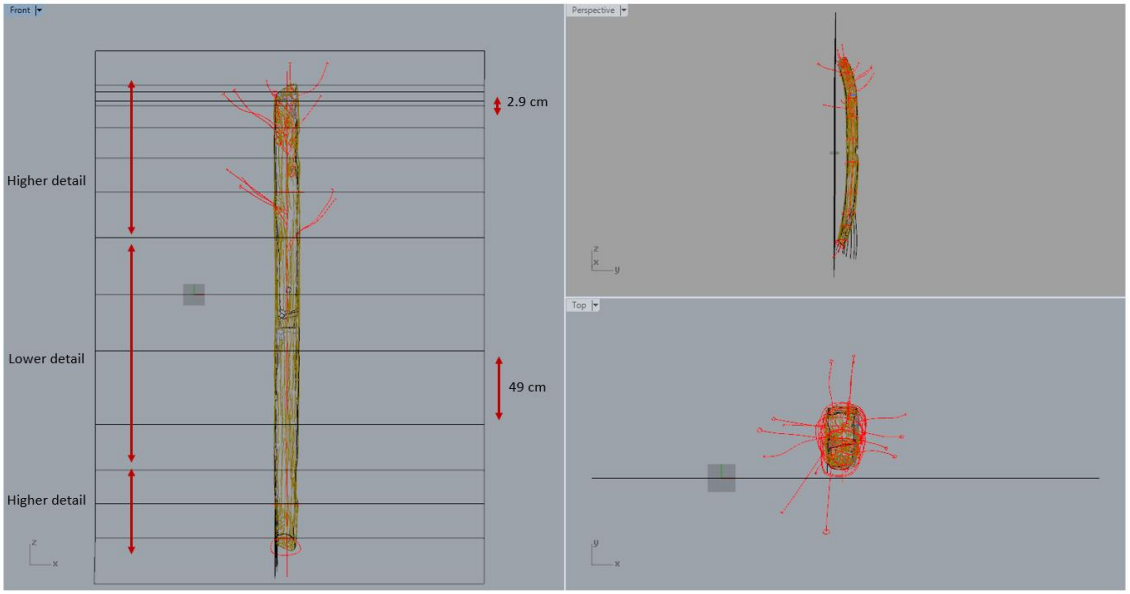


Figure 100 - Illustration of the adaptation made in the guideline grid in a way to increase the level of accuracy to the reconstruction of BEL01-003W parent tree.

e. Then using the tool Rhinoceros 3D Surface1Rail, the pith and then each circumference was selected and converted into a 3D object. This allow to provide a visualisation of an accurate model of the BEL01-003W parent tree.

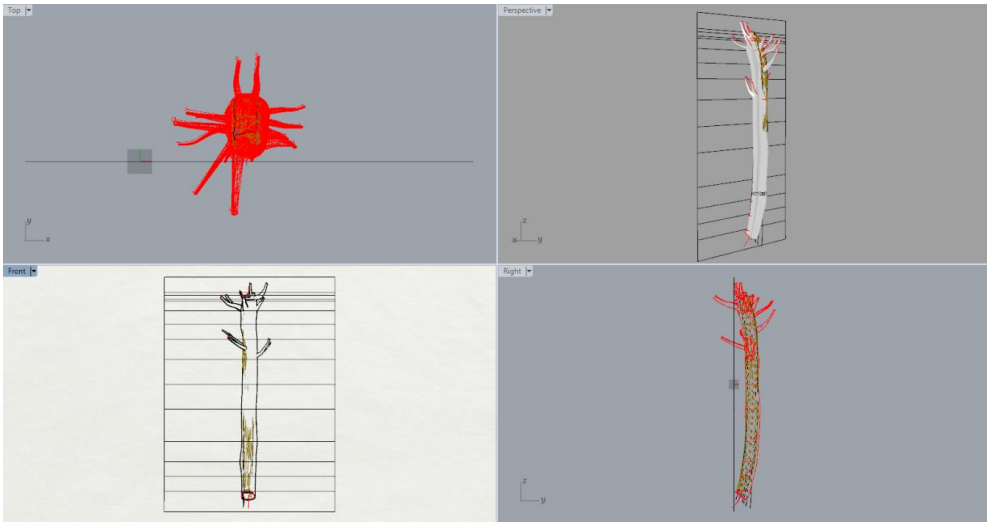


Figure 101 - Illustration of the BEL01-003W reconstructed parent tree (drawing by the author).

f. Although, a part of the reconstructed parent tree still requiring further investigation. It was not clear if the tree ended part (root/bottom of the 3D object) was, in fact, completed. The visible extruded lines (figure bellow) were not consistent with the traditional root system of an oak tree. Therefore, the grain lines (recorded during the fieldwork from the BEL01-003W face) were extruded and connected each other to form a 3D object. The result pointed to a floor timber (BEL01-003W) timber growing from a major trunk and ending in several branches.

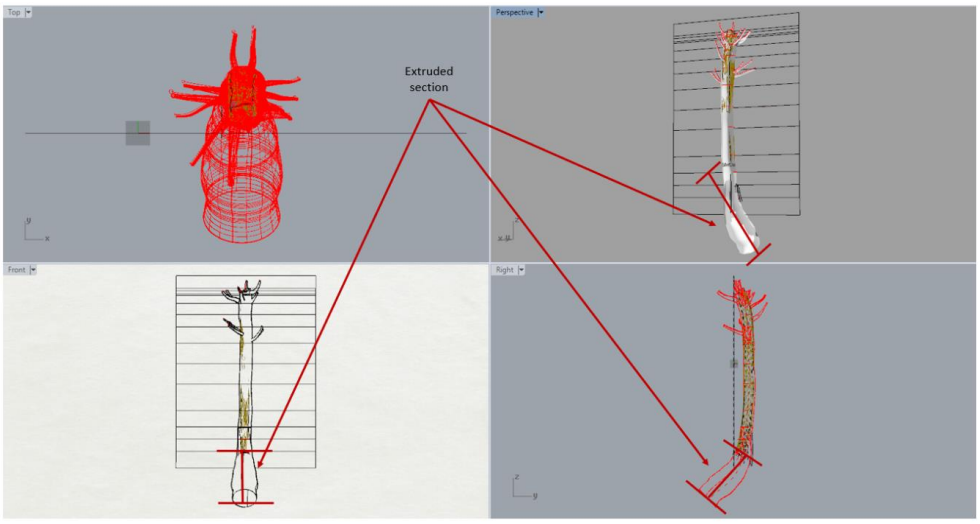


Figure 102 - Illustration of the extruded section using the recorded grain lines to obtain the perimeter, width and potential length of the BEL01-003W original branch (parent tree) (drawings by the author).

By implementing the develop approach and associated methods, it is possible to ensure with high accuracy that the floor timber BEL01-003W corresponds to:

a) Based on the observed growth pattern, the floor timber was shaped from a managed tree.
b) The growth pattern and absence of knots along a major section of the timber suggests the implementation of a regular/periodic forests practices.
c) The bottom part of the floor timber suggests the use of a pollard technique (consisting in managing the branches and cut them when suitable, leaving the main trunk to produce new shoots) (Aragon Ruano 2003).

RECONSTRUCTION OF THE FLOOR TIMBER BEL01-042W.

The recording of BEL01-042W did not follow the recording technology employed for the BEL01-001W, neither BEL01-003W. Decisions were about the timber selection process which placed the structural transversal (Y-frames, floor timbers) and longitudinal timbers (sternpost, stern knee and keel) on the top priority for the recording with a FaroArm. These decisions had their fundament in the constraints imposed by fieldwork available resources and, in the demanding pressure on the study and identification of Belinho 1 ship`s profile. Such constraints determine a low priority on the recording of surviving planks using a FaroArm. Therefore, these timbers were only recorded a more traditional methods comprising hand notes, hand sketches, 1/1/ scale drawings and photography. Nevertheless in 2017 during a short number of days, a selection of planks was photographed in a way to allow producing a 3D digital model in Agisoft Photoscan. This selection of surviving timber had its fundament on the number of surviving wood features

reflected on each timber face and, also to test and refine the developed method of using photogrammetry for the recording of wood features and tree reconstruction studies.

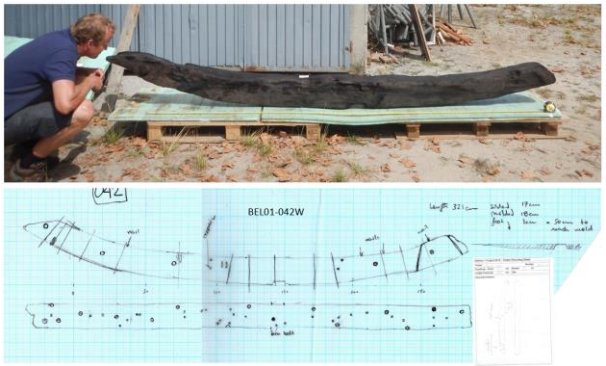


Figure 103 - Illustration of the selected timber (floor timber) recorded using photogrammetry techniques (Photograph by Ivone Magalhaes, scale drawings by Filipe Castro in the photograph Peter Groenendijk – wood scientist).

Each of the photogrammetric models was produced following the recommendations presented by Yamafune ((Yamafune 2016b) and adjusted in accordance with the above-mentioned techniques (**RECORDING TIMBERS USING THE PHOTOGRAMMETRIC TECHNIQUE.**). The use of these models provided an add-on to the developed approach and associated methods since it reflects an alternative technique to record wood features from timber faces. Photogrammetry may be used in different environments, such as: in laboratory, underwater and non-controlled open sky environment. Although, photographs must be obtained in accordance with a balance between the capture of the data, the preservation of the timber and the environment in which the timbers are located:

a) In the case of waterlogged timber:
    a. Controlled environment – Laboratory:
        i. The selected surviving timber must be cleaned from all external agents, such as small stones filling the holes and cracks.
        ii. It is required to slightly dry the timber faces, in a balanced between the capture of raw data and the preservation of the archaeological

timber. As the timber faces dry out, essential wood features became more visible and perceptible. The grain lines (growth pattern) and cracks became more visible and perceptible as the timber dries. Same situation applies to the assessment of annual rings and multiseriate rays (for the oak trees).

iii. A previous visual assessment must be ensured in a way to remove obstacles which may interfere with the path to follow by the photographs sequence.

iv. Photographs must be taken in a way that wood features are captured in detail, avoiding the reflex made by the water nested in timber holes and flat faces.

v. Lights must be displayed away from the timber to avoid blank spots in the photographs.

b. Underwater:

i. To record wood features from a timber located on the seabed must be avoided the backlight caused by the sun when hitting the sediment. This will be produced diffuse light and reflections in the camera which will have a negative direct impact in the production of a suitable photogrammetric model. In this case, either has to be chosen a different schedule in the day to the capture of wood features or to take the photographs closer to the timber face to avoid the diffuse.

ii. A commitment between the preservation of seal life and the capture of wood features. *objects* in motion will not be represented

in the photogrammetric model, although it may generate blur spots in the 3D model, reason why algae must be removed from the timber faces.

iii. The suspension represents another challenge to the acquisition of suitable photographs to the construction of a photogrammetric model. In this case, the light must be controlled to avoid reflection and incompatible photographs to the production of suitable 3D models.

c. non-controlled open sky environment:

i. as mentioned in the previous environments, the light intensity and reflection is the main challenge to the acquisition of suitable photographs. The capture of a sequence of photographs from the wood features must be at the top priority. Sunlight reflecting on a waterlogged timber may cause diffuse light rays and inhibit the construction of a suitable 3D model to be used in tree reconstruction studies.

ii. O a non-controlled environment other challenge may be the air temperature as it may cause a fast dry of the timber faces and therefore a substantial decrease of available time to the capture of a sequence of oriented photographs to the construction of a suitable 3D model.

b) Dry wood:

a. Non-controlled method.

i. In the case of capturing wood features from a non-controlled dried timber to produce a photogrammetric model, the challenge resides the suitability of such timber to produce an accurate reconstruction of its parent tree. This constraint has its cause on the accelerated collapse of the wood vessels which generates the cracking, bending and distort of its faces. Commonly, non-controlled dried wood presents sulphur on timber faces which represents an added-risk to public health but also inhibits the assessment of the wood features as it generates a blanket of silt covering the grain (growth pattern and eventually other relevant wood features such as natural cracks. Although, if removing the sulphur (by an expert wood in conservation) these timber don does not reflect the light and usually, has wood features more evidenced. Crack enlarge, and the annual rings start to split from each other.

b. Controlled- method:

i. Controlled dried timber several methods can be employed such as freeze-drying and PEG saturation dry. in the case of freeze-dried timber, much of the wood features may be observed within a low level of distortion as the method employs a low level of wood saturation by PEG and therefore the waxy faces are not such common. On the other hand, full saturation of wood by PEG may cause additional constraints to the capturing of wood features, or even the inhibit of conduction g tree reconstruction studies (further information in chapter 4 – the *VOC Batavia* case study).

Despite the above-mentioned potential circumstances, many others may cause obstacle to the capture of suitable photographs to the produce of a adequate photogrammetric model for tree reconstruction studies. Although, during the development of the present investigation were not found ideal conditions to record wood features. These included diving in shipwreck sites located in low level of visibility (Yarmouth Roads wreck – River Humble, United Kingdom), excessive sunlight reflection (Highborn Cay wreck – Bahamas), strong currents Ribadeo wreck – Spain) , non-controlled dried timber (Cais do Sodre wreck – Portugal), PEG high levels of impregnation (*VOC Batavia* – Australia), not fully accessible timbers (Bremen kogge – Germany), and high levels of suspension in relatively clear seawater (Bayonnaise wreck – Spain). In this way, general procedures to obtain suitable photographs must followed (e.g. (Yamafune 2016b)) and then adapted in accordance with the available resources, environment and timber level of preservation.

The recording of BEL01-054W represents one successful example of capturing wood features from a waterlogged timber. This plank integrates the collection of surviving timber associated to the Belinho 1 shipwreck. As mentioned in the *VOC Batavia* case study (**TREE RECONSTRUCTION OF THE VOC BATAVIA PLANKING.**) the reconstruction of planks parent tree may cause a certain level of uncertainty. These timbers were obtained by saw conversion method and may not be suitable to parent tree reconstruction if not integrating the tree`s pith. As the annual ring provides the understanding of the parent tree`s morphology if the pith did not survive in the plank, a higher level of interpretation may be required which places the reconstructed tree in a stage of conceptual theorization rather than a reconstruction focus in the wood evidence.

In the case of BEL01-042W, a successful photogrammetric representation was achieved within a low level of error. Therefore, the produced 3D object allowed to adjust, refine and adapt the developed approach to the implementation of computer vision photogrammetry of a adequate technique to reverse-engineering archaeological timber in way to reconstruct their parent trees.

The following step-by-step process will describe the employed methods:

a) Timber BEL01-042W was stored in a freshwater tank, therefore had to be removed from it and placed on a soft/smooth platform to allow the required integrity and preservation of the timber and its wood features. To ensure the maximisation of the recording, each timber face was cleaned (removed all traces of sediment[174] and the small stones filling the empty holes). and calibration of the photogrammetric model has displayed three tape measures to cover the three-axis (X, Y, Z).



Figure 104 - Illustration of the first step to the recording of wood features using photogrammetry techniques. (On the left) the photograph illustrated a moment that occurred the changing of water in the freshwater tank which made visible the collection of surviving timber in 2015. (on the right up and bottom photographs) illustrates the setting prepared to capture the wood features from a floor timber in 2017 (photographs by Ivone Magalhaes and by the author).

[174] During this stage was collected evidence of tar for analysis.

b) Produced photographs were then imported into the Agisoft software: select the photographs and drag into the *Workspace*, then in the *Workflow* menu, select *Align photos*. The adopted options were: Accuracy – high, key point limit – 40.000, tie point limit – 1.000. This configuration allowed to successfully align the obtained photographs in a way to produce a point cloud model representing the morphology/shape of the archaeological timber.

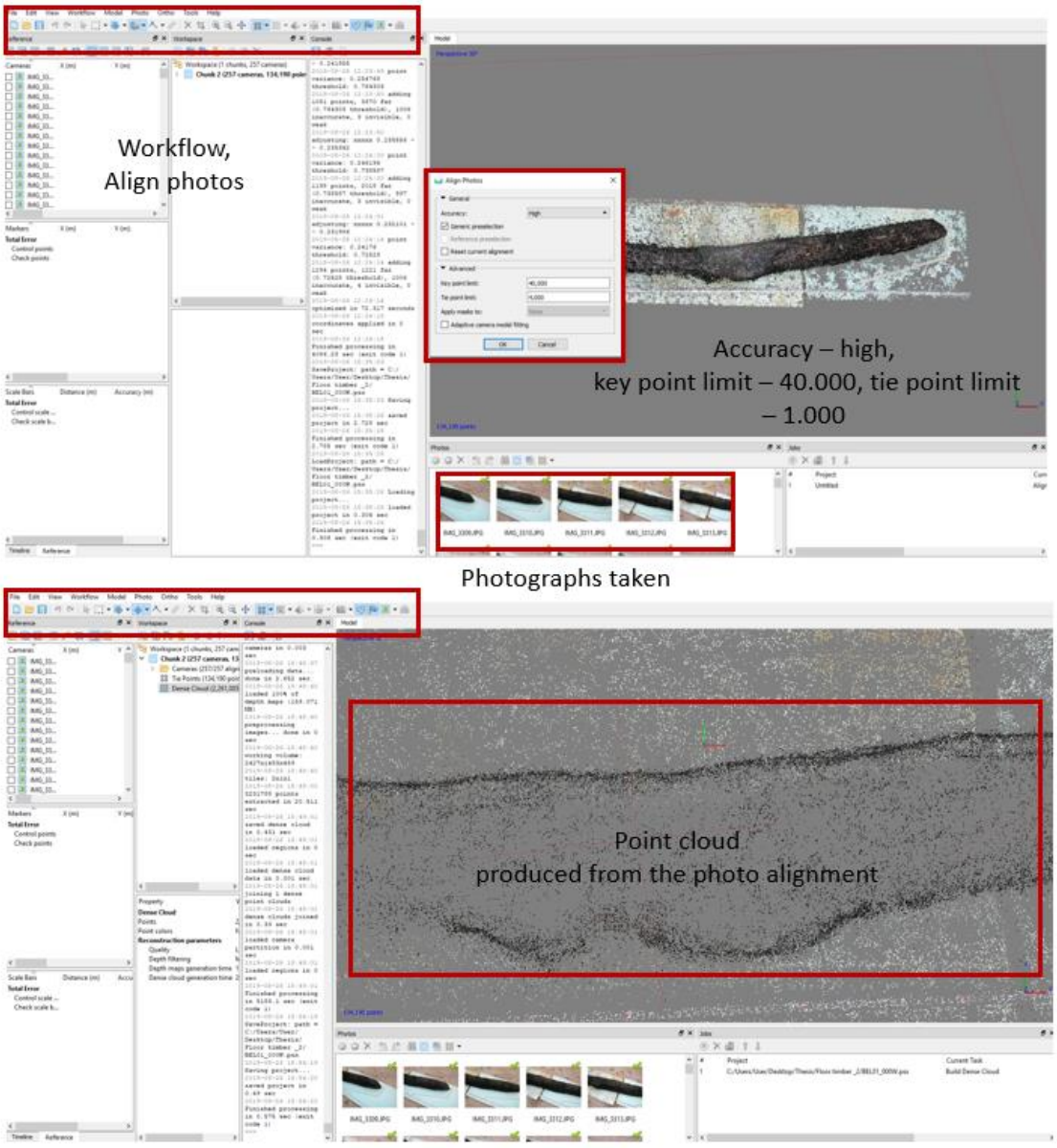


Figure 105 - Illustration of the alignment and the generating of a point cloud[175] (a process developed by the author).

[175] A point cloud is a set of data points in space forming 3D digital surfaces.

c) Then a dense cloud must be built from the aligned photographs (point cloud) to allow creating links between each point (by triangulation) to produce a dense cloud. This cloud is the intermediary between the point cloud and the mesh (3D object). The adopted setting was from the *Workflow* menu, select *Build dense cloud* and then *Quality – Low*, *depth filtering – Mild* (for further information about the chosen settings (Yamafune 2016, 59).

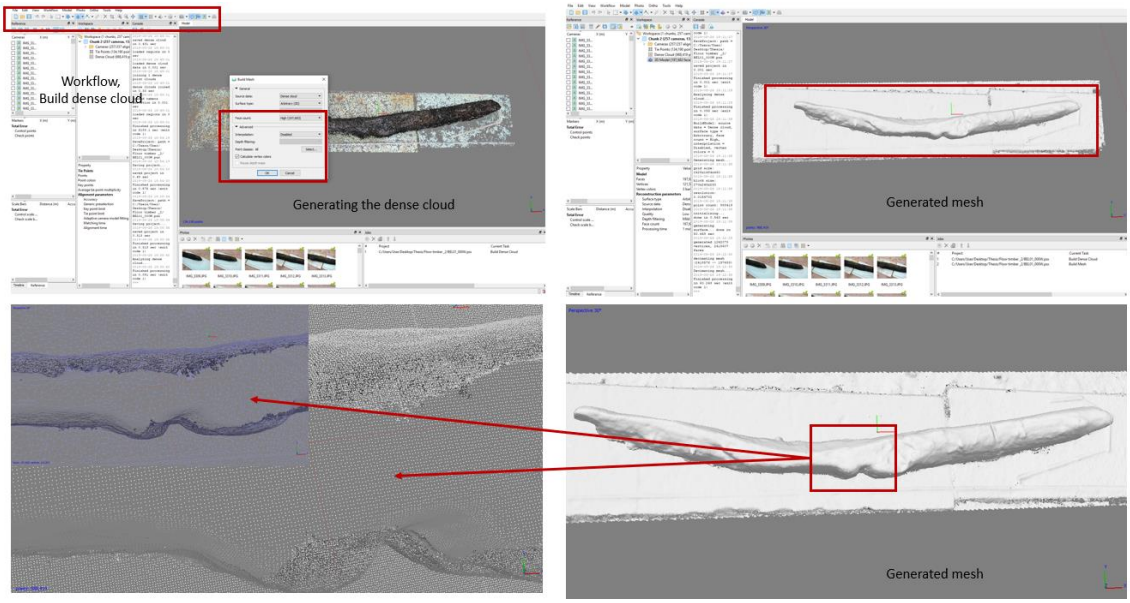


Figure 106 - Illustration of the technique adopted to the build of dense cloud and mesh (process developed by the author).

d) The next step was to build texture. This step is, in fact, the most relevant part of the photogrammetric end-product as it converges in one 3D digital model the entire collection of wood features as a surface. The generated model of an archaeological timber must possess several quality features:

   a. Through represent, the timber faces on a unique surface.

   b. Possess a high-level quality texture to identify the surviving wood features.

   c. Must be sufficiently accurate to avoid misinterpretations and inaccurate reconstruction of a timber`s parent tree.

d. and, despite has been used the Agisoft Photoscan/Metashape during this investigation there are other software available to the produced photogrammetric models. Therefore, the employed software needs to have export compatible file extensions to allow the next strep – parent tree reconstruction based on the produced 3D digital model.

e) The adopted settings to this step comprised the options on the Workflow menu: Build texture, mapping mode – generic, blending mode – average, texture size/count – 4096 x 4.

In this stage, is also important to ensure a clear assessment of the numbers in the tape measure to allow the calibration of the photogrammetric model.

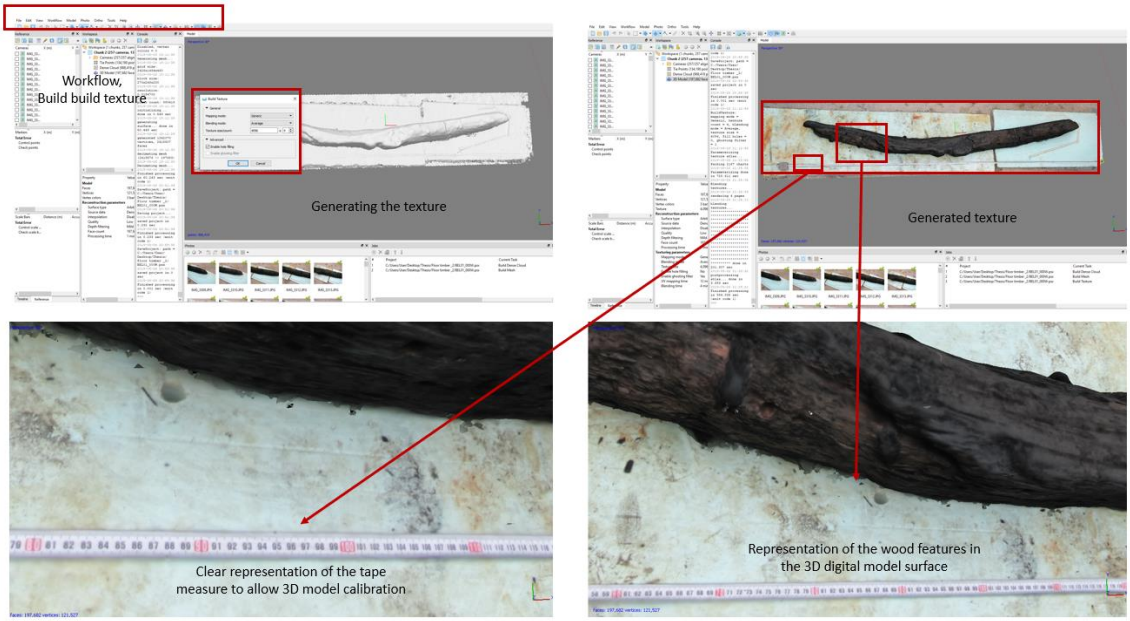


Figure 107 - Illustration of the technique adopted to build texture (process developed by the author).

f) The calibration of the 3D photogrammetric model represents the next step. On top of represented tape measure must be placed a series of points to define the distances between each other within the three-axis X, Y and Z. By clicking on the mouse right button select the option *Add marker* and then after adding two markers in the box *Markers* must be defined the distance between each other by

using mouse right-click and the *Create scale bar*. this process must be repeated on the entire length of the object always using the Add marker in the same orientation (on the bottom of the tape measure or ate the top of the tape measure). Once finished the Add markers and establish the distances between each other.

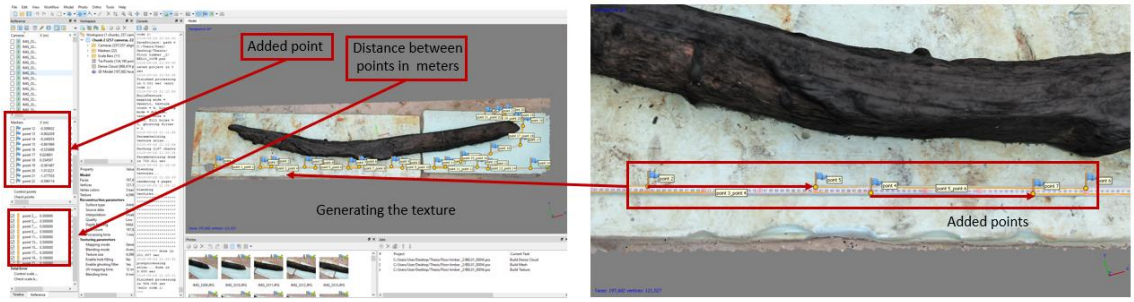


Figure 108 - Illustration of the technique adopted to measure the distance between points to allow the calibration of the photogrammetric model (process developed by the author).

g) To complete the calibration of the model, select the option *Rectangle selection* and in the model select and remove all surfaces not associated to the archaeological timber (added markers must be hidden to avoid deleting them). Then in the *File* menu, select the *Import* option and then *Import masks*. This will reduce the working area to the minimum to avoid extra time consuming during the next step.

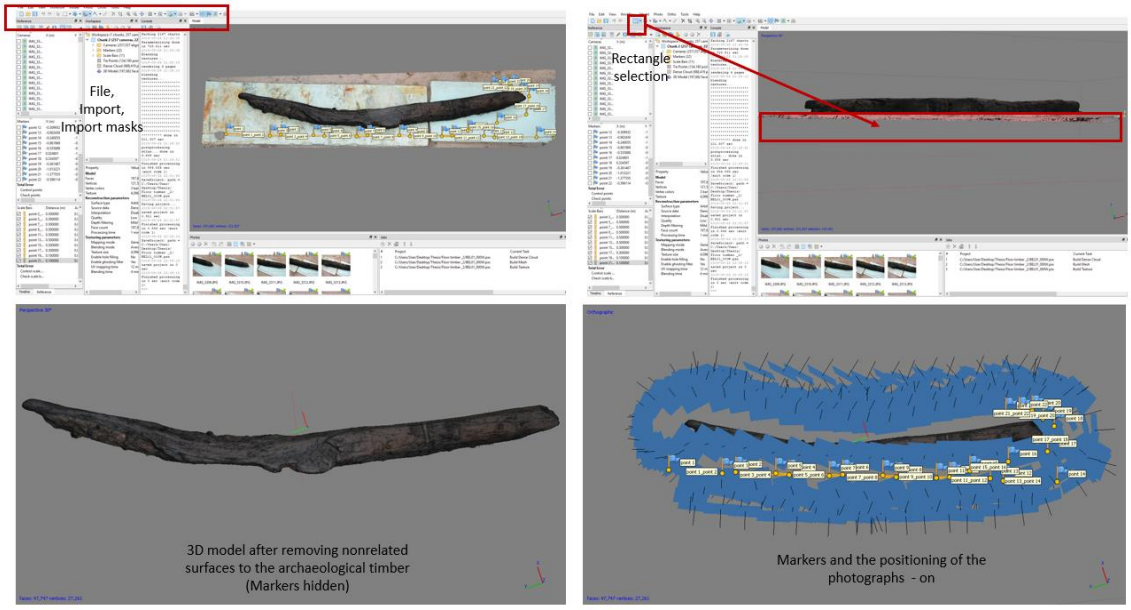


Figure 109 - Illustration of the technique adopted to remove nonrelated surfaces from the photogrammetric model (process developed by the author).

h) The next step is to calibrate the 3D model. Having imported masks and select update in the reference box, the photographs must be realigned using the masks. This time, the alignment process will only consider parts of each photograph and have the distances between markers as the established scale to produce the photogrammetric model. Reason why it is important to clean the model from unrelated surfaces and to add precise markers from the tape measure reproduced on the original model.

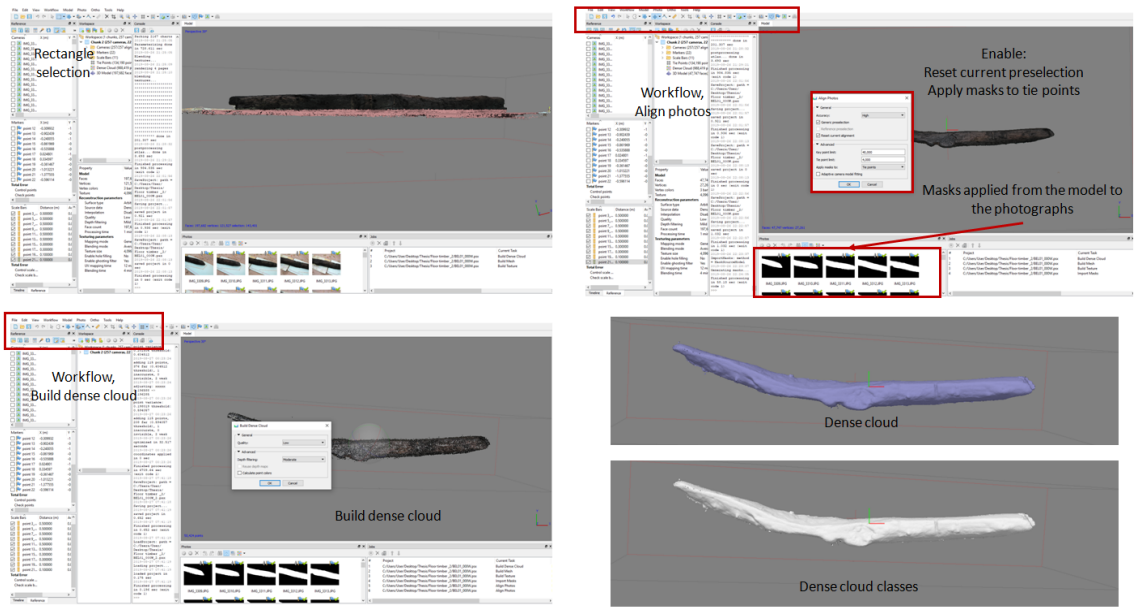


Figure 110 - Illustration of the technique adopted to realign the photographs using a imported masks and by performing the process of building an accurate 3D model of timber BEL01-042W (floor timber) (process developed by the author).

i) After performing the adequate process to build the photogrammetric surface, the model must be exported as an *obj* file to conduct tree reconstruction analysis in the Rhinoceros 3D software. Although, after the completion of the process to build an accurate digital representation model (surface), some wood features became immediately visible such as natural tree edges (heartwood to sapwood edge), grain lines (growth pattern) and the tree`s knots.

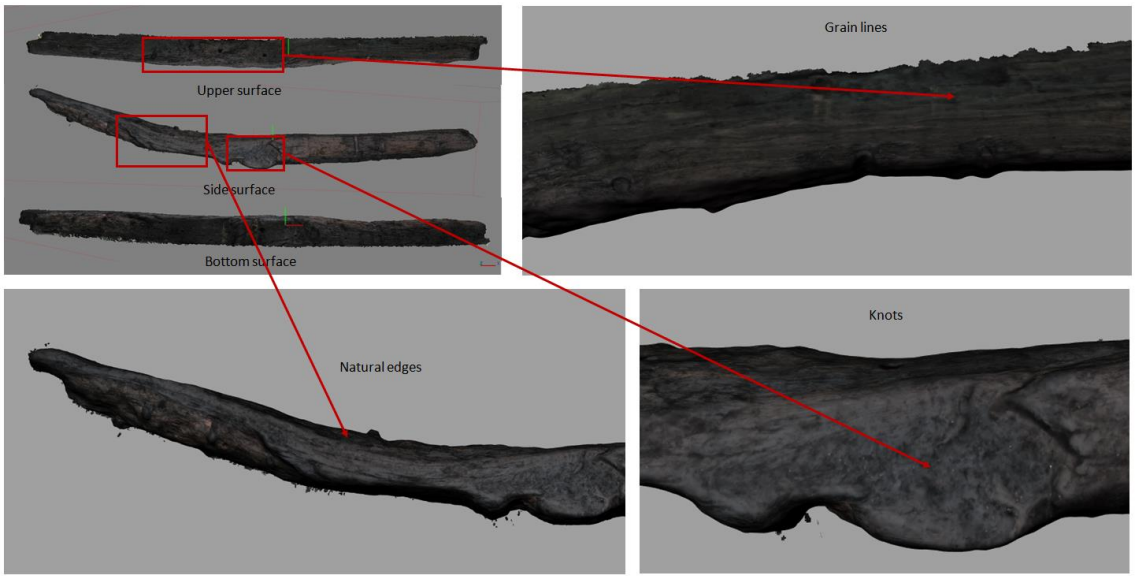


Figure 111 - Illustration of the wood features evidenced after the completion of the photogrammetric model in which are clearly visible the heartwood /sapwood edges (on the upper surface), the grain lines indicating the growth pattern and a relatively large knot (a process developed by the author).

j) There are several methods of importing the obj files into the Rhinoceros 3D. The adopted option to the present thesis consisted of the following sequence: File, Import, select the file and then open file using the default options on the next box. After importing the surfaces, it is suggested to group the collection of surfaces that provide a representation of BEL01-042W. This suggestion relies on the fact that the produced photogrammetric model was built from several surfaces which if disconnected, it is very difficult to realign the surfaces within the accurate initial positioning. Therefore, the use of the Rhinoceros 3D tool Group (Ctrl + G) will prevent the surfaces from becoming disarticulated.

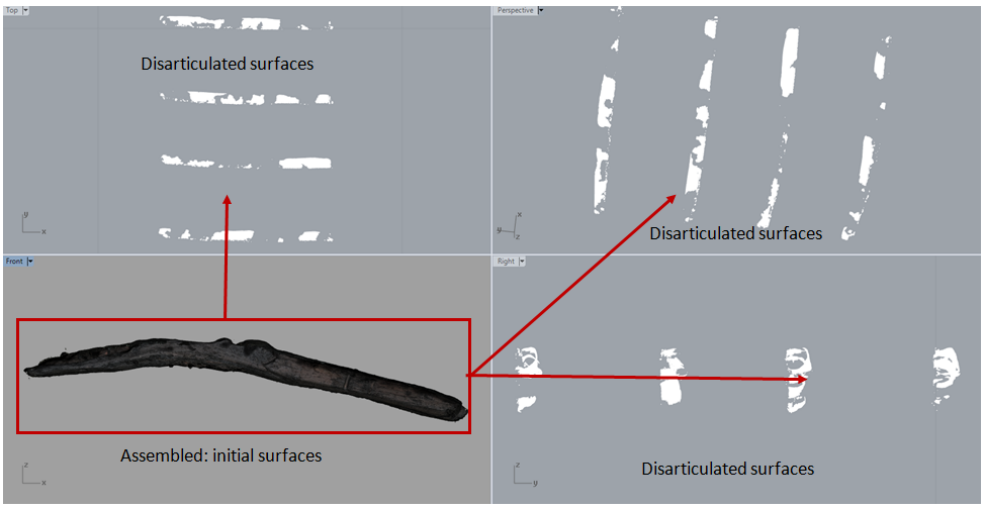


Figure 112 - Illustration of the risk of having the surfaces disarticulated from each other (a process developed by the author).

h) The next step consist scale the surface in the Rhinoceros 3D environment. Using the tool *Scale* and the original hand notes and photographs a line having two vertices must be draw in which the centre line represents the exact length of the timber. then the surface must be oriented in relation to the 3D digital axis X, Y and Z using the tools *rotate* and the software *gumball* having the option *Ortho* selected.

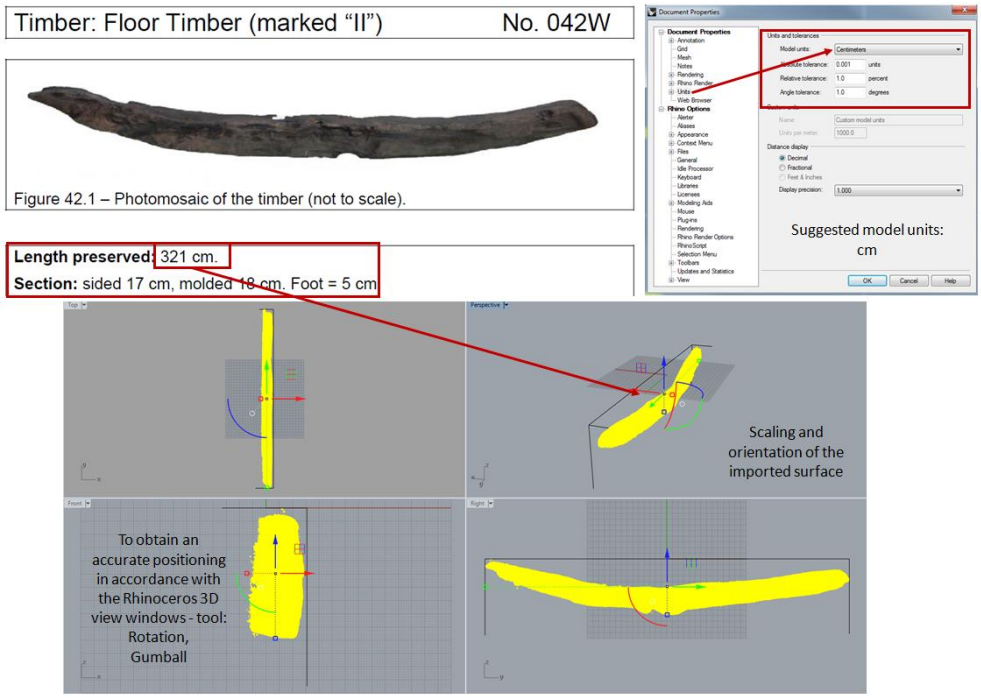


Figure 113 - Illustration of the scale and rotation process to obtain an accurate positioning and scaling of the produced surface (a process developed by the author).

i) Having set the Rhinoceros 3D windows and prepared the produced surfaces, it may be initiated the BEL01-042W parent tree reconstruction process. Despite the use of a different tool from the acquisition of line drawing using a FaroArm, the template must be set in accordance with functional place of the timber in analysis. Therefore, a template identical to the employed in the recording of BEL01-003W was used to record the BEL01-042W wood features (cross ref BEL01-003W). This may be set by selecting the developed template from the stored folder and drag it into the layers box. Then must be produced a scale (for the BEL01-042W the adopted scale was built having four section of 50 cm each).

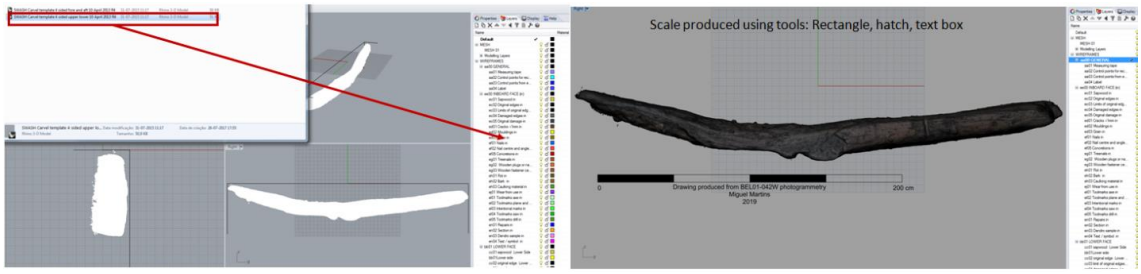


Figure 114 - Illustration of the attribution of an adequate layer template and the produce of a precise scale to reference the surface (process developed by the author).

j) The next step was to type tool *PolylineOnMesh*, follow the options in the command line and select the correspondent layer and start drawing the wood features. First-line to be addressed should be the edges and then the grain lines, followed by the knot and cracks. If using the line drawings to the investigation of shipbuilding architecture, all other features must be recorded following the produced manual from Toby Jones (Jones 2013a) with the adaptations (if required).

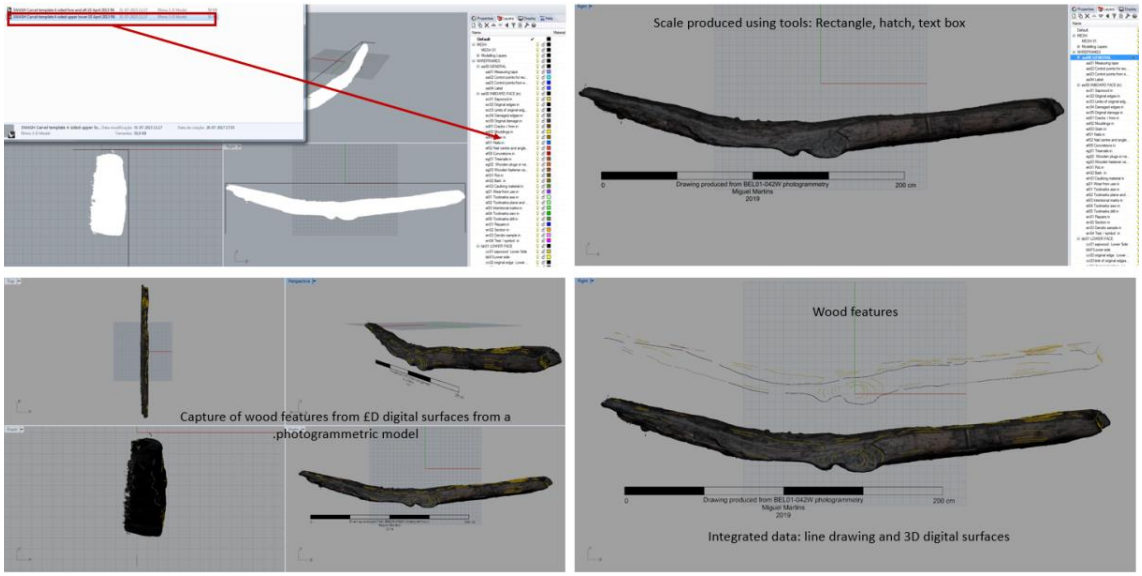


Figure 115 - Illustration of the produced line data from the 3D digital surfaces (photogrammetric model) (process developed by the author).

k) To the development of tree reconstruction studies focus on collecting the data surface and line data from BEL01-042W, was followed similar techniques to the reconstruction of BEL01-003W.

RECONSTRUCTION OF THE KEEL SECTION BEL01-071W.

The recording of BEL01-071W represented an added value to the development of tree reconstruction studies. The surviving length of this timber and the complexity of recording a highly eroded timber with a substantial number of fasteners involved the use of advanced digital recording techniques such as multiple stages of leapfrogging and permanent 3D digitiser calibration sequences. This section of the Belinho 1 keel also is highly cracked from the centre of the timber to the aft part which aggravated the level of concerns to maintain its preservation and integrity during its transfer across the working stations. Nonetheless, the results obtained from the analysis of such representative of shipbuilding technology worth the time-consuming and assumed risk while assessing BEL01-071W.

The keel is a square shape timber which, would be displayed from aft to forward of the ship hull. Due vessels` size it is not common to find a keel made from just one timber, but as many sections as the carpenter needed. Those subdivisions were shaped from trees of the same species and if possible similar features (size length and age). Each section linked with others by employing suitable techniques, such as scarfs and reinforced by bolts, iron nails or / and treenails.

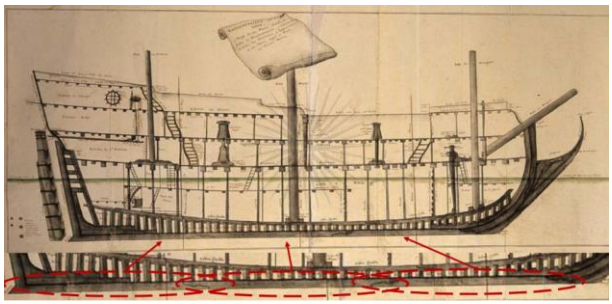


Figure 116 - Detail of the keel section on a drawing from the Album do Marques de Victoria (Navarro 1756, 15). Although, there is a representation of the 1st section due the direction of the scarf.

Although to avoid hull floods or breaches on the hull, the scarfs were shaped in a way that water could get in while the ship was sailing. Equally, these should be sufficiently far from tension areas as the mast step. All scarfs were carefully caulked in every joinery to insure waterproof from the linkage with the sternpost until the stem post. The timber or set of timbers is considered crucial on shipbuilding, and it's the first object to display on the shipyard to start to build the vessel. There are many possible shapes, regarding the Iberian ships, the shape has a peculiar silhouette. From one or more standing trees with suitable size and wood strength, close observation of the grain flow is essential to define in which part of the trunk, is adequate to meet the predesigned timber requirements. This process was developed by following shipwrights' drawings or eventually by experienced shipbuilders using the *graminhos*. The designation of the ended scarfs is

alefriz (Portuguese word) or back rabbet (English form). It should have different angles in order to enable the joinery of the hull planks. The rabbet had angles that vary from the stern to the midship and from there to the stem. Those angles were directly related with angles of the turn of the bilge. This way the hull planks would perfectly match on the keel to provide a waterproof hull system. The keel (section) of the Belinho 1 ship was shaped from a standing tree which, would have more than 9 m high. It has several knots with significant size on the rear part (inboard face) and other on the outboard face slightly smaller. The upper face (inboard face) is considerable flat as it would be in general. This shape allowed to display the upper timbers – floor timbers and bottom timbers. The BEL01-071W does not have significant changes in the back-rabbet angles which, suggest that the known section of the keel should fit into the midship area. Furthermore, two iron bolts perfectly match in distance (between bolts and its diameter) with the mast step bolt holes.

A similar section of the keel was found during the recording of the Aveiro A remains (Alves, Reith, et al. 2001, 317-345). The Aveiro A ship sank on a lagoon in the area nearby the city of Aveiro in the northern part of Portugal. According to the author, the vessel sank after a fire on board. At that time, it was carrying a cargo of regional pottery which, part of it still remains on the wreck site. Aveiro A was considered as an example of an Iberian shipbuilding technique (Alves, Reith, et al. 2001; Oertling 2001), following the assemblage methods that may be observed on the treatise produced by João Batista Lavanha (1608/16). The remains of the ship were recovered during major intervention. Archaeologists disassemble every timber after removing ballast and a significant collection of local pottery. The wooden remains due in CNANS to the conservation process.

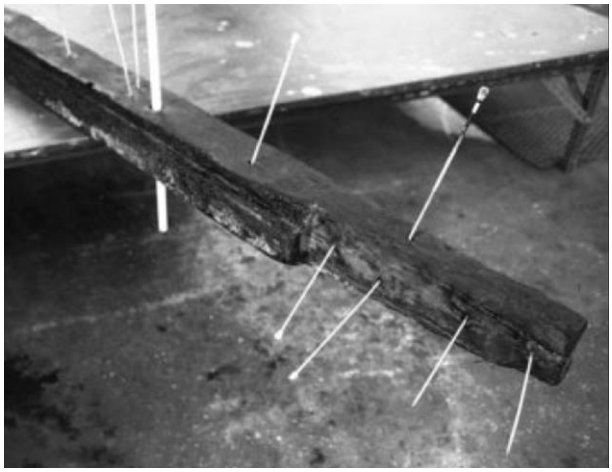


Figure 117 - Keel scarf on the Aveiro A wreck (Alves, Reith, et al. 2001, 323).

BEL01-071W[176] is the only known longitudinal timber of this type associated to the Belinho 1 shipwreck. Its maximum preserved dimensions were 872.7 cm in length, 11 cm sided (aft), 22.7 cm mid-section and 19 cm at the forward section (coincident in dimensions to the bottom face of timber BEL01-001W. The moulded dimensions also vary along with the timber having 8.8 cm at the aft 10.5 cm at the half and 15.9 cm at the forward section. The connection with the hull planks was achieved with iron nails (1.1 cm), sub-horizontal, all along the preserved length. Some frames fastened with iron bolts (2.7 cm, heads 5.5/6 cm, recesses 6/7 cm, 25 mm deep, on the bottom face). Every other frame not fastened to the keel. Along the section of the keel were included bolts at: 4, 42, 108, 181, 249, 319, 333, 392, 465, 576, 646, 712, 717, 783, 859 cm (Castro et al. 2015). Bolts and iron nails show evidence of fastening from outboard to inboard faces (bolts) and on each side (iron nails) to clamp the hull plunks. Closed visual inspection did not detect tool marks. This may be a consequence of a high level of erosion that BEL01-071W was subjected. Rabbet angles do not have significant changes from aft to forward (72`/67`, 74`/71`, 72`/65`, 64`/72`, 80`/65`, 78`/59`).The timber conversion method was not identified, although it resembles a

[176] Previous investigation undertaken by CHAM/FCSH-UNL recorded this floor timber with the catalogue number PB14-007 (Bettencourt et al. 2015).

standing tree which increases the number of knots toward to forward face. No information was collected about annual ring as a consequence of the high level of degradation and erosion, which inhibited the observation of tree rings.

In accordance with the studies focusing the Belinho 1 ship`s profile this section of the keel represents an added challenge to identify its correct positioning in regard to the remaining timbers (exception made to the floor timber BEL01-003W and the mast step (BEL01-051W). This undefinition of achieving a high accuracy about the correct location of the surviving keel is deeply related to the high level of degradation in the forward and aft extremities of BEL01-071W where no scarfs were observed after closed visual inspection. However, same challenge was solved regarding the floor timber and the mast step. The existing fastening system is entirely consistent in location, width and angle between the three timbers which turned them into the second group of Belinho 1 surviving timbers the first group: aft section: Y-frames, stern knee and sternpost and, the second group: floor timber, keel and mast step.

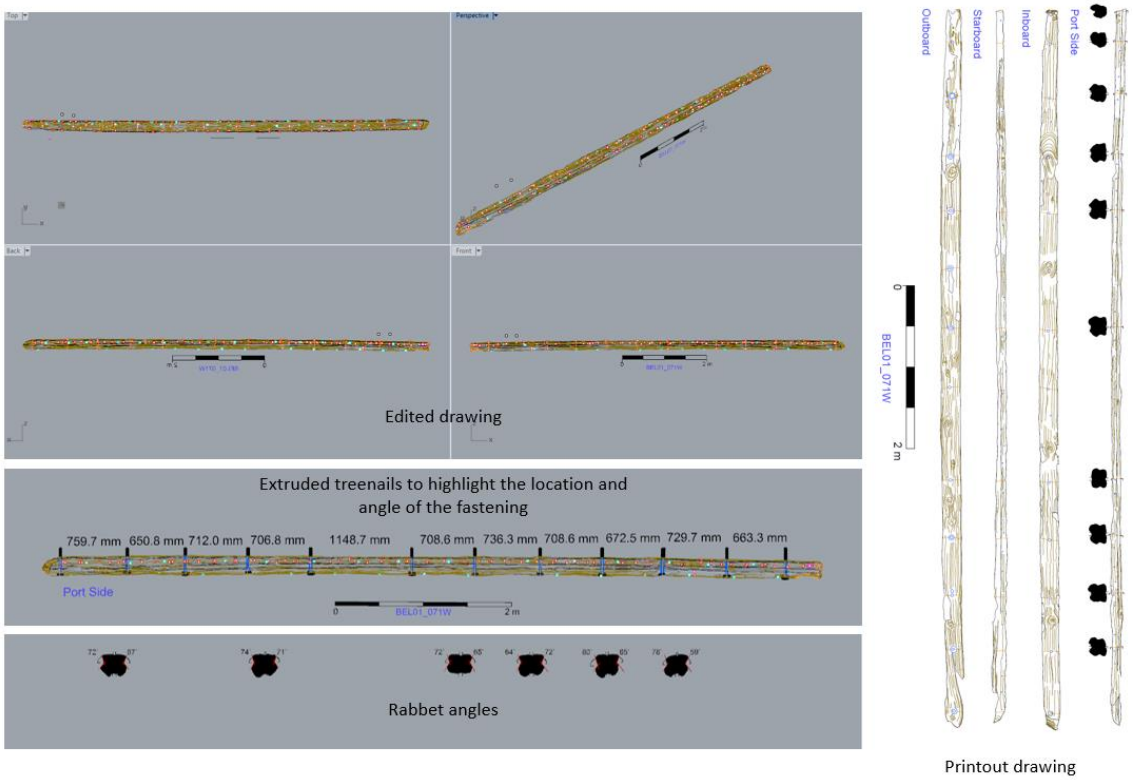


Figure 118 - Illustration of the produced drawings from timber BEL01-071W (keel) (drawing by the author).

The recording methods employed to capture information from the BEL01-071W timber faces followed the same criteria applied to the Y-frame BEL01-001W. This included the FaroArm drawing (following the above-mentioned techniques), FaroArm edited drawings, FaroArm printout drawing, photogrammetry, extruded fastening drawing and the extruded trunk and branches.

The BEL01-071W parent tree reconstruction represented a new challenge to the developed approach. The section of the keel was shaped from a long-standing tree with a high number of knots along its entire length. The knots width varies from 2.7 cm to 56.4 cm, on each face were recorded: four on portside, six on the inboard side, zero on the starboard side and thirteen on the outboard side. Thus, the selected parent tree to shape the section of the keel may not be considered as *good* timber to the given propose and functionality – longitudinal structural timber. Considering the first impressions taken on

the quality of BEL01-071W to the purpose of shipbuilding, it became relevant to perform tree reconstruction studies focusing this timber.

The adopted techniques to the reconstruction of BEL01-071W followed the methods developed and presented within the present thesis. Although, the rather apparent simple shape of this timber revealed to possess a complex morphology in particular in regard to the bigger knots/side branches. Therefore, its reconstruction combined the methods developed and employed during the reconstruction of the Bremen Ship planks, BEL01-001W (Y-frame) and BEL01-003W (floor timber).

The following step-by-step process will describe the employed methods:

a) To identify particularities in morphology along the entire length of the keel´s section the grid had to be placed in multiple axis having a 200 cm width and 40 cm between the horizontal lines.

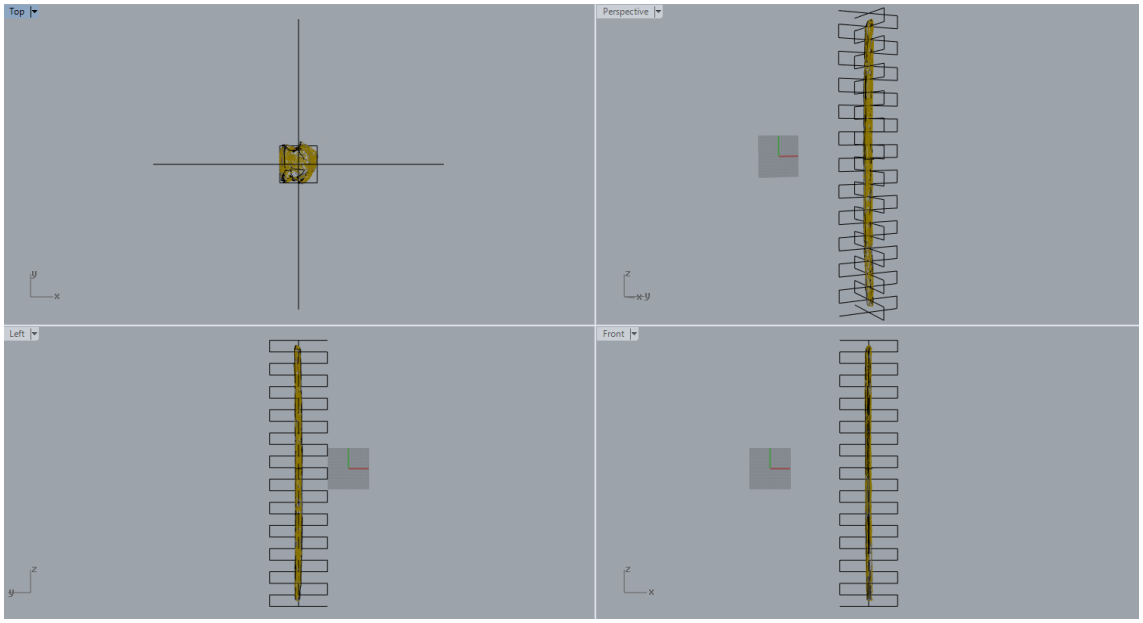


Figure 119 - Illustration of the constructed grid to allow the reconstruction of the BEL01-071W parent tree within a smooth and consistent shape (drawings by the author).

b) After the construction of the grid, *Points* (Rhinoceros 3D tool) were included in the intersection of the side and front grids. Considering that BEL01-071W is relatively bent due to the timber degradation process but in its original positioning would be straight, the points were placed in the intersection (side and front grid) of the constructed grid system. To the reconstruction of the BEL01-071W parent tree, the predesigned grid (**TREE RECONSTRUCTION OF THE BREMEN KOGGE PLANKING PARENT TREES.**) had to be adjusted in way to obtain a better accuracy of the 3D digital model. The surviving dimensions of the keel increased the challenge of capturing relevant data about the location of knots, cracks and particularly the information about the pith location. This adaptation allowed to capture wood features in greater detail by following a segment-by-segment (bottom to the upper faces) covering both views: left and front Rhinoceros 3D windows.

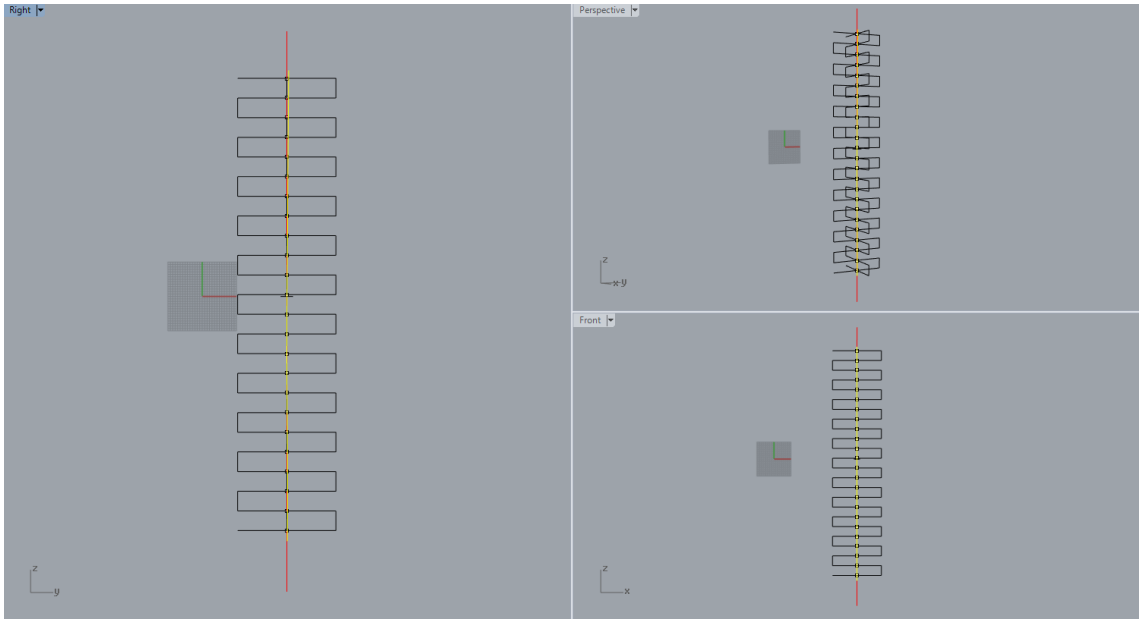


Figure 120 - Illustration of the differences between a straight line (red line) and the line (Yellow) formed by the centre axis of BEL01-071W. The draw of a straight line allowed to restore the original shape of the parent in accordance with the knowledge obtains during the development of the present thesis - chapter 2 (drawings by the author).

c) The next step was to draw the knots from each timber face. The method consisted of in hiding unnecessary faces and use the view window in Rhinoceros 3D in accordance with the knot to draw. Once completed the drawing in a face, the corresponded layer to that face must be hidden and heightened the next face to draw. In this way, it is possible to avoid mistakes such as drawing knots to a wrong face/positioning. Knots can be drawn using the Rhinoceros 3D tool *Circle* and then highlight the point (*Points – on*) and drag them to the correct position to overlap the knots draw using the FaroArm. This process allows identifying the knots width and their position regarding the main pith.

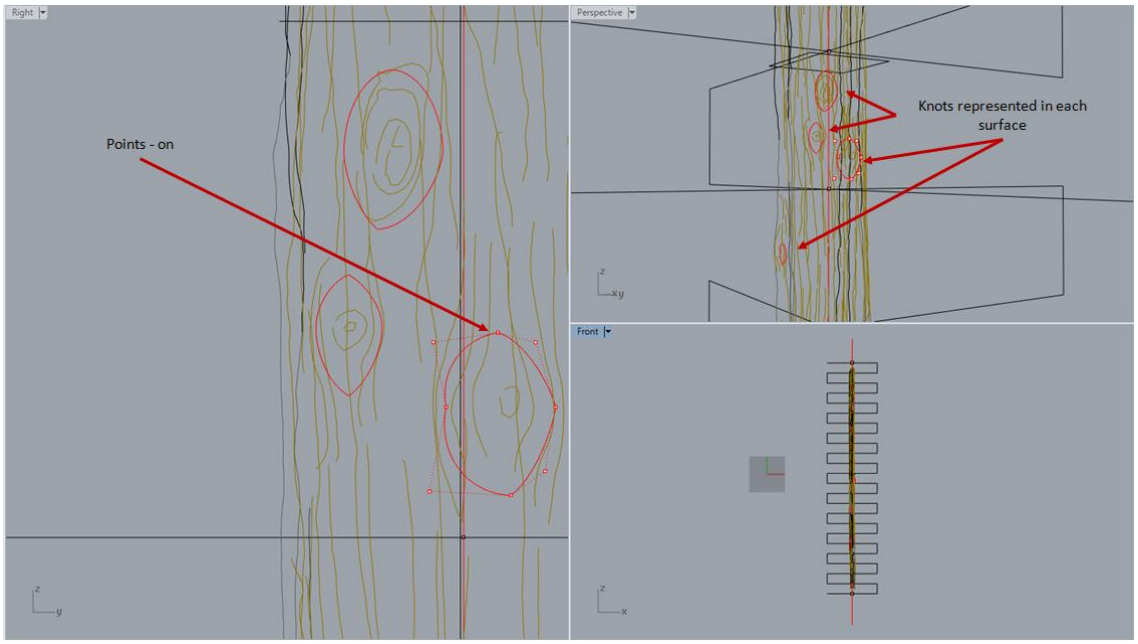


Figure 121 - Illustration of the developed method to identify the width and positioning of each knot and the method to accurately represent the knot morphology (drawings by the author).

d) In the selected the *Perspective* window view each circle representing the knots (red circles) was at the time and rotated until a place in the correct face position. It must be noted that the red circle representing the knots located in the rabbet area must follow the orientation of the parent tree face rather than the timber shape. Otherwise, the direction of the branches will not be accurate.



Figure 122 - Illustration of the differences between adding the knots circle connected to the timber face and the positioning of the circles in accordance with trees natural morphologies (drawing by the author).

e) The next step was to draw the lines from the main pith through the centre of each recorded knot. In this way, it is possible to obtain a clear understanding of the grown branches on the trunk full extension. This lines also will allow being used to generate the 3D objects representing the knots direction, width and potential size (small knots: short dimension / Bigger knots: longer dimension). After completing the knots line data, certain modification may have to be considered in regard to the morphology of the central pith. Considering that straight standing trees such as BEL01-071W have relatively large branches (Figure 59 - *Illustration containing the correlation between the planted trees in the side of the River Weser and the timber used to build the Bremen kogge (drawings by the author).*) the trunk must be strengthened in some section along its entire length. Meaning that long-standing trees having relatively large side branches are not absolutely vertical. Small variation may occur during their growth to challenge the gravity effects caused by branches.

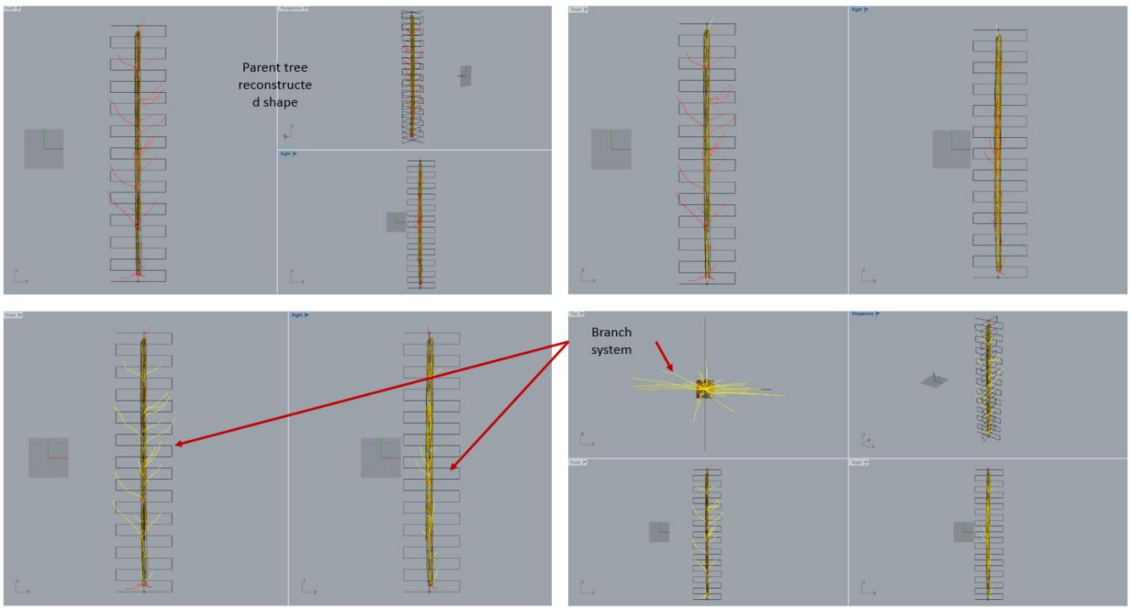


Figure 123 - Illustration of BEL01-071W parent tree based on the recorded wood features using line data (drawings by the author).

f) The analysis and reconstruction of BEL01-071W parent tree specific wood features highlighted some wood features that initially were less understood. These included the large branches along the trunk but in greater part the aft of the keel section, where evidence has shown the remains of the root system. A conclusion that arose after close inspection to the branch's orientation along the trunk from the bottom to the upper part (wider ring width on the bottom part as opposed to the narrow ring width in the upper part of the branch). As opposed to the entire collection of branches which have wider ring width towards to the aft part of the keel, the first collection of knots (in the aft part) have wider rings in the upper part of each surviving knot.

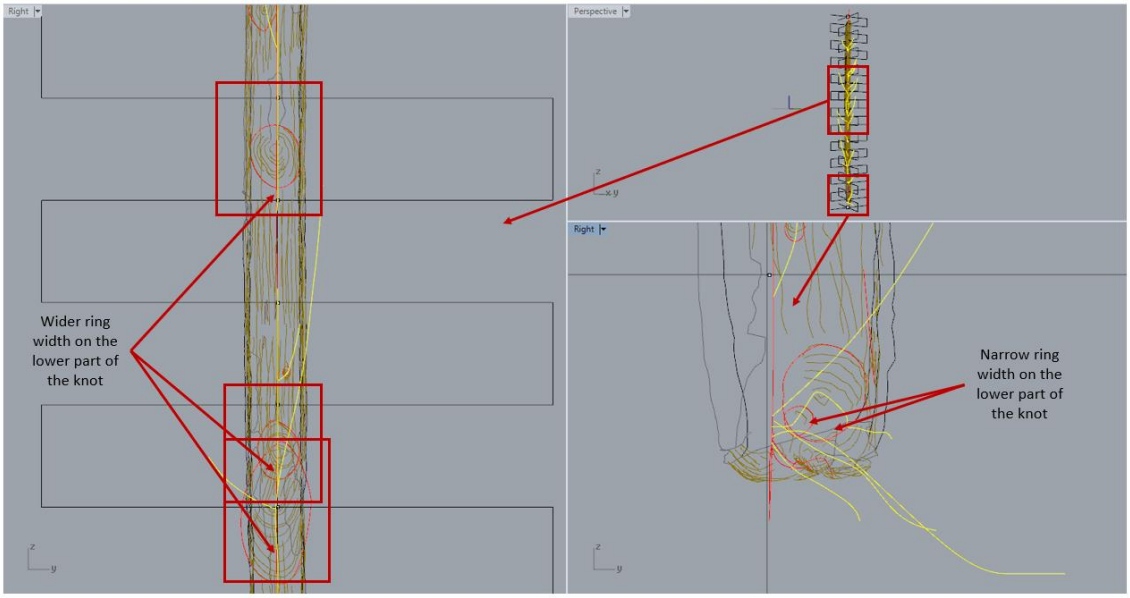


Figure 124 - Illustration of the differences in the ring width between the branch and root system in which evidence pointed to the use of a maximum available extension of a tree to the construction of the ship`s keel (drawings by the author).

g) Having reconstructed the pith from the trunk and branches and identified the width of each knot, the next step was to provide a morphology to the branches in accordance with the knowledge obtain during the investigation undertaken within the **Chapter 2 - The Iberian shipbuilding tradition and the morphologies of trees woodlands, shipyards and treatises**. Followed by the accurate construction of 3D objects to reconstruct BEL01-071W parent tree morphology. The reconstruction of the trunk must be as accurate as possible to avoid misinterpretations of the overall parent tree morphology. Following the step-by-step process to reconstruct the BEL01-001W (Y-frame) and the BEL01-003W (floor timber) a number of circles have to be placed in accordance with pre-established grid intersections. Although, a long-standing tree as straight as it may seemed, the trunk as its own shape and should not be represented as a tubular object. Therefore, the points added to the intersections between grids have to be attached to the redesigned pith in accordance with the grain pattern. Meaning that the centre of the tree would have to be dislocated to resist against the gravity, branches weight, landscape

morphology and natural agents such as predominant strong wind and the competition against the surrounding trees to obtain the solar energy. The following figure represents the differences between an accurate representation of the tree`s trunk as opposed to a more simplistic reproduction of the same trunk.

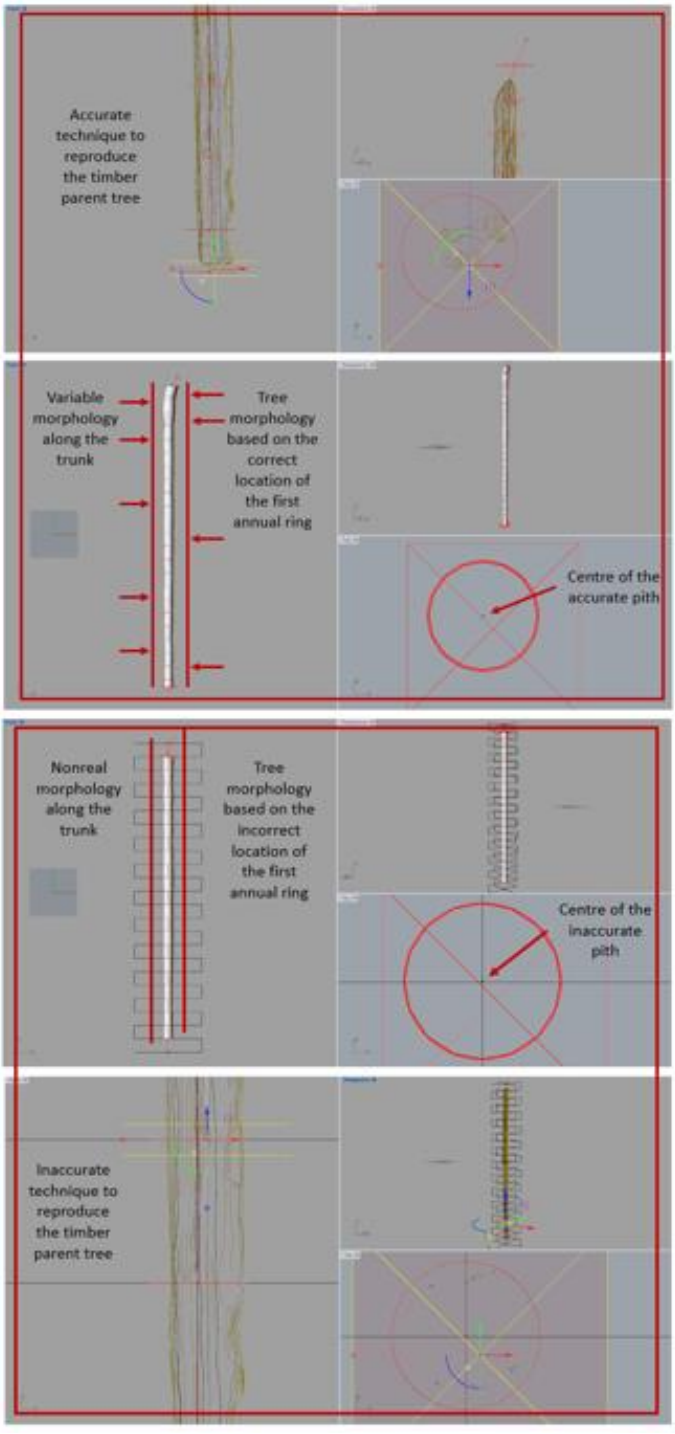


Figure 125 - Illustration of the technique to obtain an accurate representation of the parent tree trunk morphology (drawings by the author).

h) The following step gather the reconstruction of the tree`s trunk and the branches based on the entire collection of wood features recorded with a FaroArm. As mentioned in the reconstruction of the Bremen Ship planks and other Belinho 1 shipwreck timbers each similar wood feature must be associated to a layer in a way to provide a critical analysis of the surviving timbers. This method applies to the recording of each timber face and to the tree reconstruction step-by-step process. Therefore, the drawing of the reconstructed pith, branches` pith must be associated to a predesigned layer and colour (e.g. Pith , knots , grid , trunk and branches). Once completed the line drawing the next step is to create the 3D objects: the trunk, branches (and in the case of BEL01-071W – the roots). The process is similar to the method employed in BEL01-001W and BEL01-003W. Using the Rhinoceros 3D tool *Surface1Rail* the pith must be selected and then each circle in a sequence bottom-up or *vice versa* to construct the trunk. To the reconstruction of side branches, red circles representing the branches` width must be copied (Ctrl-C), reduced in scale and placed at the end of each branch pith. To generate the 3D object the adequate Rhinoceros 3D tool is *Surface1Rail* but first selecting the pith and both circles from each branch. In the case of replicating the knots circles and place them with equal dimensions on each end of the branch pith, will generate inaccurate representation of the knot. As mentioned in the chapter two: **Chapter 2 - The Iberian shipbuilding tradition and the morphologies of trees woodlands, shipyards and treatises,** the growth pattern of a tree attends to provide a vertical shape to the tree but also more robust in the bottom (close to the root system) and narrower in the upper part (canopy).

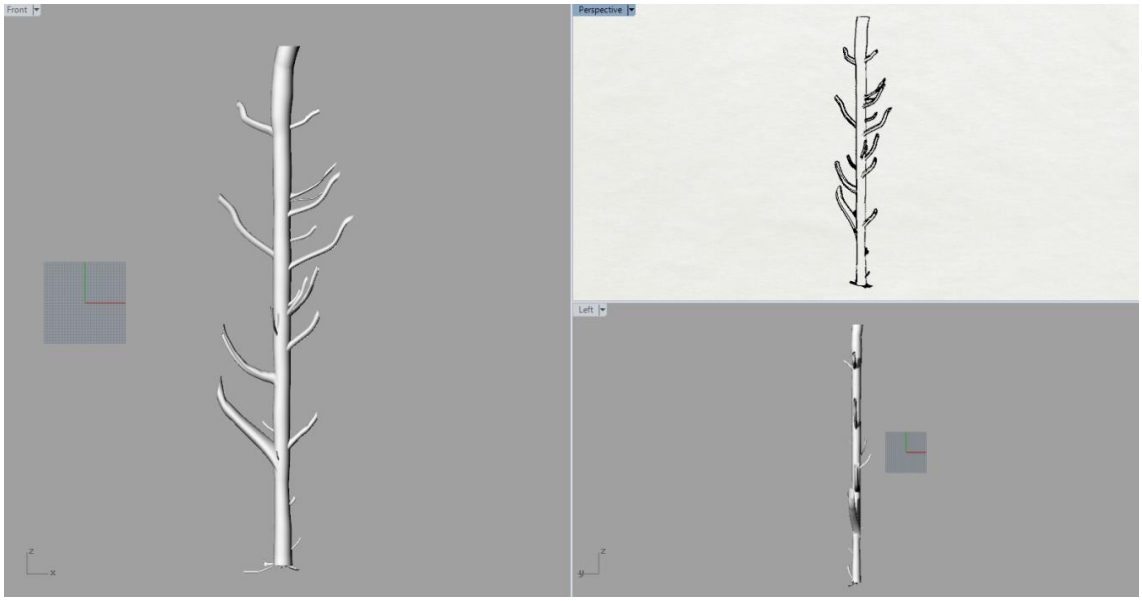


Figure 126 - Illustration of the BEL01-071W reconstructed parent tree (drawing by the author).

By implementing the developed approach and associated methods, it is possible to ensure with high accuracy that the keel section BEL01-071W corresponds to:

a) Based on the observed growth pattern, the floor timber was shaped from a managed tree potentially by employing pollarding techniques to cut side branches planted in a relatively dense forest. In accordance with the number of branches on outboard and inboard faces it may be assumed that this tree was planted in a filed closed to other trees of same age but at a higher distance from others. This conclusion was achieved by the reduced number of existing knots on two of the faces (port and starboard).

b) The growth pattern and number of knots along trunk suggests the implementation of casual side branch cutting. A conclusion achieved after analysing the width of the side branches which vary from 2.7 cm to 56.4 cm.

c) Considering the evidence recorded from the root system at the aft part of the timber, it may be assumed that BEL01-071W parent tree was used on its maximum extent in a way to fulfil the shipbuilder’s requirements in the keel`s

length. In addition, the upper part (forward part) represents the split of the trunk into several small branches which corroborate the achieved conclusion of using a tree on its maximum length.

RECONSTRUCTION OF THE STERN KNEE BEL01-072W.

Belinho 1 shipwreck timber BEL01-072W represents a structural element of the vessel`s hull: a stern knee. This timber was connected in the aft to the keel, Y-frames and planking.

According with João Barata (Barata 1965, 259), the stern knee is the round timber which, reinforce the linkage between the keel and the sternpost or the stem post. The *coral de popa* in Portuguese terminology was also used to narrowing the hull on each end. There the Y-frames were displayed in way that the hull V or U shapes could have different angles. The difference between the stern knee and the stem knee is mainly related with angles / longitudinal curvature. Stern knee on the called Iberian shipbuilding tradition has a V shape as may be observed on the BEL01-072W. It has the same thickness as the keel and the sternpost inboard face and should be long enough to give strength to the joinery between the keel and the sternpost or stem post.

Similar timber features in terms of shape and function were found during the investigation of the Western Ledge Reef Wreck by INA. The initial investigation took place between 1988 and 1991. Later this research project was undertaken by Piotr and Katie Bojalowski since 2007 and is located in Santa Lucia, Bermuda. The ship remains consists of almost the entire bottom of the vessel's hull (125 ship timbers) including the keel, keelson

with the mast step and six buttresses, 14 floor timbers (with dovetail), 21 first futtocks, external planks, ceiling planks and the entire stern assembly.

The late-15th-century Aveiro A wreck, founded in 1992 on the Aveiro Laguna, Portugal also has a similar stern knee. This research undertaken by Francisco Alves started in 1996 and still last under the coordination of José Bettencourt and Patricia Carvalho since 2011). The ship remains consists of a significant percentage of the ship´s stern including bottom frames, Y-frames, the stern heel, keel, first futtocks, keelson, stringers and planking besides a large number of ceramics. The stern knee does not look similar to the existent on the Western Ledge Reef wreck (Bojakowski 2011; Bojakowski 2012), or in Belinho 1 (Castro et al. 2015; Martins et al. 2017), however, it has the same function. The Aveiro A stern knee is smaller in height and the junction between the bottom outboard face and the after outboard face is not highly pronounced as in the other two wrecks. The lower end of the sternpost formed a single piece with the aft end of the keel (Alves, Reith, et al. 2001, 324). The inboard face forms an angle of 63º in relation with the outboard face of the keel.

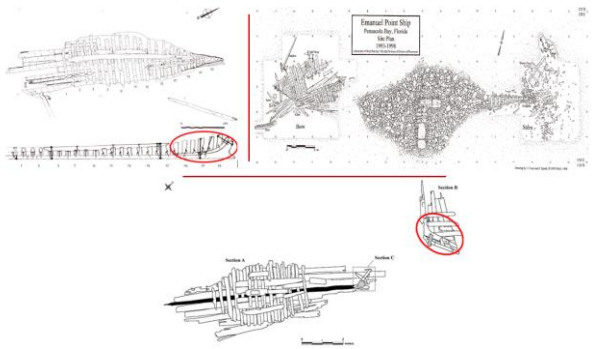


Figure 127 - (on the left side) Aveiro A wreck 2D drawing of the preserved ship timbers, including the stern knee (Alves, Reith, et al. 2001, 321, 335). On the right side, the Emanuel Point shipwreck site plan (Smith 2001, 296). On the bottom, Western Ledge Reef Wreck Research Project Documents and Drawings[177].

[177] http://nauticalarch.org/western-ledge-reef-wreck-research-project-documents-and-drawings/

The remaining ship timbers of the Emanuel Point 1 wreck, Pensacola also comprehend a stern knee similar the existent in Belinho 1. The exposed stern timbers consist of in keelson, 11 aft frames, four lower hull strakes and the stern knee (Smith 2001; Collis 2008; Smith 2018).

As in the case of the BEL01-071W (keel section), no other similar timbers were found or associated in similarity to the BEL01-072W.

BEL01-072W[178] maximum preserved dimensions 173.3 cm in length on the upper outboard face, 277.4 cm lower outboard face, 145.9 cm upper inboard face, 244.2 cm lower inboard face. 21 cm sided on the joining of the upper and lower inboard faces, 55.9 cm moulded between joining of upper and inboard faces and the joining between the upper and lower outboard face and the angle of 105` in the aft face.

The fastening evidence has shown that this timber has a notch on the inboard face to receive a tenon from the foot of Y-frames BEL01-001W, BEL01-032W, BEL01-036W, BEL01-037W, BEL01-039W, BEL01-040W and BEL01-043W and, on the aft face to connect to the sternpost (BEL01-073W). This timber presents some grooves next to the recesses for the fastener's heads that are similar to the ones found on the Pepper Wreck floor timbers (Castro 2005). Bolts at: 26.5 cm, 80, 150 cm, counting from the base. The bolt pattern matches that of the sternpost. No evidence of tool marks was found. The employed conversion method followed the same as to the other associated timbers to the Belinho 1

[178] Previous investigation undertaken by CHAM/FCSH-UNL recorded the floor timber with the catalogue number PB14-009 (Bettencourt et al. 2015).

shipwreck. The employed tree species to the shape of the timber was *Quercus sp.* but no information about the number of rings is available.

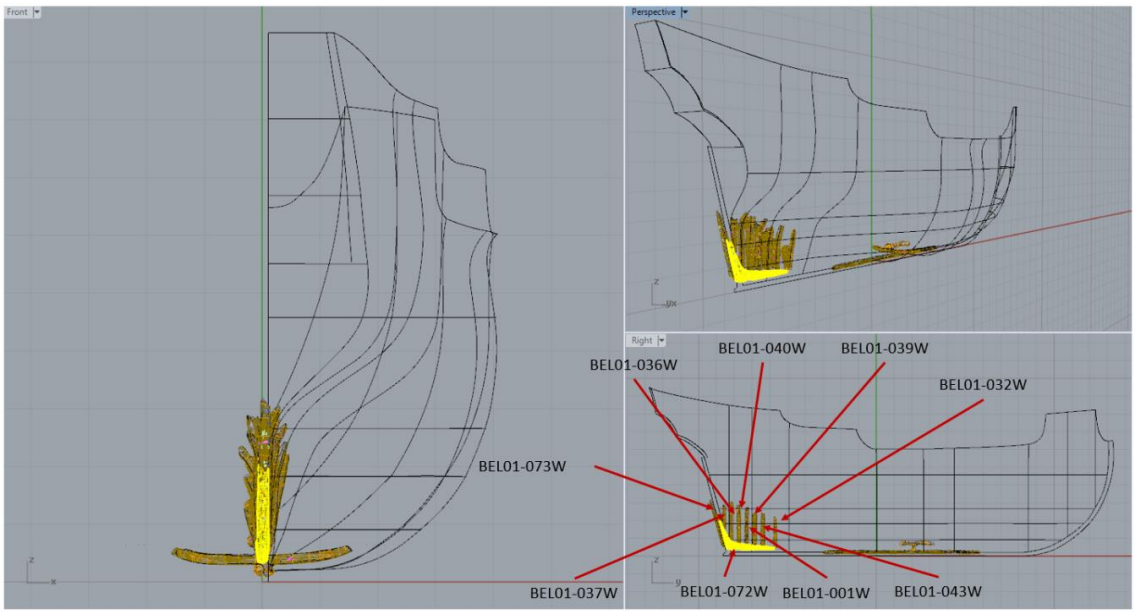


Figure 128 - Illustration of the original positioning of BEL01-072W on the Belinho 1 reconstructed ship`s hull

The recording methods employed to capture information from the BEL01-072W timber faces followed the same criteria applied to the Y-frame BEL01-001W, BEL01-003W and BEL01-071W. This included the FaroArm drawing (following the above-mentioned techniques), FaroArm edited drawings, FaroArm printout drawing, photogrammetry, extruded fastening drawing and the extruded trunk and branches.

BEL01-072W represents a different pattern in tree reconstruction studies. The required morphology of the predesigned timber having an *L* shape demanded the selection of a tree possessing different wood features from the trees selected to obtain Y-frames, floor timber, keel or hull planking. Thus, it became imperative to develop studies to identify the morphology of BEL01-072W parent tree.

From the studies performed focusing the BEL01-001W – Y-frame it was required by shipbuilders a tree having a low number of knots along the trunk and a clear split of it into two dominant branches to form the Y shape. To the floor timber BEL01-003W, it required by the shipyards to select a tree or trees planted in which the curvature of their branches would be adequate to the designated curvature taken from the ship`s line drawing and geometric plans. To the keel, shipbuilders required a long-standing tree, preferably with a low number of knots on the maximum available extension of the tree (although, as mentioned before such requirement was not taken into consideration to the shape of BEL01-071W). To the case of a stern knee as a crucial structural element of a ship's hull shipbuilders would require a tree potentially having a short, strong trunk and robust side branches. The selected tree would have to provide the required width in the trunk and at least a side branch with a compatible angle to the predesigned aft shape of the ship`s hull. Such requirement and demanding selection of a compatible tree would oblige to search for a tree in the woodlands having been planted supposedly in an open landscape. Although, these assumptions may only be confirmed or rejected if researchers undertake complementary studies, in particular, on tree reconstruction focusing on the surviving evidence recorded from BEL01-072W or similar timber shape.

The adopted techniques to the reconstruction of BEL01-072W parent tree followed the methods developed and presented within the present thesis. Although, adjustments have been made to the above-described methods because of the substantial discrepancies in shape and potential parent tree morphology in comparison with the studies conducted focusing other archaeological timber included in this doctoral study. Therefore, the adopted process will be presented within a step-by-step description of the developed techniques:

a) The first step was to hide the non-relevant layers to the reconstruction of the BEL01-072W parent tree. In this way, only became visible the recorded wood features such as natural edges, damaged edges, original edges, grain and cracks. Then a grid was constructed to provide accurate analysis to allow parent tree reconstruction. As opposed to the reconstruction of BEL01-001W, BEL01-003W and BEL01-071W, this grid comprised two different axis as the timber evolves through the horizontal axis (*Y*-axis) and vertical axis (*Z*-axis). The length of each perpendicular line was calculated in a way to cover the entire drawing port and starboard faces. The distance between each perpendicular line was designed to have 40 cm to allow focusing the attention in a relatively small section of the timber to obtain a high level of detail about wood features. After including the grid, close inspection on each face allowed to identify the growth pattern and to rotate the entire collection of line data to the original profile of the parent tree (roots as opposed to the canopy).

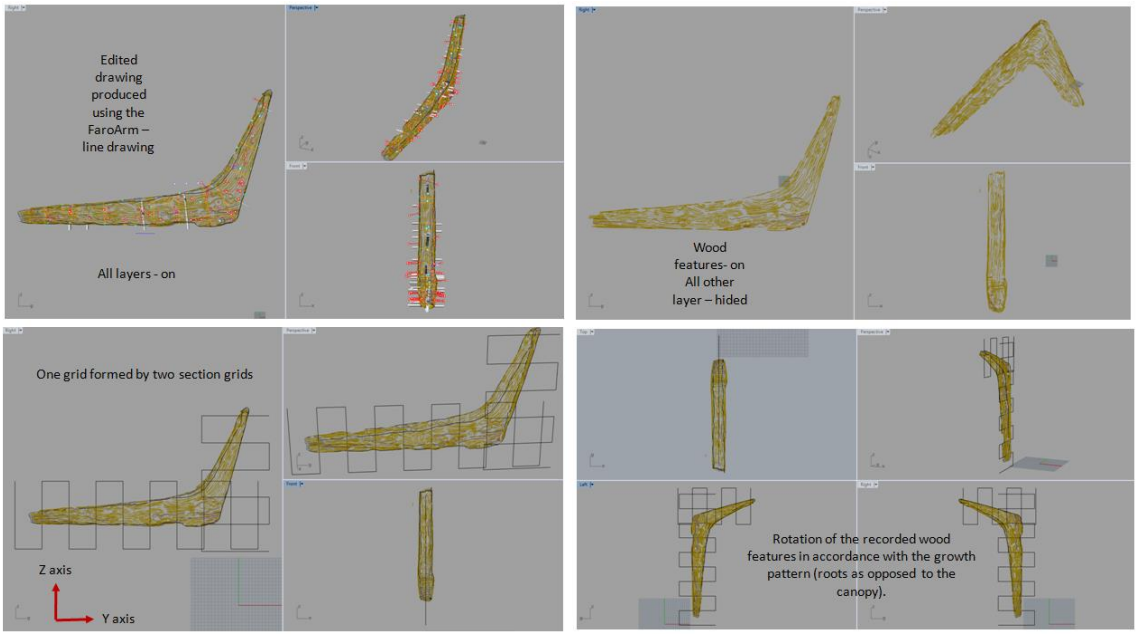


Figure 129 - Illustration of the developed process to create a group of section to allow a higher attention in the surviving wood features recorded during fieldwork (drawings by the author).

b) The next step consisted in identifying the pith location. A process that was applied to the trunk and surviving branch. To the identification of the pith greater attention was given to the natural crack and the bottom (forward face) and top part (aft face) of the drawing. The use of this technique is directly correlated to the visible rings and multiseriate rays which provided relevant information about path followed by the first annual ring in the tree´s trunk. To the surviving branch, same technique was applied to the end part (upper face) and to the other end the analysis of natural cracks to identify in which section of the trunk occurred the spit of the trunk´s pith to the branch.

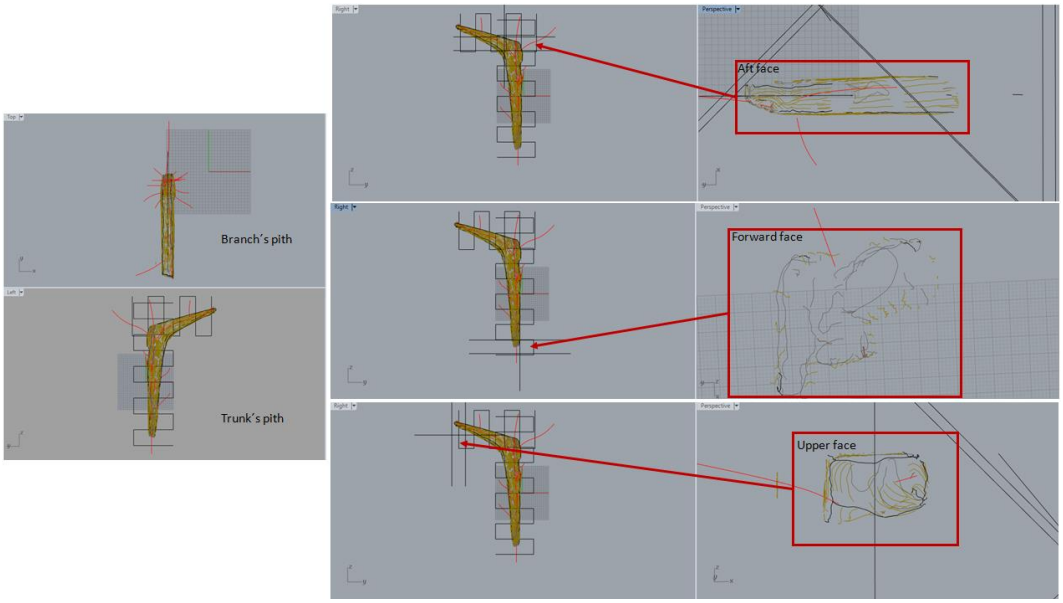


Figure 130 - (on the left side) Illustration of the trunk´s and brunches pith and (on the right side) Illustration of the data collected from the timber three ends (forward, aft and upper faces) (drawings by the author).

c) Considering the width, orientation and positioning of each knot, circles were created to reproduce these features in a way to allow the reconstruction of their morphology. To the trunk, the adopted technique followed the developed methods used during the reconstruction of BEL01-001W, BEL01-003W and BEL01-

071W. This included the construction of circles centred in the pith having a perimeter compliant with the surviving timber edges.

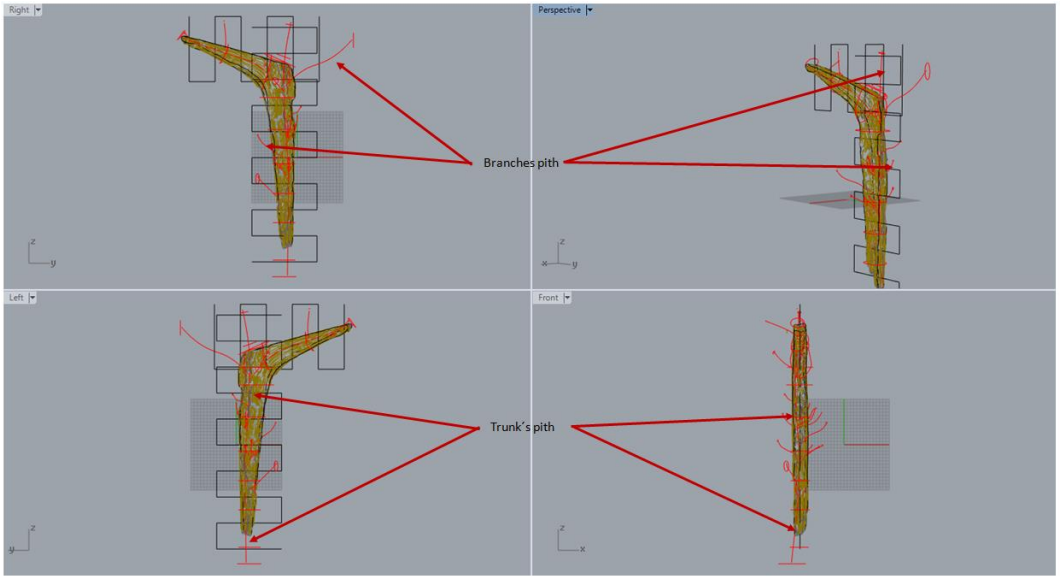


Figure 131 - Illustration of the achieved conclusion regarding the pith location (trunk and branches) and the width of the trunk and branches (drawings by the author).

d) Having reconstructed the fundamental section of the BEL01-072W parent tree, it was imperative to generate 3D objects within a high level of accuracy. The creation of these objects followed the same methods employed in the other reconstructed parent trees.

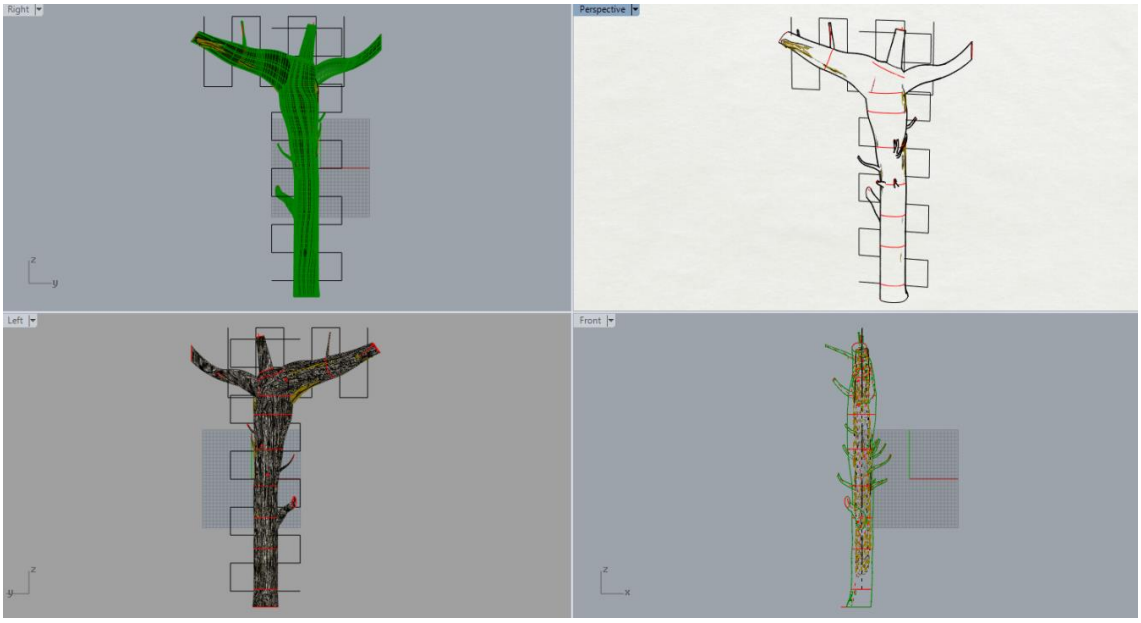


Figure 132 - Illustration of the BEL01-072W accurate reconstruction of its parent tree (drawings by the author).

Based on the implemented develop an approach and associated methods, it is possible to ensure with high accuracy that the Stern knee BEL01-072W corresponds to:

a) A relatively small tree (surviving trunk of 300 cm) having robust sided branches.

b) Under the achieved conclusions, the trunk has a low number of knots, and the existing have a reduced width which potentially indicates the voluntary/involuntary use of cattle to control the branch growth along the trunk.

e) The robust sided branch that forms the upper part of the timber indicates a tree planted on an open landscape. These trees are in general small in the trunks length and possess a high number of branches growing in every direction to capture the solar energy (dense forest – high competition for the solar energy = long trunks, as opposed to open landscape – low competition for solar energy = short and robust trunk and branches).

Reconstructing landscapes based on archaeological evidence and wood characterisation.

The innovative approach of reconstructing archaeological timbers parent trees offers the opportunity of reconstructing past landscapes. Within the developed approach and associated methods, several parent trees were reconstructed in high accuracy. These three-dimensional digital reconstructions were performed to gain a better understanding of the trees employed in the shipbuilding industry during the Iberian Age of Discoveries (15th to the 18th-centuries). Therefore, greater attention was given to the remains of Iberian ships sunk across the world. Some of these shipwrecks' features were addressed in chapter one: **Chapter 1 – To be or not to be an Iberian ship** with particular relevance to the theme of the present thesis. In this way, a substantial number of data was collected in regard to the employed timbers during the construction of Iberian vessels (within this chronology). This data collected from archival investigation, digital recording of the surviving timbers and the analysis of raw data allowed performing a comparative study to identify potential patterns in the selection of trees to the construction of these vessels.

The selection of these trees obliged a group of techniques and (empirical) understanding of trees anatomy and their morphology. To obtain the good timber, carpenters had; in general, to manage woodlands/forests by employing forest practice techniques (as mentioned in chapter two - **Chapter 2 – The Iberian shipbuilding tradition and the wood requirements: woodlands, shipyards and treatises**). Thus, the use of collected data revealed to be essential to obtain a comprehensive understanding about the tree´s morphologies required by shipbuilders to build the *naos*.

The performed comparative study included the observation, recording and analysis of a selection of timbers from the Corpo Santo Wreck, Cais do Sodré Wreck[179] and Belinho 1 wreck. Based the analysis on the surviving wood features and the tree reconstruction studies performed on the selected ship timbers, it was possible to reach the following conclusions in regard to the requirements imposed by the Iberian shipbuilding – parent trees` general features:

a) Absence of knots along the main stem.
b) The growth rate (i.e. average ring width) is consistent with higher levels of moisture (precipitation/groundwater levels).
c) The growth-pattern seemed to be consistent with oak trees of about 60 years (average of annual 50 rings plus rings lost by erosion, or removal of sap and bark).
d) The sapwood was removed to shape the timber, but the heartwood seems to preserve its maximum extent (some traces of sapwood.)
e) Fast grown oak trees – productivity and higher wood density.
f) Straight stem, low number of knots - avoiding weak point on timbers.
g) Consistent grain flow orientation with the required timber shape – avoid cracking by tension.
h) Specific wood shapes – to meet the required angles and curvatures (e.g. Y-frames, floor timbers).
i) Deciduous oak having a variable number of rings suggesting different provenances.

[179] Further information about these shipwrecks in **Chapter 1 – To be or not to be an Iberian ship.**



Stern knee

Figure 133 - Illustration of the end-product from the tree reconstruction studies performed on the BEL01-072W (stern knee) from the Belinho 1 shipwreck (drawings and photograph by the author).



Floor timber

Figure 134 - Illustration of the end-product from the tree reconstruction studies performed on the BEL01-003W (floor timber) from the Belinho 1 shipwreck (drawings and photograph by the author).



Figure 135 - Illustration of the end-product from the tree reconstruction studies performed on the BEL01-001W (Y-frame) from the Belinho 1 shipwreck (drawings by the author).

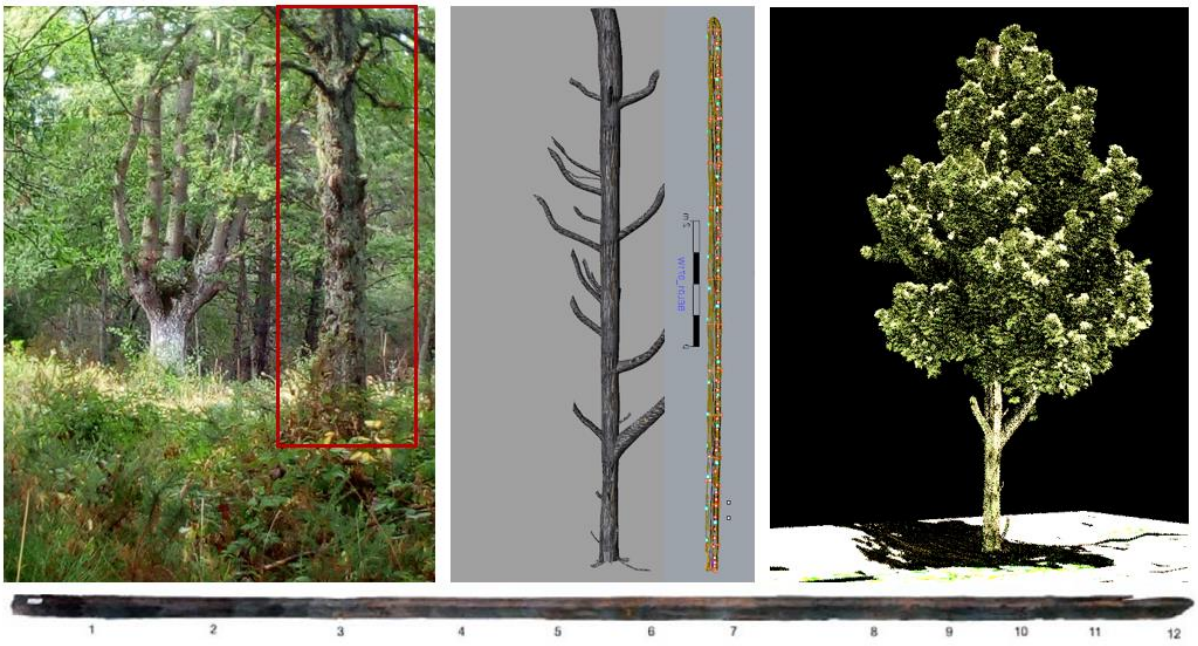


Figure 136 - Illustration of the end-product from the tree reconstruction studies performed on the BEL01-072W (Y-frame) from the Belinho 1 shipwreck (drawings and photograph by the author).

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CONCLUSIONS.

The reconstruction of trees and landscapes based on evidence collected from ship timbers assemblages reflects the developed approach and associated techniques to successfully achieve that goal. Although, why to dedicate much effort and dedication may the first question. The reason for such inquiry resides on the fact that no consistent information was yet found between a real correlation between a predesigned ship timber shape and trees morphologies. Therefore, it urged to investigate these potential links within a systematic, comprehensive and tested approach.

Every year, new data is being placed in the discussion through the publication of the conclusions taken from analysed archaeological information. Much of these publications refer to the vessel`s shipbuilding architectural signature and other aspects about their cargo and surviving evidence. Despite the investigation of the ship`s profile and the particularities of their cargo, many other adjacent investigations are taking place such the dating of the vessel which sometimes refers to a correlation between the cargo and the surviving timbers, but in general to the radiocarbon and dendrochronological dating. Other data has also become part in the publication such as the tree species (e.g. Quercus sp., Pinus sp.) and then eventually the timber provenance if the dendrochronological series match against the known dendro series. Other publication (in small number) also refers the timber conversion techniques (e.g. radial split, tangential sawn) and the conversion adopted method (e.g. half, quarters). Although, there many data still available to include which can trace the planted trees in the woodlands, forest practices, tree selection criteria and even clues about in which woodscapes trees were planted. An

enormous number of data that can be explored and take the investigation of a vessel into a new level in science. Much of this surviving data, if recorded following a specific protocol will enable a brain shift in which the ship timber is much more than a part in a jigsaw formed by the collection of timber in a ship`s hull. Each timber can be analysed as an individual having (in most cases) a unique parent tree. The recoding of surviving wood features can be achieved within several techniques, such as:

a) A more traditional method (non-contact tracing) in which archaeologists perform the acquisition of data using a laser pen and a marker to draw in 1/1 scale the features to record on transparent plastic film on top of a translucent board over the timber face to record. This method allows to mark a series of points and then draw lines by linking the points but without touching the timber during the recording process.
b) A more technological method (non-contact tracing) in which is employed a laser scanning or CT scanning to the acquisition of wood features in 1/1 scale which in any stage the recording method involves the contact with the timber faces. This recording technique end-product is a digital file(s) containing surface mesh representing the timber faces recording without the interpretation of the recording operator.
c) The photogrammetry techniques such as computer vision photogrammetry in which archaeologists capture the wood features with texture within an accurate resolution (if followed the required procedure). This method of recording produces a point cloud and from it, a mesh/surface from which the wood features can be analysed.

d) The use of a FaroArm to draw a collection of polylines representing the wood features. In this case as opposed to the above-section b) and C) the end-product reflects the interpretation of the FaroArm operator which during the entire recording process must follow the established protocol but make a judgment about the features to record and to which layers/attribute will be linked with.
e) Other types of recording such as 1/10 hand scale drawings, hand notes, sketches and other developed techniques.

The assessment and recording of wood features correspond to one of the most critical stages in the process of the reconstruction of archaeological timber parent trees. The quality and accuracy of such recording will determine the success of the developed approach within this doctoral study. This variable has been widely discussed during chapters four and five (CHAPTER 4 – A PROPOSED METHODOLOGY FOR THE COMPREHENSIVE UNDERSTANDING OF SURVIVING SHIP TIMBERS: THREE-DIMENSIONAL TREE RECONSTRUCTION., THE RECORDING OF WOOD MORPHOLOGIES: A STEP-BY-STEP DEVELOPED METHODOLOGY.).

The next stage is also crucial as the involves the analysis and focusing on the wood features which constitutes a brain-shift from an approach focusing in ship timbers as representative of a specific shipbuilding architecture, to a more wood features oriented in which the wood and the tree is at the centre of discussion. It is in this stage that this doctoral study has been centred and which will contribute to science by adding a new step in knowledge. An innovative contribute which enhance the timbers faces as part of a vessel but above all, as a tree potentially managed and carefully selected to be part of a ship. As mentioned in the previous chapter, several surviving ship timbers were recorded

using several methods in some cases were tested different techniques to the acquisition of data and successfully reconstructed their parent trees. Although, there are limitations in the process (see further information on chapter 4 TREE RECONSTRUCTION OF THE VOC BATAVIA PLANKING., THE HIGHBORN CAY WRECK.). Nonetheless, what may vary in the developed approach is the data acquisition/recording technique which may employ a technique to produce surfaces (not interpreted by the operator) or line drawings (having the operator making decisions).

The developed approach has been tested and adapted and can be readapted to the reality of each scenario. The entire collection of case studies included in the doctoral thesis comprise a substantial number of analysed shipwrecks. Mainly, from the 15th to the 18th-century following the Iberian Age of Discoveries[180] architectural signature, however, the approach has been tested in the *VOC Batavia* and in the Bremen Ship which by their differences in the architectural signature and/or chronology proved to be a relevant exercise. The employed techniques to recording wood features from these vessels generate the above-mentioned two types of recorded data *VOC Batavia* (photogrammetry – Mesh, surfaces (see further information on TREE RECONSTRUCTION OF THE VOC BATAVIA PLANKING.) and the Bremen ship (FaroArm drawings in conjunction with photogrammetry – line drawings with surfaces (see further information on TREE RECONSTRUCTION OF THE BREMEN KOGGE PLANKING PARENT TREES.). It is also in this stage of the approach that relevant information must analysed taking into account not having the core business focusing the social segment about the relation between foresters, intermediaries, carpenters and shipwrights but in the archaeological evidence.

[180] Theme of the ForSEAdiscovery Project (see further information on PREFACE.).

At this stage, the knowledge obtains in chapter two (CHAPTER 2 – THE IBERIAN SHIPBUILDING TRADITION AND THE WOOD REQUIREMENTS: WOODLANDS, SHIPYARDS AND TREATISES.) is essential to decipher the wood features and demystify the morphology of timbers` parent trees. As mentioned in chapter two section (see further information on MODERN ANALYSIS ON THE TREES TO A BETTER CATEGORIZATION OF SHIPYARD`S WOODEN RAW MATERIAL.CHAPTER 2 – THE IBERIAN SHIPBUILDING TRADITION AND THE WOOD REQUIREMENTS: WOODLANDS, SHIPYARDS AND TREATISES.) tree`s growth patterns may not be sufficiently clear and understood, as many external agents interfere in the process. Abnormal rainy years, extremely dry seasons, deforestation, the impact made by cattle and above all the human abusive interfering in nature. All these agents had a direct impact in trees growth, morphology and forest regeneration. Therefore, a number of variables must be placed in discussion to formulate a general hypothesis or a testable explanation about why carpenters employed a certain type of tree`s species having a specific growth pattern and a well-determined morphology. Therefore, in the hypothesis the more than one human agent had to be included: the carpenters in the shipyards demanding the supply of specific timber logs and, the foresters in the woodlands practising their techniques to manage woodlands in a way to provide the *good* timber. However, another human agent has had a direct impact in this entire process involving carpenter and foresters: the shipwright by drawing the geometric plans making the ships` profile (see further information on WOOD CHARACTERISATION OF AN IBERIAN SHIP DURING THE 15TH TO 17TH-CENTURIES.). A human agent who demanded the supply of specific timber logs to the different parts of the vessels, to be assembled by the carpenters in the shipyards with trees managed by the foresters in the woodland. Some of the analysed shipwrecks provided information

about a functional relation between timber selection and the predesigned ship timber (see further information on THE CORPO SANTO WRECK., THE CAIS DO SODRÉ WRECK. THE DEVELOPED METHOD TO RECONSTRUCT ARCHAEOLOGICAL TIMBER`S PARENT TREES BASED ON SURVIVING EVIDENCE.). Other cases revealed a less compatible use of the selected trees to the construction of ships (see further information on TREE RECONSTRUCTION OF THE BREMEN KOGGE PLANKING PARENT TREES.).

The shipbuilding industry had a direct impact on the landscape and in the development of societies. The pressure imposed on woodlands by the increased timber supply during the Iberian Golden Age of Discoveries, place the foresters in a predominant and crucial level in the society. *Suddenly*, one of the Iberian crowns biggest challenge was to supply shipyards with *good* timber to build the most needed vessels to the *Carreira da Indias* and the *Carreira das Indias Ocidentais*.

The *good* timber could not be produced in sufficient quantity and quality to face the increased demand to build the fleets. As interests in the commercial routes populating the Atlantic and Indian routes ships also were built bigger and heavier in a direct correlation with the increased demand in timber. As discussed in chapter two and five, the employed trees in the shipbuilding industry have in general, at about 40 to 60 annual rings on average. Meaning that trees had to be planted at about 40 to 60 year early than the construction of a vessels and yet have to have a direct correlation between the predesigned timbers and the trees morphologies (see more information on CHAPTER 1 – TO BE OR NOT TO BE AN IBERIAN SHIP:). Such interdependency would only be possible by a system in which woodlands and foresters were linked to the shipyards and carpenters. In these links resides one of the major questions in shipbuilding archaeology – how

foresters could know and interpret the requirements imposed by the shipwright and carpenters. This symbiotic relation had to be maintained across centuries and over many generations. In a way to produce and supply good timber within an increased scale and criteria. The other question resides in the adjustment and development of forests practices to ensure the supply of oak and pine trees in such quantity to be employed in the construction of *naos* to sail on the two-year routes to India, China and Japan and America (Western Indias). To such supply was also required that timber would need to integrate ship`s hull sailing in different salinity, temperature, swell and sealife. The strength of each vessel was tested in many ways by the carrying cargo (mostly overloaded), by the quality of the fastening and assembling techniques (fasten and scarves), by the architecture (predesigned timbers), but also and perhaps the more crucial element – the quality of the timber.

Within the theme of the present doctoral thesis, such reflection was made as the knowledge about shipbuilding techniques is being refined, and new data is being explored and studied every year. Historians published documentation and their studies about the timber requirements and the importance of maintaining routines in timber supply and how the crown attempt to solve these issues (see further information on INTRODUCTION). Archaeologists have conducted their studies focusing on the material culture to identify particularities in the shipbuilding architecture (see further information on CHAPTER 1 – TO BE OR NOT TO BE AN IBERIAN SHIP:) and, wood scientists have also conducted studies to provide information to date the ship`s remains and wood provenance (see further information on CHAPTER 2 – THE IBERIAN SHIPBUILDING TRADITION AND THE WOOD REQUIREMENTS: WOODLANDS, SHIPYARDS AND TREATISES.). Although, despite some studies (see further information on CHAPTER 3 –

SHIP TIMBERS PARENT TREES: THE PROGRESS MADE TO OBTAIN EVIDENCE OF WOOD MORPHOLOGIES FROM ARCHAEOLOGICAL DATA.) made an attempt to integrate the study of tree morphologies in the investigation of the ship remains. The correlation between these elements required a comprehensive and distinctive approach (see further information on chapter 5 - THE DEVELOPED METHOD TO RECONSTRUCT ARCHAEOLOGICAL TIMBER`S PARENT TREES BASED ON SURVIVING EVIDENCE.).

The adoption of the developed approach and associated methods enables the opportunity to obtain an integrated study in which:

a) Provides the information required to assess archaeological timber to conduct integrated studies in which timber possess greater relevance. Such condition may apply to the study of ships but also the investigation of historic houses and other building. The associated methods in the present doctoral studies were entirely focused on the investigation of ship`s timbers, although, the same techniques can be applied to the study of other types of wooden structures.
b) Provides detailed information about how archaeologists can assess timbers within a perspective that wooden structures are more than surviving or initially present/show. In most cases, the tasks undertaken prior to their construction survived on the timber employed to their construction, although, the human eye has to be the focus and prepared to observe the surviving wood features.
c) The produce of digital drawings and advanced digital reconstructions of ship timber parent trees reflect a long-term conceptualisation and theorisation of the developed process to present to an audience which elements the author has seen when assessing a timber. The relevance of the knots and growth pattern was

elevated to a new level of knowledge and discussion. The digital reconstructions presented in this thesis are the result of a matured group of tasks using several techniques within an approach focusing on the importance of trees not as objects but as relevant elements in the human evolution

d) Allows a shift in the researcher`s *brain* to the acquisition and analysis of data that was not included in the archaeological investigations. The quest and recording of surviving wood features to characterise ship timbers comprise and innovative approach which enables the interpretation of the several stages of woodlands and trees prior to the construction of the vessels.

e) Provides a comprehensive and integrated recoding of wood and ship timber features will provide a two-way collection of data. This data may be obtained using more expensive equipment such as the combination of a FaroArm and the Rhinoceros 3D software or, by using computer vision photogrammetry and yet obtain and high level of accurate data. Differences between each technique reside on the acquisition of interpretative data through line data using the digitiser or non-interpretative data by using photogrammetry to produce mesh data.
The two-way data gained its expression in the optimisation from the versatility of the acquired data. In fact, the resources employed during the recording of archaeological timber can be used by archaeologists focusing their studies in ship reconstruction and the identification of ship`s architecture and, also by archaeologists focusing their research on the upstream event prior to the construction of a ship – tree/landscape reconstructions.

This approach enabled the option of systematic recording of wood features within a methodological approach to gain a better understanding of ship timbers parent trees to identify and analyse:

a) The adopted tree selection criteria,
b) The dedicated forests practices to ensure productivity maximisation,
c) The established links between foresters and the shipyard carpenters,
d) The maintenance of the dedicated woodlands through foresters' generations,
e) The direct correlation between tree`s morphologies and the predesigned ship timbers,
f) The foresters` techniques to obtain good timber for shipbuilding,
g) also, the later rupture in the established links by the adoption of imported timber logs to face a potential shortage in local timber supply.
h) Archaeology is the science that studies the human material culture through time within a systematic approach. *Logy* (science) determines the adoption of broader accepted methodologies to investigate an archaeological context/artefact. Such methodologies, accepted by the scientific community, reside on a group of tasks developed following ethics, commitment and methods that enable the production of knowledge. Although a high number of investigations do not attend to include the development of methods but only the adoption and adjustment of pre-existing methodological approaches, this does not mean that limitations were imposed on research, neither that researchers are not aiming to increase knowledge. This does mean that sometimes the existing methods are not able to respond to the place of the question in research. Therefore, a new method or a new approach has to be designed and tested in order to face new scenarios and a

sort of new questions. Nowadays, the increased multidisciplinary research projects widening the questions made by experts in different areas which in broader terms reflect the persistent will of knowing more and in greater detail.

In completion of the present doctoral study, it is now important to stress the applicability of the developed approach and associated methods. Within this thesis was wide discussed the theme and the purpose of Reconstructing trees from ship timber assemblages using 3D modelling technology. Intrinsically related to the quest for answers about the employed forest practices and the correlation between the forest, foresters, carpenters and shipwrights. It was also widely discussed the conceptualisation and the paradigm of the developed approach and described the several techniques to the acquisition, analysis and interpretation of wood features which culminates on a tested methodology. The developed approach can be employed in the investigation of archaeological wood independently from their provenance, specimen and chronology. The methodology was employed to the production of knowledge about shipbuilding architecture and woodscapes forest practices but also tested in dry timbers from historic buildings and waterlogged timber associated with small ships. The performing of the included case studies and the knowledge obtained from the produce of a cast literature review focusing on this theme in three working fronts: maritime archaeology, wood sciences and 3D development allowed a situation of *brain shift* to centre the attention on the surviving wood features and in the production of knowledge based on a method of observation, analysis and reconstruction past woodscapes.

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ENDNOTES FROM THE AUTHOR.

The investigation undertaken within the present doctoral study does not end in this thesis. The developed approach has been tested and employed in the study of several shipwrecks and historic building from a variety of chronologies. Much has been achieved, and much more can be improved within the following years. Apart from the development of the dendroarchaeological approach Reconstructing Trees from Ship timber Assemblages Using 3D Modelling Techniques, much of the analysed material was performed within an international, multicultural, multidisciplinary team of researchers. The data acquisition from ships lying on the seabed and timbers stored in warehouses was performed by a group of researchers focusing their attention in the different surviving evidence but working towards to reach the next level knowledge. The developed approach incisively and objectively contributes to the investigation of archaeological timber and the interpretation of relevant data to the reconstruction of woodscapes, forest practices and the study of wooden vessels raw material.

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

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APPENDICES 1 – PUBLISHED PAPERS WITHIN THE PRESENT THESIS.

Castro, L.F.M.V. de et al. 2015. *Belinho 1 Shipwreck. Timber Catalogue*. USA: ForSEAdiscovery Project.

Martins, A.M.B.P.S. 2015a. Belinho1: Timber Recording and Sampling Project Design.

Martins, A.M.B.P.S. 2015b. How can we see trees in timbers? an approach to the Golden Age of Shipbuilding. In *A Gestao dos Recursos FlorestaisIbericos na Construcao Navalda Idade Moderna: Historia e Arqueologia*, 1–12. Portugal

Martins, A.M.B.P.S. 2017. Reconstructing Trees from Ship Timbers: Data Analysis and Schematics. In *Arvores, barcos e homens na Peninsula Iberica (Seculos XVI-XVIII) ForSEAdiscovery Project (PITN-GA-2013-607545)*, 63–76. Portugal Available at: https://www.academia.edu/36778547/RECONSTRUCTING_TREES_FROM_SHIP_TIMBERS_DATA_ANALYSIS_AND_SCHEMATICS [Accessed June 13, 2018].

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Martins, A.M.B.P.S., & Ali, S. 2018. Using Three-Dimensional Software to Reconstruct Frames of the Past Based on Archaeological Evidence. *Antrope* 9: p.58–68.

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Belasus, M. Forthcoming. The Bremen Cog - Environmental Issues. In France

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Belinho 1 Shipwreck

Timber Catalogue

Esposende

August 4 to 20, 2015

PITN-2013 GA607545, Marie Curie EU Grant

Filipe Castro

College Station, September 2015

INSTITUTO DE HISTÓRIA CONTEMPORÂNEA
FACULDADE DE CIÊNCIAS SOCIAIS E HUMANAS
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Team:

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Adolfo Martins
Alexandre Monteiro
Nigel Nayling
António Santos
Koldo Trapaga

Inventory

No.	Description	Size	1/10	3D	Photo	CHAM
01	Y-frame	212	-	Adolfo	Peter	-
02	Plank	81	Flavio	-	Chris	-
03	Floor timber	313	-	Adolfo	Peter	003
04	Plank	84	Peter	-	Peter	-
05	Plank	117	-	-	Peter	-
06	Plank	40	-	-	Peter	-
07	Plank	137	-	-	Peter	-
08	Plank	92	-	-	Peter	-
09	Plank	106	-	-	Peter	-
10	Plank fragment	66	-	-	Peter	-
11	Stringer fragment?	106	-	-	Peter	-
12	Fragment	26	-	-	Peter	-
13	Plank repair?	38	Peter	-	Peter	-
14	Frag. transv. timber?	40	-	-	Peter	-
15	Plank fragment	21.5	-	-	Peter	-
16	Fragment	50	-	-	Peter	-
17	Fragment	71	-	-	Peter	-
18	Fragment – ceiling?	24	-	-	Peter	-
19	Fragment	38	-	-	Peter	-
20	Fragment	41	-	-	Peter	-
21	Fragment	52	-	-	Peter	-
22	Fragment	19	-	-	Peter	-
23	Fragment	43	-	-	Peter	-
24	Plank fragment	77	-	-	Chris	-
25	Plank fragment	128	-	-	FC	-
26	Plank fragment	23	-	-	Peter	-

27	Fragment	23	-	-	FC	-
28	Fragment	30	-	-	FC	-
29	Plank fragment	63	-	-	Peter	-
30	Fragment	25	-	-	FC	-
31	Plank fragment	59	-	-	Peter	-
32	Y-Frame	177	-	Adolfo	Isis/PG	-
33	Plank Fragment	140	-	-	Peter	-
34	Frame frag.	112	FC	-	FC	-
35	Frame frag.	102	FC	-	FC	-
36	Y-Frame	140	-	-	Adolfo	-
37	Y-Frame	223	-	-	Adolfo	-
38	Deck knee?	153	FC	-	FC	-
39	Y-Frame	220	-	Adolfo	Adolfo	-
40	Y-Frame	186	-	Adolfo	Adolfo	-
41	Floor timber	119	FC	-	FC	-
42	Floor timber	321	FC	-	FC	-
43	Y-Frame	204	-	Adolfo	Adolfo	-
44	Floor timber	308	FC	-	FC	011
45	Floor timber	282	FC	-	FC	010
46	Fragment hard wood	139	-	-	FC	-
47	Deck knee?	134	FC	-	FC	-
48	Fragment	158	-	-	FC	-
49	Waterway	396	FC	-	FC	-
50	Plank	213	FC	-	FC	-
51	Mast steep	*200*	-	-	FC	008
52	Plank	333	FC	-	FC	-
53	Plank	332	FC	-	FC	004
54	Plank	280	FC	-	FC	-
55	Plank	280	FC	-	FC	005
56	Plank	301	P./Fl.	-	FC	002
57	Plank	275	FC	-	FC	-
58	Plank	123	FC	-	FC	-
59	Plank	146	FC	-	FC	-
60	Plank	153	FC	-	FC	-

61	Plank	129	FC	-	FC	-
62	Wood Fragment	127	-	-	Peter/Isis	-
63	Fragment	208	-	-	Peter/Isis	-
64	Plank Fragment	93	-	-	Peter/Isis	-
65	Fragment	130	-	-	Peter/Isis	-
66	Stringer	190	-	-	Peter/Isis	-
67	Fragment / Mast step?	61	-	-	Peter/Isis	-
68	Fragment / Mast step?	80	-	-	Peter/Isis	-
69	Frame Fragment	118	FC	-	FC	006
70	Wood Fragment	13	-	-	Peter/Isis	-
71	Keel	879	-	Adolfo	Adolfo	007
72	Stern Knee	281	-		FC	009
73	Stern Post	290	-	Adolfo	Adolfo	001
74	Plank Fragment	42		-	FC	-

This report follows up on a preliminary assessment made in 2014 by a team from the Centre de História de Além Mar (CHAM) from Universidade Nova de Lisboa. The drawings published by CHAM – describing 12 timbers – were included in this report by courtesy of CHAM, to acknowledge this previous effort.

Longitudinal Structure

Keel 071

Sternpost 073

Stern knee 072

Maststep 051

Timber: Keel section No. 071W



Figure 71.1 – Photomosaic of the timber (not to scale).

Length preserved: 879 cm.

Section: sided 22/24 cm, molded 19 cm.

Conversion: It is a standing tree, with the roots on the bottom and the branches forming the arms.

Tool Marks: All surfaces eroded.

Joinery: The rabbet occupies almost half of the keel molded dimension, and its angle doesn't vary much along the 9 m of length preserved. No fore and aft scarves were preserved.

Fasteners: Planks fastened with iron nails (11 mm), sub-horizontal, all along the preserved length. Some frames fastened with iron bolts (27 mm, heads 55/60 mm, recesses 60/70 mm, 25 mm deep, on the bottom face). Every other frame not fastened to the keel.

Bolts at: 4, 42, 108, 181, 249, 319, 333, 392, 465, 576, 646, 712, 717, 783, 859 cm.

None of the distances between the holes fit the distance preserved in the maststep, suggesting – together with the shape of the rabbet and the timber assemblage washed ashore - that this is probably part of the after portion of the keel.

Comments: These timbers are similar to those of the 1559 Emanuel Point shipwreck. The scantlings are similar, and the timber shapes also.

Recording: CHAM 007. Full FARO Arm drawing (Adolfo).

Details:



Fig. 071.2 – Bottom surface: bolt hole and recess. Note the mistaken hole opened nearby and abandoned, halfway through the height of the keel section. The two holes converge and only one appears on the keel upper surface.



Fig. 072.4 – Side face of the keel showing the almost rectangular rabbet and the almost horizontal nail holes.

Faro Arm drawings:

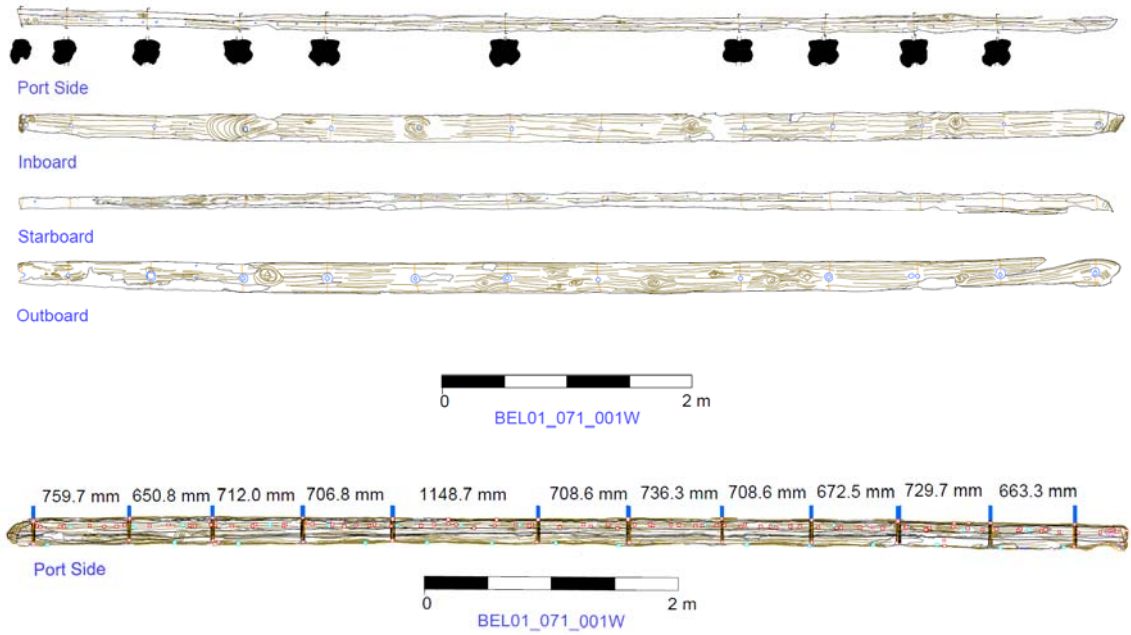
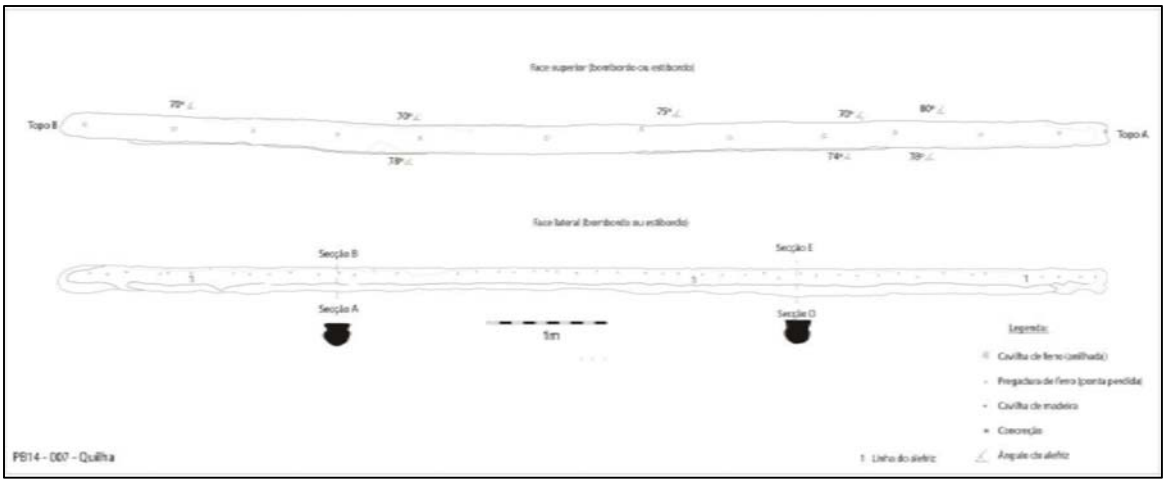


Figure 71.4 – FARO Arm 3D model of the timber (Adolfo Martins).

CHAM image (2014):



Timber: Stern Post No. 073W



Figure 73.1 – Photomosaic of the timber (not to scale).

Length preserved: 290 cm

Section: sided 22/24 cm, molded 19 cm.

Conversion: It is a standing tree, with the roots on the bottom and the branches forming the arms.

Tool Marks: All surfaces eroded.

Coatings: Not apparent in this timber.

Fasteners: Planks fastened with iron nails (11 mm) and treenails (25 mm). Three iron bolts connect it to the stern knee, (30 mm, heads 55/60 mm, recesses 60/70 mm, 25 mm deep) 53 and 70 cm apart. The after face has three protrusions difficult to explain. They were probably not used to receive the gudgeons because the best preserved one has two diagonal nail holes in the corners (Fig. 073.2). Planks were connected to the after face of the sternpost with square nails (11 mm).

On the starboard side there are four instances of two nails and what looks like carpenter marks (Fig. 073.3).

Bolts at: 26.5 cm, 80, 150 cm, counting from the base of the adjacent stern knee. The bottom 20 cm are missing.

Planks: On the starboard four plank hoods seem to fit the rabbet (059,060,056, gap 51 cm, 053). To port side three plank hoods fit the garboard (057, 054, 055).

Other timber associations: Nail holes on the after face of the sternpost suggest that there were timbers fastened to this face.

Recording: CHAM 001. Full FARO Arm drawing (Adolfo).

Details:

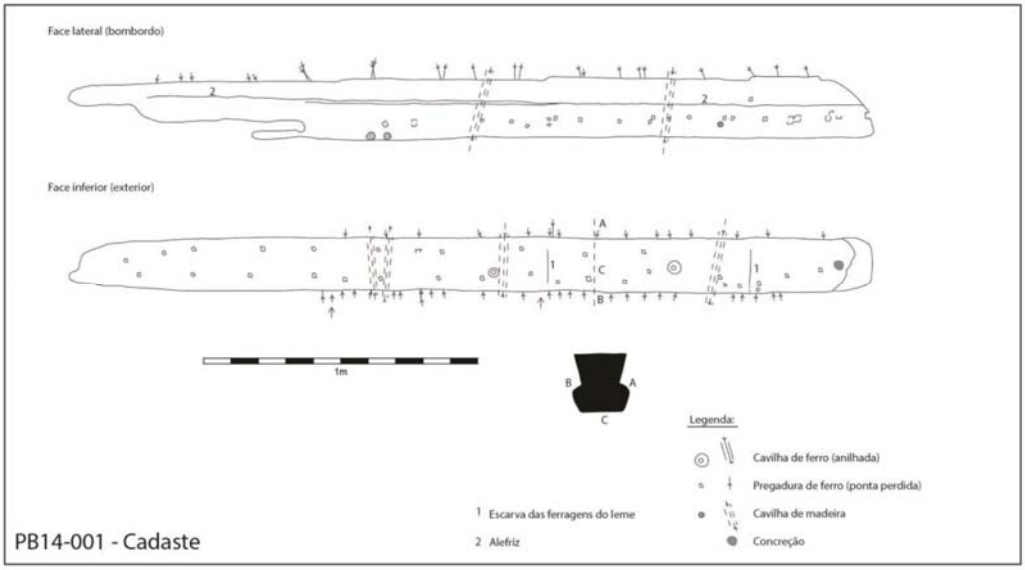


Fig. 073.2 – Nail pattern and possible carpenter marks.



Fig. 073.3 – Protrusion on the after face of the sternpost and diagonal nails.

CHAM images (2014):



CHAM images (2014):



Timber: Stern Knee No. 072W



Figure 72.1 – Photomosaic of the timber (not to scale).

Length preserved: 281 cm

Section: sided 18 cm (narrower on the bottom), molded 56 to 15 cm.

Conversion: Portion of a trunk and a branch.

Tool Marks: Not apparent at a first inspection.

Joinery: This timber has a notch on the starboard side to receive a tenon from the foot of a Y-frame, possibly timber 043.

Fasteners: Planks fastened with iron nails (11 mm) and treenails (25 mm). Three iron bolts connect it to the sternpost (27 mm, heads 55/60 mm, recesses 60/70 mm, 25 mm deep) 26.5, 53 and 70 cm counting from its base.

This timber presents some grooves next to the recesses for the fastener's heads that are similar to the ones found on the Pepper Wreck floor timbers.

The bolt pattern matches that of the sternpost.

Bolts at: 26.5 cm, 80, 150 cm, counting from the base.

Recording: CHAM 009. Full FARO Arm drawing (Adolfo).

Transversal Structure

Y-Frame 037

Y-Frame 036

Y-Frame 039

Y-Frame 001

Y-Frame 040

Y-Frame 043

Y-Frame 032

Floor Timber 003

Floor Timber 042

Floor Timber 044

Floor Timber 045

Floor Timber (short) 041

Frame fragment 069

Frame fragment 034

Frame fragment 035

Knee 038

Knee 047

Fragment 014

Timber: Y-Frame No. 037W



Figure 37.1 – Photomosaic of the timber (not to scale).

Length preserved: 140 cm.

Section: sided 21 cm, molded 21 cm.

Bottom bevel: Approx. 70º. The slope of the stern knee (072W) has a mark that may correspond to the base of this Y-Frame, which is possibly the aftermost frame of this ship.

Conversion: Almost round section. Looks like the top of a standing tree, with the roots on one side and the branches on the other. Sapwood is missing.

Tool Marks: All surfaces eroded.

Fasteners: Planks fastened with treenails (27 mm and 22 mm) and iron nails (11 mm).

Recording: Peter Photogrammetry, Full FARO Arm drawing (Adolfo).

Faro Arm drawing:

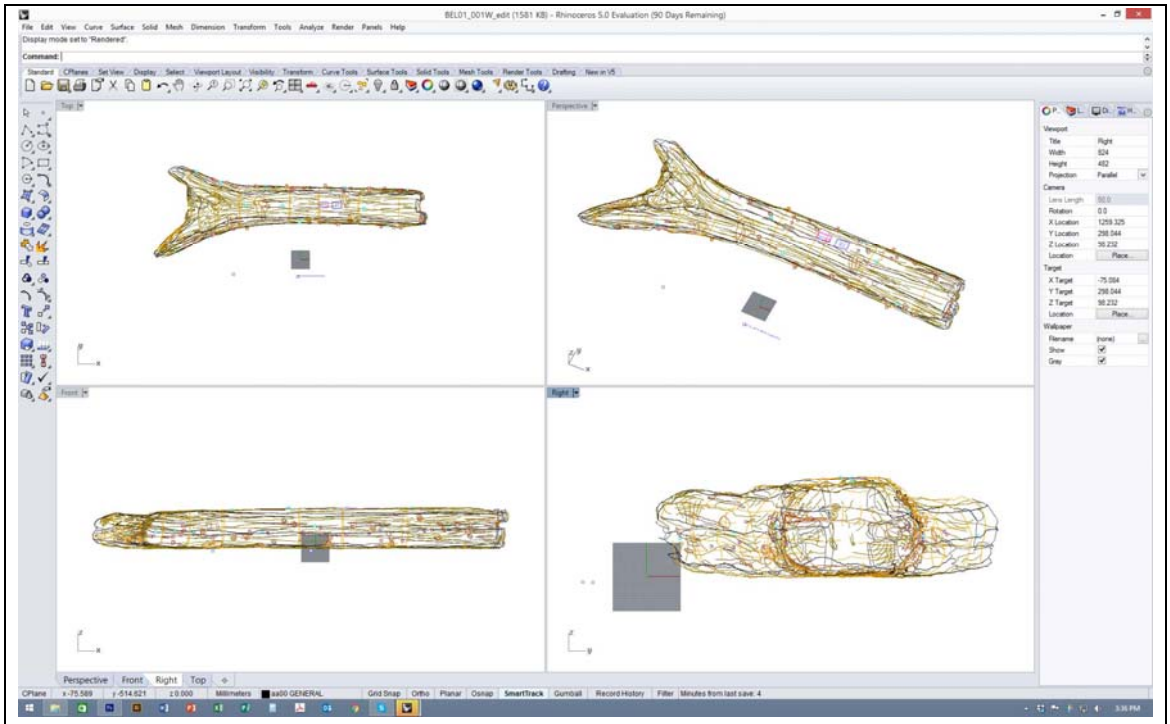
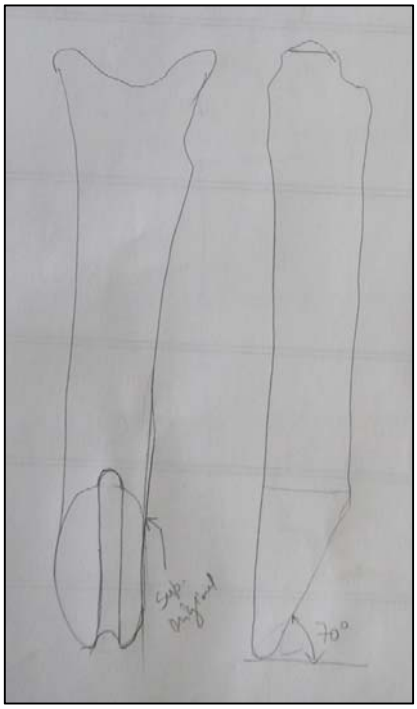


Figure 37.2 – FARO Arm 3D model of the timber (Adolfo Martins).

Sketch:



Timber: Y-Frame	No. 036W



Figure 36.1 – Photomosaic of the timber (not to scale).

Length preserved: 223 cm.

Section: sided 22 cm, molded 22 cm.

Bottom bevel: approx.. 45º.

Conversion: Almost round section. Looks like the top of a standing tree, with the roots on one side and the branches on the other. Sapwood is missing.

Tool Marks: All surfaces eroded.

Fasteners: Planks fastened with treenails (27 mm and 22 mm) and iron nails (11 mm).

Recording: Peter Photogrammetry, Full FARO Arm drawing (Adolfo).

Faro Arm drawing:

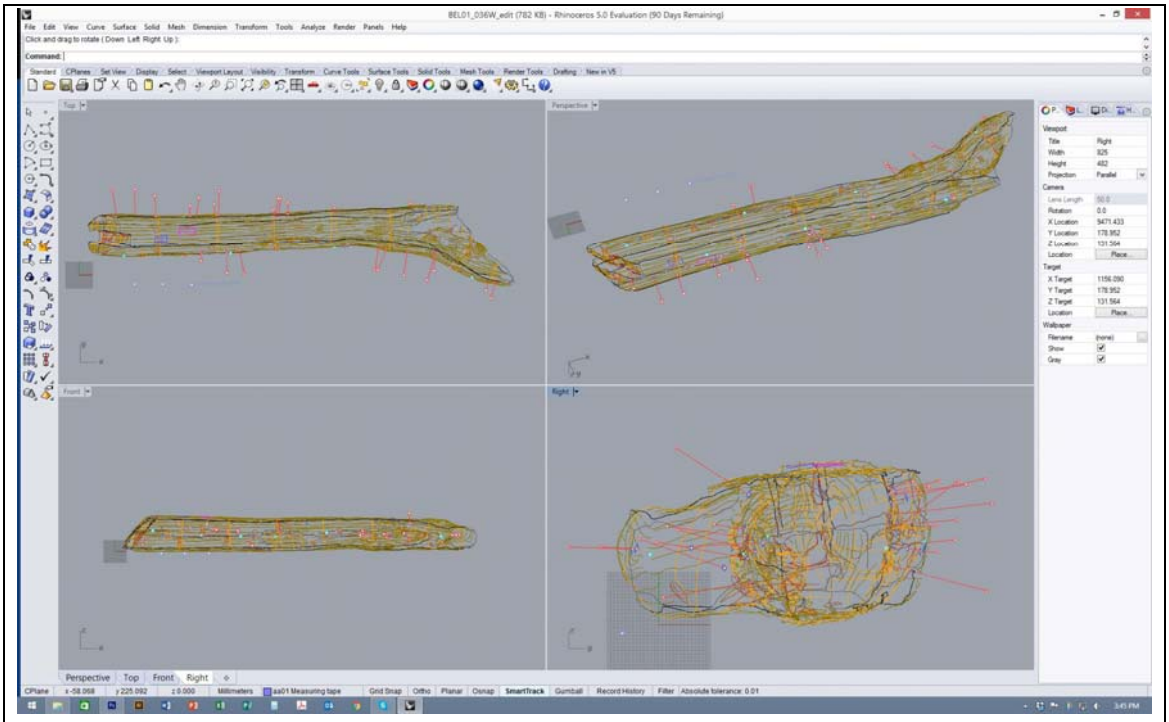
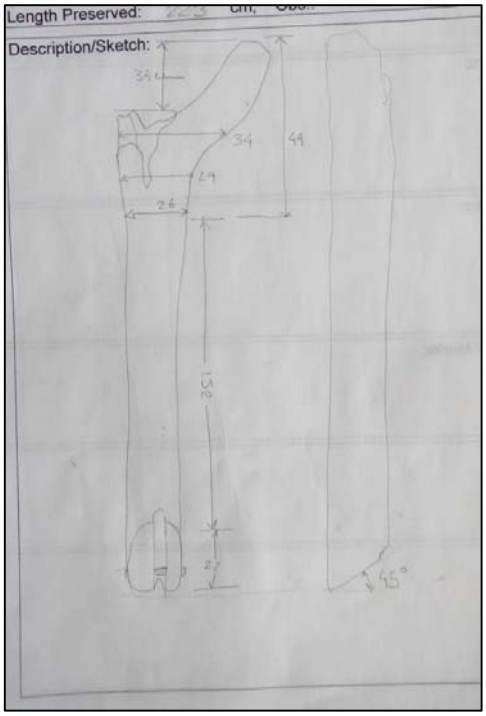


Figure 36.2 – FARO Arm 3D model of the timber (Adolfo Martins).

Sketch:



Timber: Y-Frame	No. 039W



Figure 39.1 – Photomosaic of the timber (not to scale).

Length preserved: 220 cm.

Section: sided 25 cm, molded 19 cm.

Bottom bevel: 20º (to be confirmed).

Conversion: Almost round section. Looks like the top of a standing tree, with the roots on one side and the branches on the other. Sapwood is missing.

Tool Marks: All surfaces eroded.

Fasteners: Planks fastened with treenails (27 mm and 22 mm) and iron nails (11 mm).

Recording: Full FARO Arm drawing (Adolfo).

Faro Arm drawing:

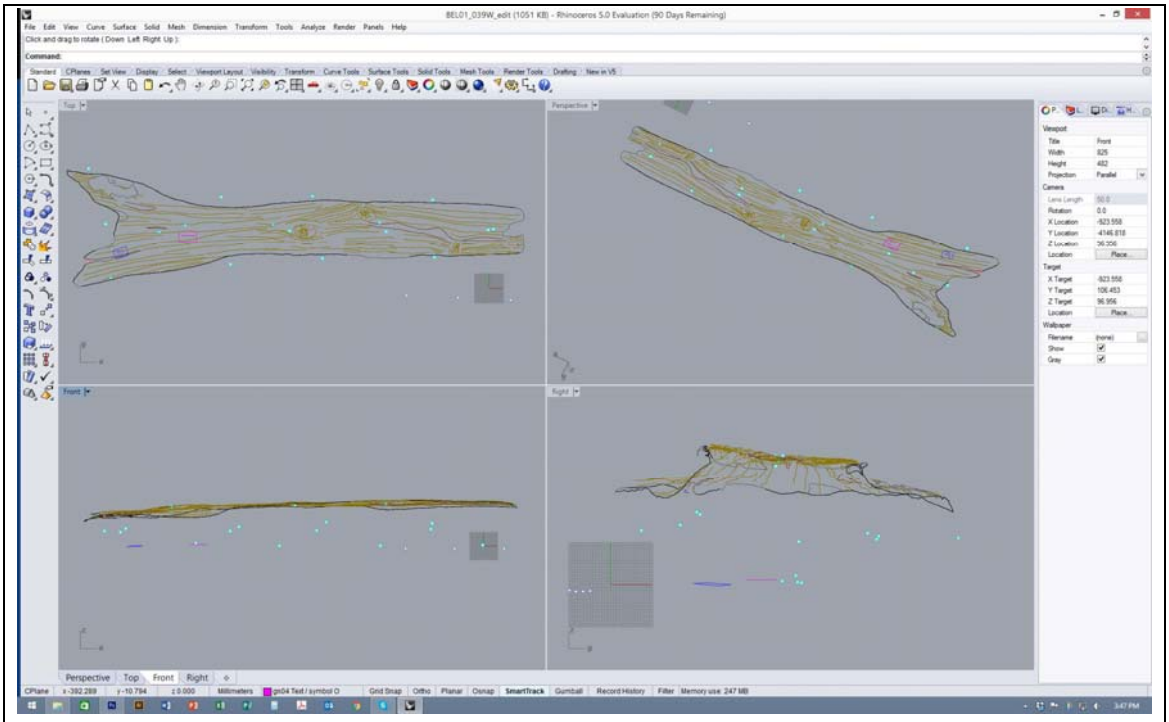
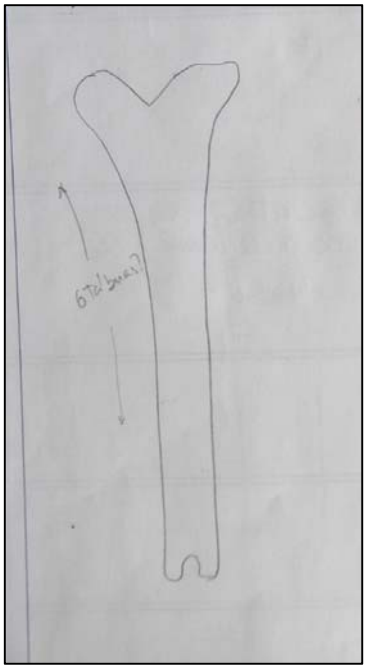


Figure 39.2 – FARO Arm 3D model of the timber (Adolfo Martins).

Sketch:



Timber: Y-Frame	No. 001W



Figure 01.1 – Photomosaic of the timber (not to scale).

Length preserved: 212 cm.

Section: sided 28 cm, molded 20 cm.

Bottom angle: too destroyed to be accurately measured.

Conversion: It is a standing tree, with the roots on the bottom and the branches forming the arms. Sapwood is missing.

Fasteners: Planks fastened with treenails (27 mm and 22 mm) and iron nails (11 mm).

Recording: Full FARO Arm drawing (Adolfo).

Faro Arm drawing:

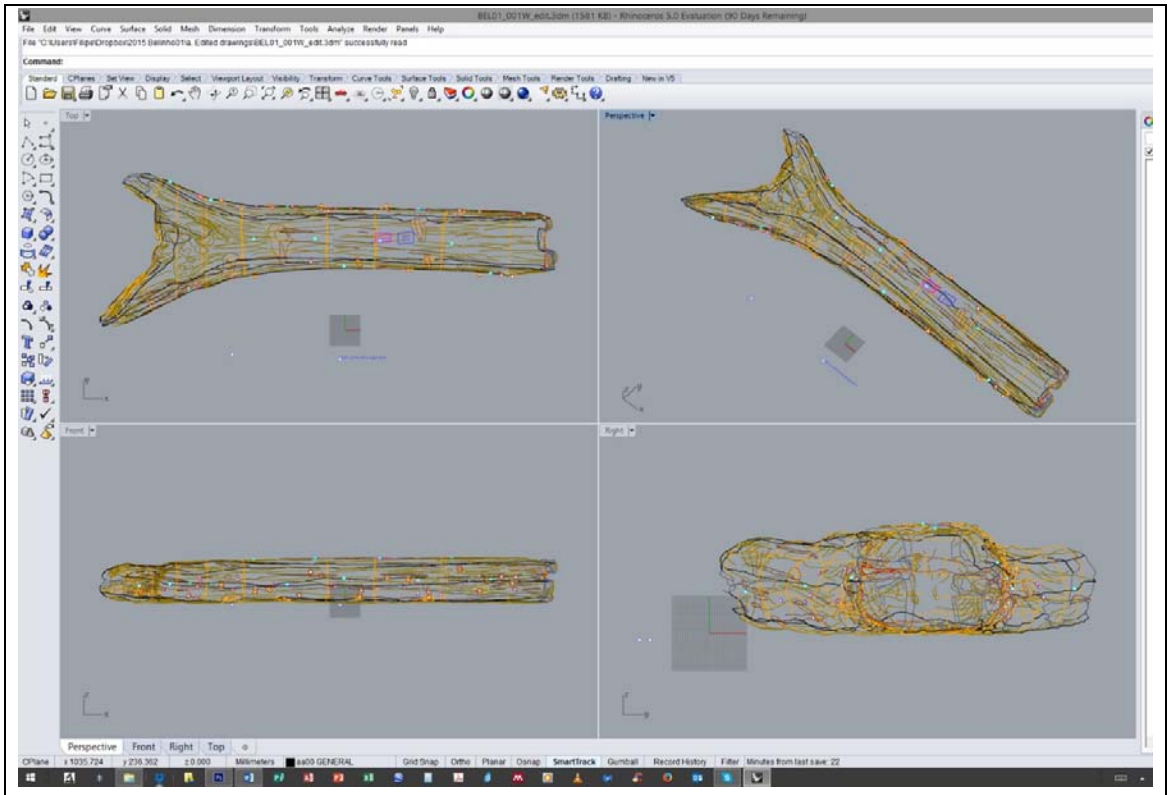
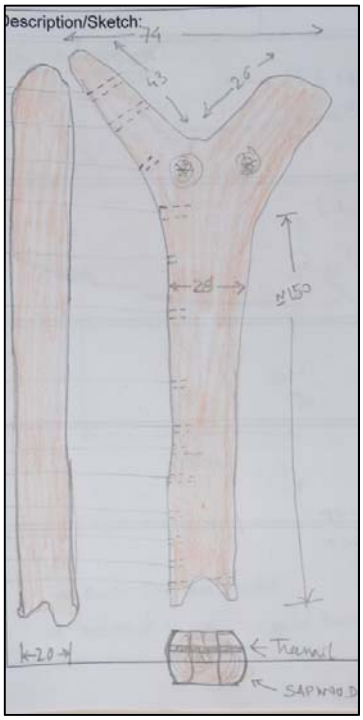


Figure 01.2 – FARO Arm 3D model of the timber (Adolfo Martins).

Sketch:



Timber: Y-Frame	No. 040W



Figure 40.1 – Photomosaic of the timber (not to scale and picture taken at an angle).

Length preserved: 186 cm.

Section: sided 26.5 cm, molded 18 cm.

Bottom bevel: around 15º? (3/26.5=6.5º).

Conversion: It is a standing tree, with the roots on one side and the branches on the other. Sapwood is missing.

Tool Marks: All surfaces eroded.

Fasteners: Planks fastened with treenails (27 mm and 22 mm) and iron nails (11 mm).

Recording: Full FARO Arm drawing (Adolfo).

Faro Arm drawing:

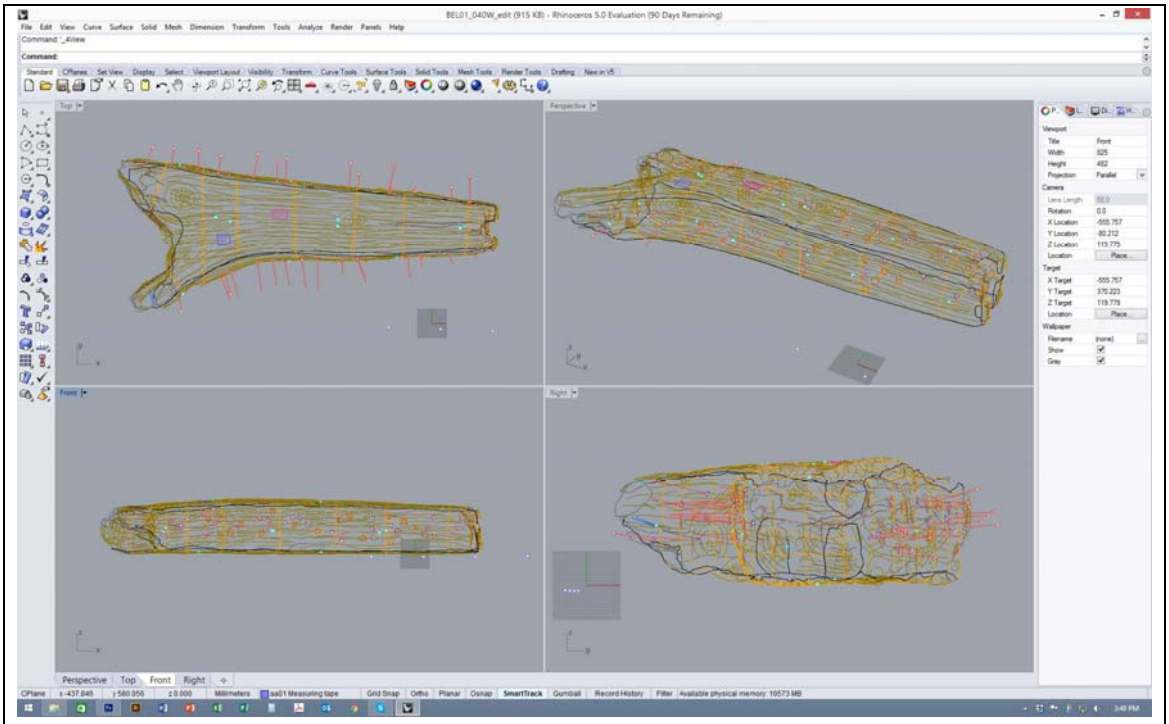
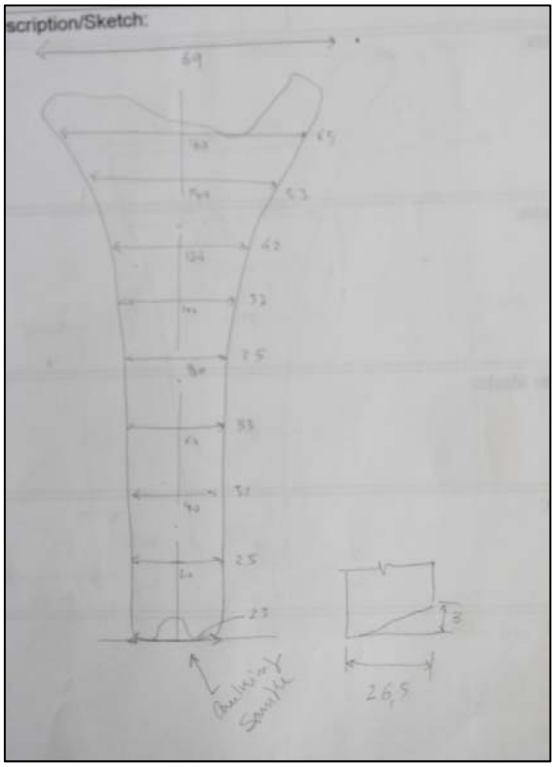


Figure 40.2 – FARO Arm 3D model of the timber (Adolfo Martins).

Sketch:



Timber: Y-Frame	No. 043W



Figure 43.1 – Photomosaic of the timber (not to scale).

Length preserved: 204 cm.

Section: sided 26 cm, molded 23 cm.

Bottom bevel: 10/23 = 23º.

Conversion: It is a standing tree, a branches forming the arm.

Tool Marks: All surfaces eroded.

Fasteners: Planks fastened with treenails (27 mm and 22 mm) and iron nails (11 mm).

Joinery: This timber has a protrusion in the base that fits (should fit) the upper layer of the stern knee.

Recording: Full FARO Arm drawing (Adolfo).

Faro Arm drawing:

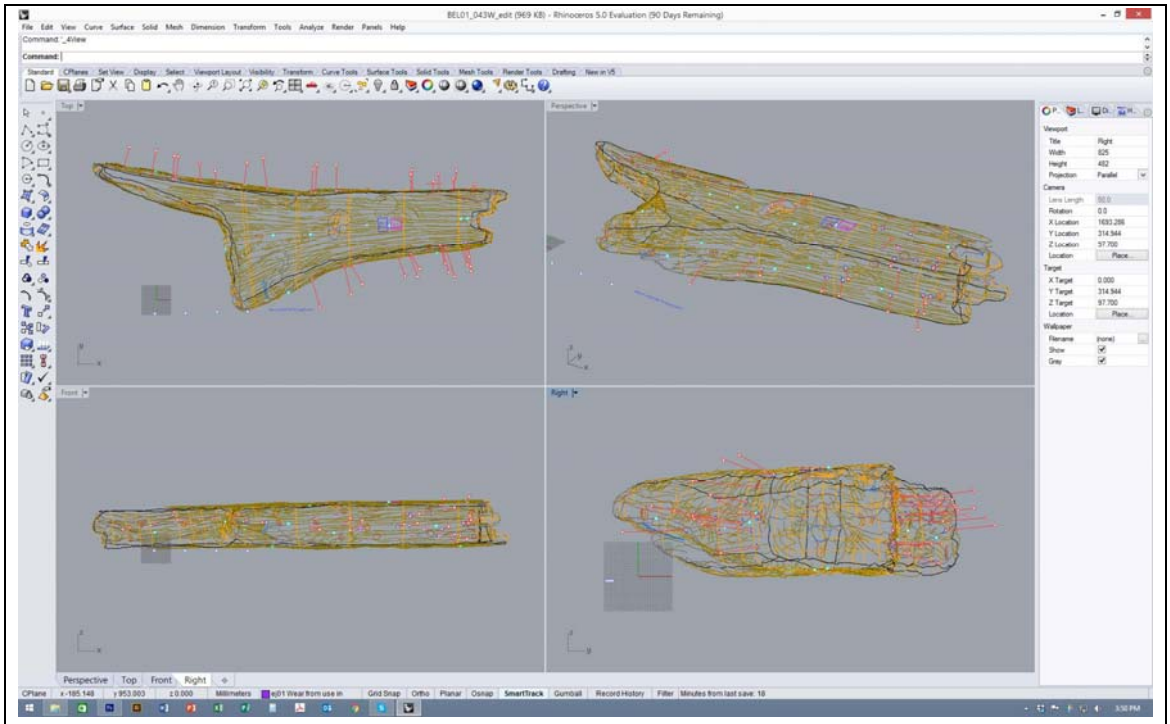
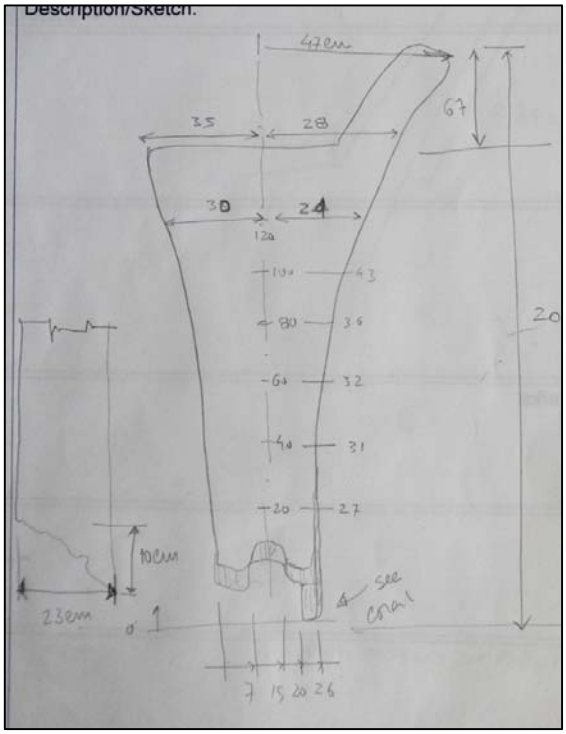


Figure 43.2 – FARO Arm 3D model of the timber (Adolfo Martins).

Sketch:



Timber: Y-Frame	No. 032W



Figure 32.1 – Photomosaic of the timber (not to scale).

Length preserved: 177 cm

Section: sided 28 cm, molded 20 cm.

Conversion: It is a standing tree, a branch forming the arm.

Tool Marks: All surfaces eroded.

Fasteners: Planks fastened with iron nails (11 mm) and treenails (25 mm). Three iron bolts connect it to the stern knee, (30 mm, heads 55/60 mm, recesses 60/70 mm, 25 mm deep) 53 and 70 cm apart. The after face has three protrusions probably to receive the gudgeons. Planks were connected to the after face of the sternpost with square nails (11 mm).

Recording: CHAM 12. Full FARO Arm drawing (Adolfo).

Faro Arm drawing:

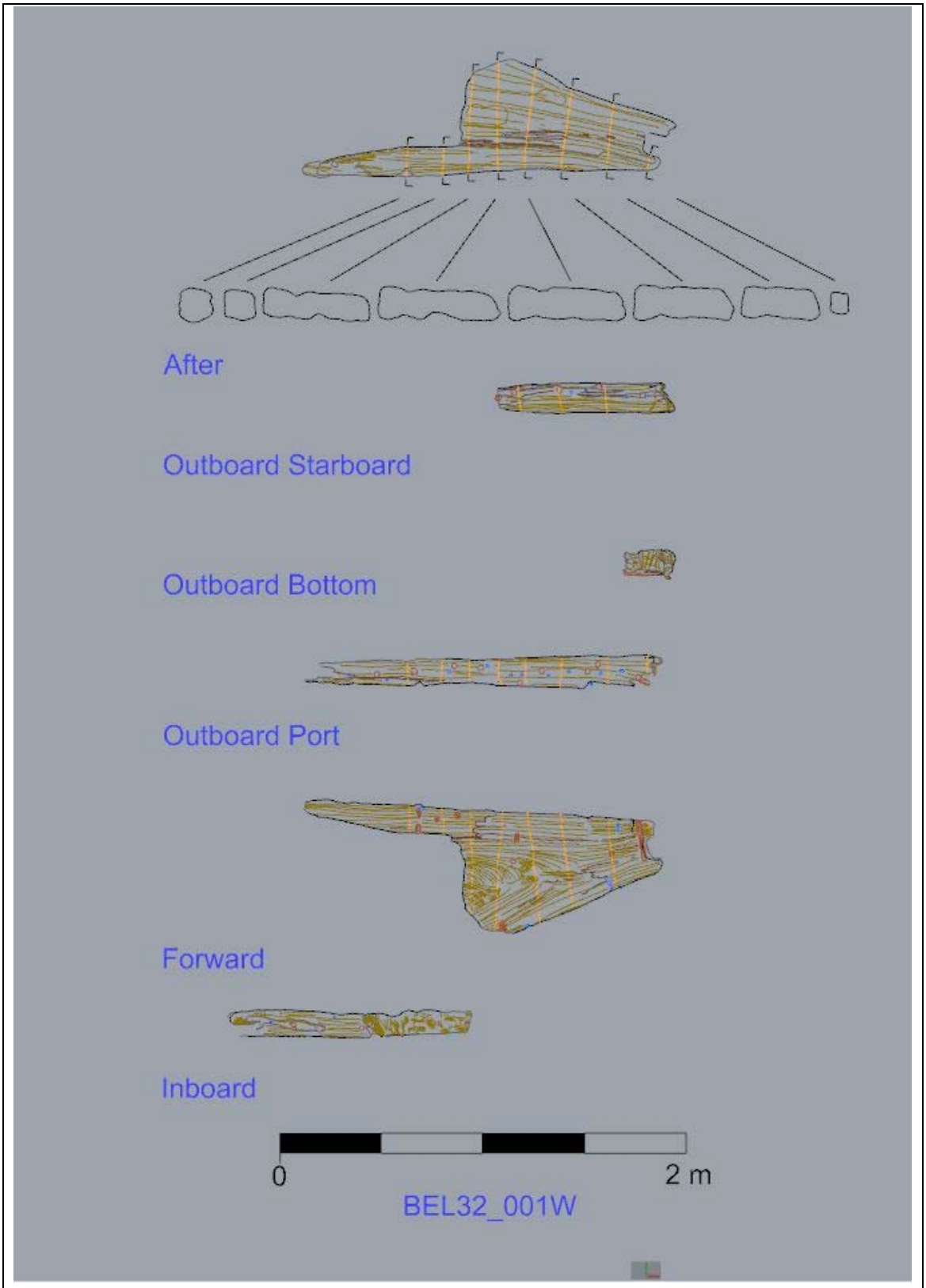
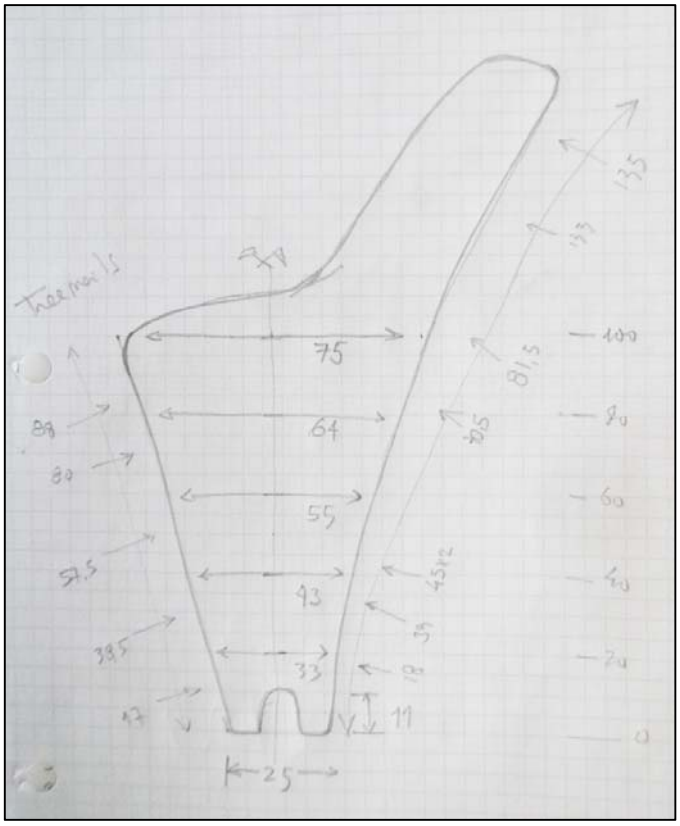


Figure 32.2 – FARO Arm 3D model of the timber (Adolfo Martins).

Sketch:



Timber: Floor Timber	No. 003W



Figure 03.1 – Photomosaic of the timber (not to scale).

Length preserved: 313 cm.

Section: sided 18 cm, molded 18 cm.

Bottom bevel: None.

Conversion: It is a standing tree, with the roots on one side and the branches on the other. Sapwood is missing.

Tool Marks: All surfaces eroded.

Fasteners: Fastened to the keel with one iron bolt. Planks fastened with treenails (27 mm and 22 mm) and iron nails (10-11 mm). It looks like 2 iron nails per treenail. Sometimes it seems that the holes are larger than the iron nails.

Joinery: dovetail scarves, carved, 16, 26 cm, carved, 2 treenails, 2/3 nails. There is no pronounced reduction of the section on the ends, although they slope and are longer on the face that contacts with the futtocks.

Recording: CHAM 003; Full FARO Arm drawing (Adolfo).



Figure 03.2 – Detail of the dovetail scarf.

Faro Arm drawing:

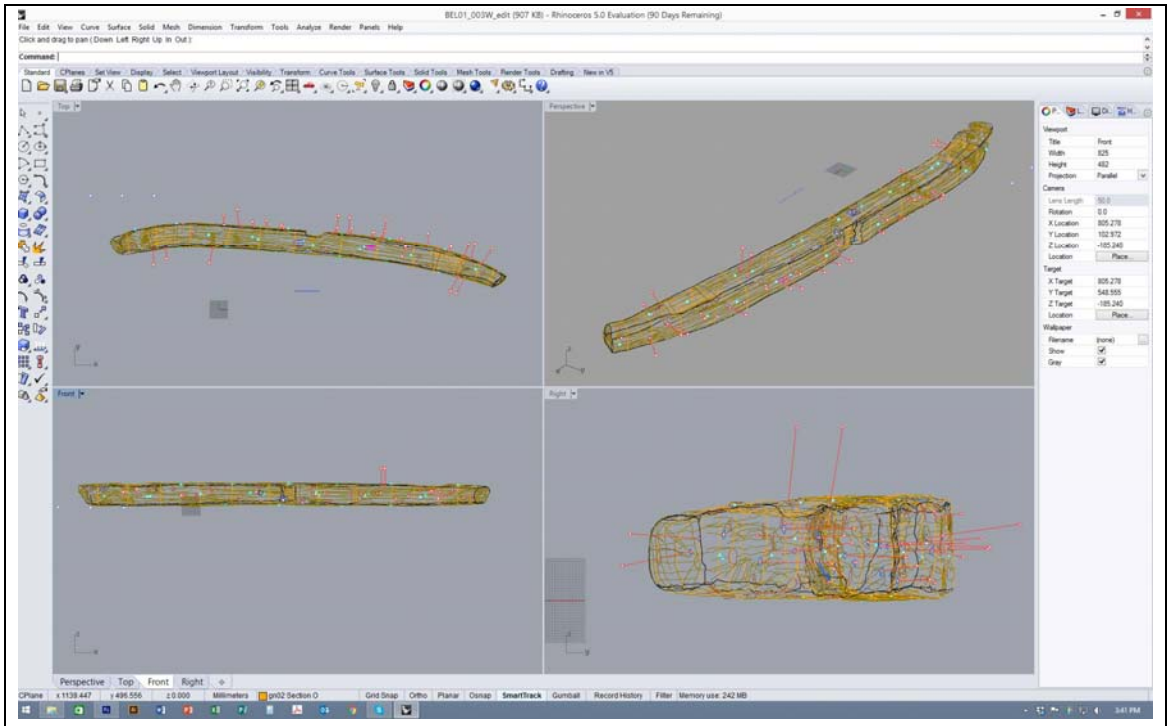
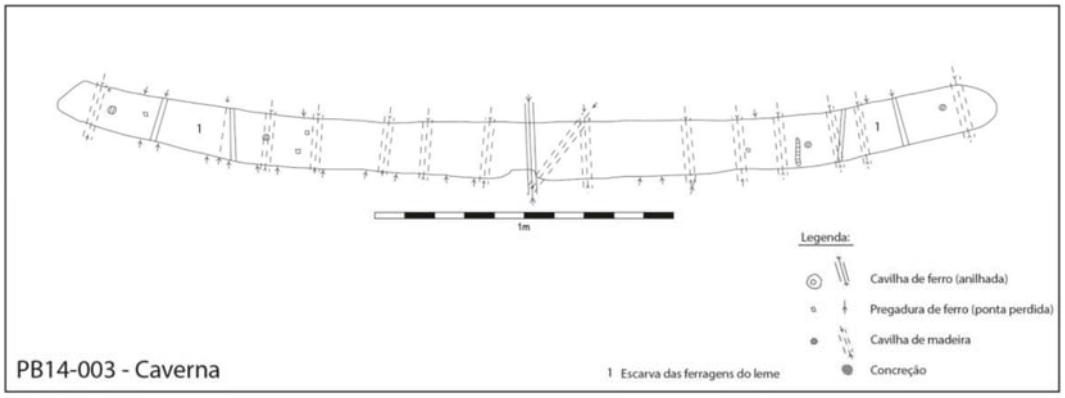


Figure 32.2 – FARO Arm 3D model of the timber (Adolfo Martins).

CHAM images:



CHAM images:



Timber: Floor Timber (marked “II”) No. 042W



Figure 42.1 – Photomosaic of the timber (not to scale).

Length preserved: 321 cm.

Section: sided 17 cm, molded 18 cm. Foot = 5 cm.

Bottom bevel: None.

Conversion: It is a standing tree, with the roots on one side and the branches on the other. Sapwood is missing.

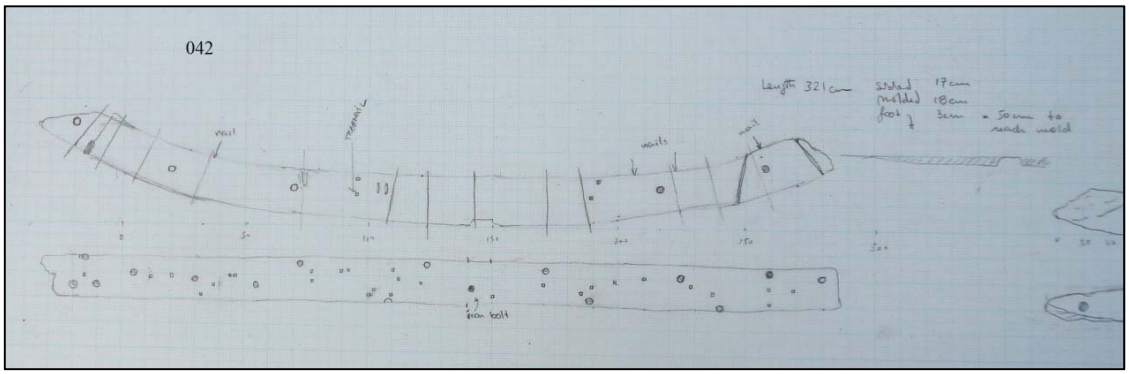
Tool Marks: All surfaces eroded.

Fasteners: Planks fastened with treenails (27 mm and 22 mm) and iron nails (11 mm).

Joinery: dovetail scarf on one of the sides, carved, 23, 28 cm, 2 treenails (1 missing), 2 nails from the futtock side. One of the sides shows a stepped, pronounced reduction of the floor timber section. At least one nail was inserted on the futtock through this step,

Recording: 1/10 (FC).

1/10 Drawing:



Timber: Floor Timber No. 044W



Figure 44.1 – Photomosaic of the timber (not to scale).

Length preserved: 310 cm.

Section: sided 16 cm, molded 18 cm.

Bottom bevel: None.

Conversion: It is a standing tree, with the roots on one side and the branches on the other. About 30 rings maximum. Sapwood is missing.

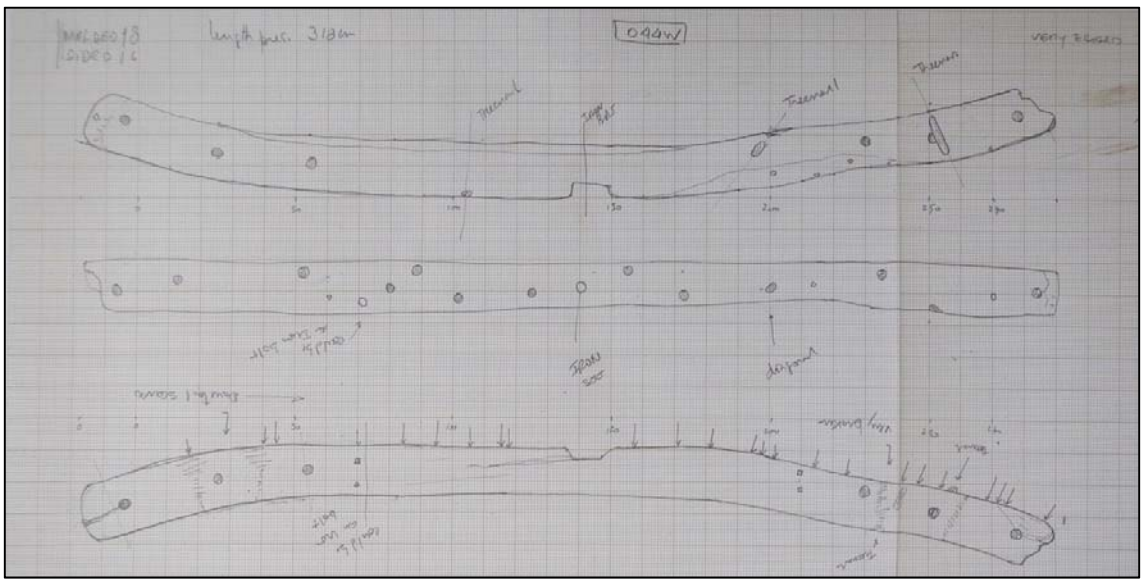
Tool Marks: All surfaces eroded.

Fasteners: Planks fastened with treenails (27 mm and 22 mm) and iron nails (11 mm).

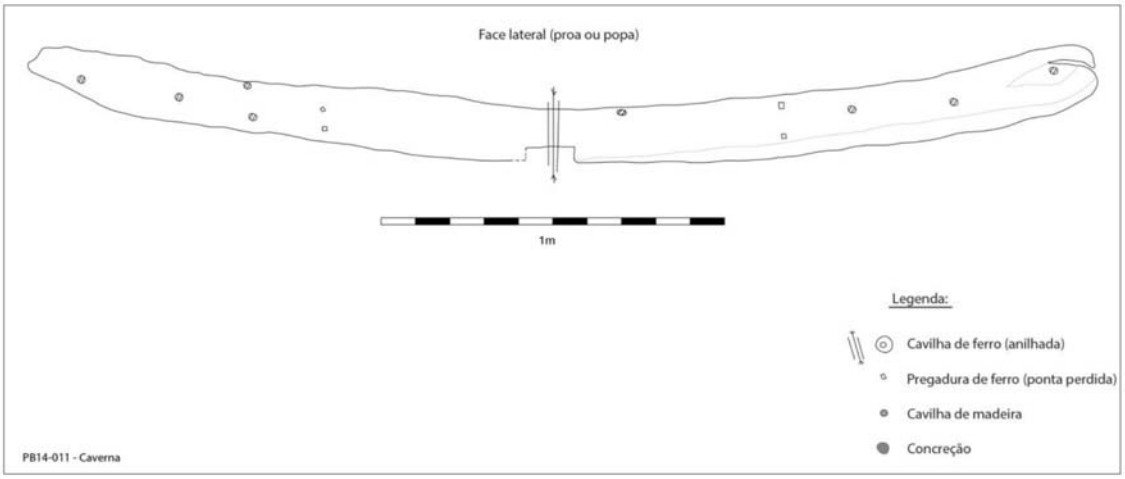
Joinery: dovetail scarves, carved, 16, 26 cm, 3 treenails, 2 nails inserted from the futtock. One of the sides shows a stepped, pronounced reduction of the floor timber section. At least one nail was inserted on the futtock through this step,

Recording: CHAM 011; 1/10 (FC).

1/10 Drawing:



CHAM images:


Face lateral (proa ou popa)
1m
Legenda:
Cavilha de ferro (anilhada)
Pregadura de ferro (ponta perdida)
Cavilha de madeira
Concreção
PB14-011 - Caverna


CHAM
0
0.5
1 m
PB14-011 - Caverna

Timber: Floor Timber No. 045W



Figure 45.1 – Photomosaic of the timber (not to scale).

Length preserved: 282 cm.

Section: sided 15 cm, molded 18 cm.

Bottom bevel: A few centimeters (1.5 cm).

Conversion: It is a standing tree, with the roots on one side and the branches on the other. Sapwood is missing.

Tool Marks: All surfaces eroded.

Fasteners: Planks fastened with treenails (27 mm and 22 mm) and iron nails (10-11 mm).

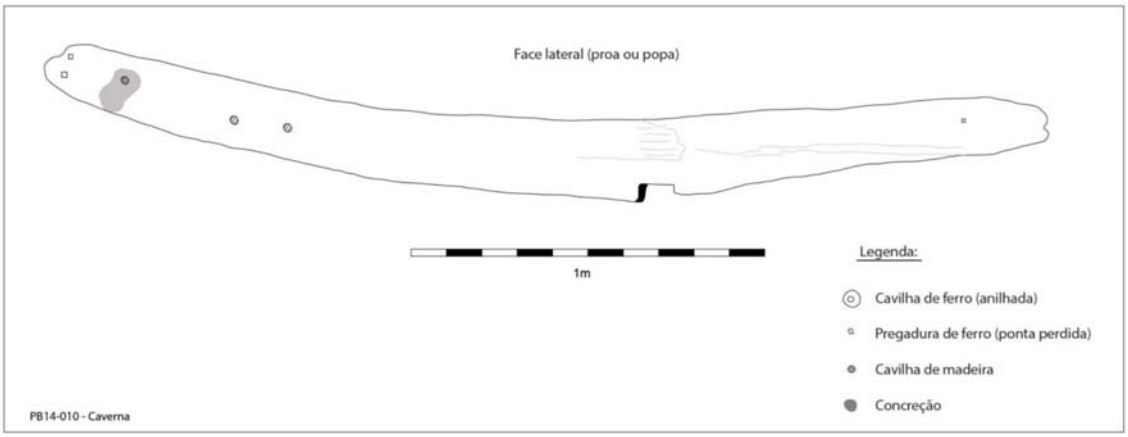
Joinery: not apparent, 3 treenails, 2 nails from the floor and 2 from the futtock. The preserved side showed a stepped, pronounced reduction of the floor timber section. At least one nail was inserted on the futtock through this step,

Recording: CHAM 010; 1/10 (FC).

1/10 Drawing:



CHAM images:


Face lateral (proa ou popa)
1m
Legenda:
Cavilha de ferro (anilhada)
Pregadura de ferro (ponta perdida)
Cavilha de madeira
Concreção
PB14-010 - Caverna


Centro de História d'Aquém e d'Além-Mar
CHAM
Universidade Nova de Lisboa
Faculdade de Ciências Sociais e Humanas
Universidade dos Açores
0
0.5
1 m
PB14-010 - Caverna

Timber: Floor Timber fragment No. 041W



Figure 41.1 – Photomosaic of the timber (not to scale).

Length preserved: 119 cm

Section: sided 21.5 cm, molded 16.5 cm.

Bottom bevel: Not apparent.

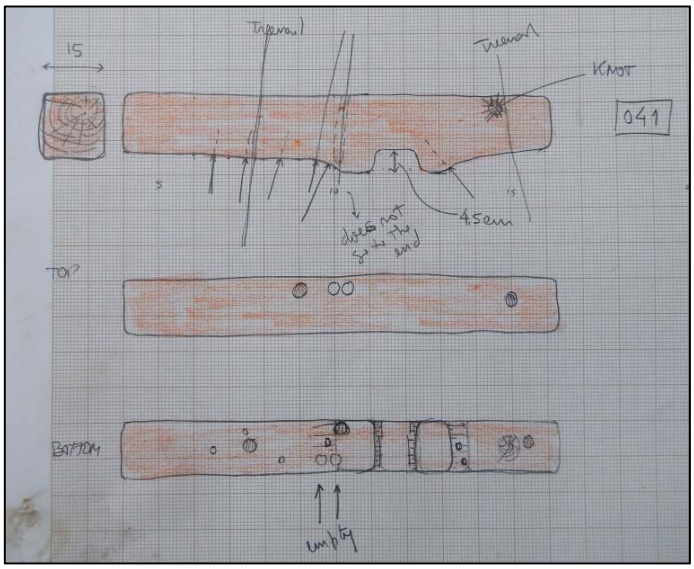
Conversion: Straight grain.

Tool Marks: All surfaces eroded.

Fasteners: Planks fastened with treenails (27 mm and 22 mm) and iron nails (11 mm).

Recording: 1/10 (FC).

1/10 Drawing:



Timber: Frame fragment No. 069W



Figure 69.1 – Photomosaic of the timber (not to scale).

Length preserved: 110 cm.

Section: sided 16 cm, molded 18 cm.

Bottom bevel: 2.5 cm on one of the ends.

Conversion: The grain seems to run diagonally to the edges of the timber in this area.

Tool Marks: All surfaces eroded.

Fasteners: Planks fastened with treenails (27 mm and 22 mm) and iron nails (10 mm).

Joinery: dovetail scarf, salient, 14-20 cm, 2 treenails, 1 nails. One of the sides shows a stepped, pronounced reduction of the floor timber section.

Comments: The salient dovetail scarf may indicate this is part of a futtock.

Recording: CHAM 006; 1/10 (FC).

Details:

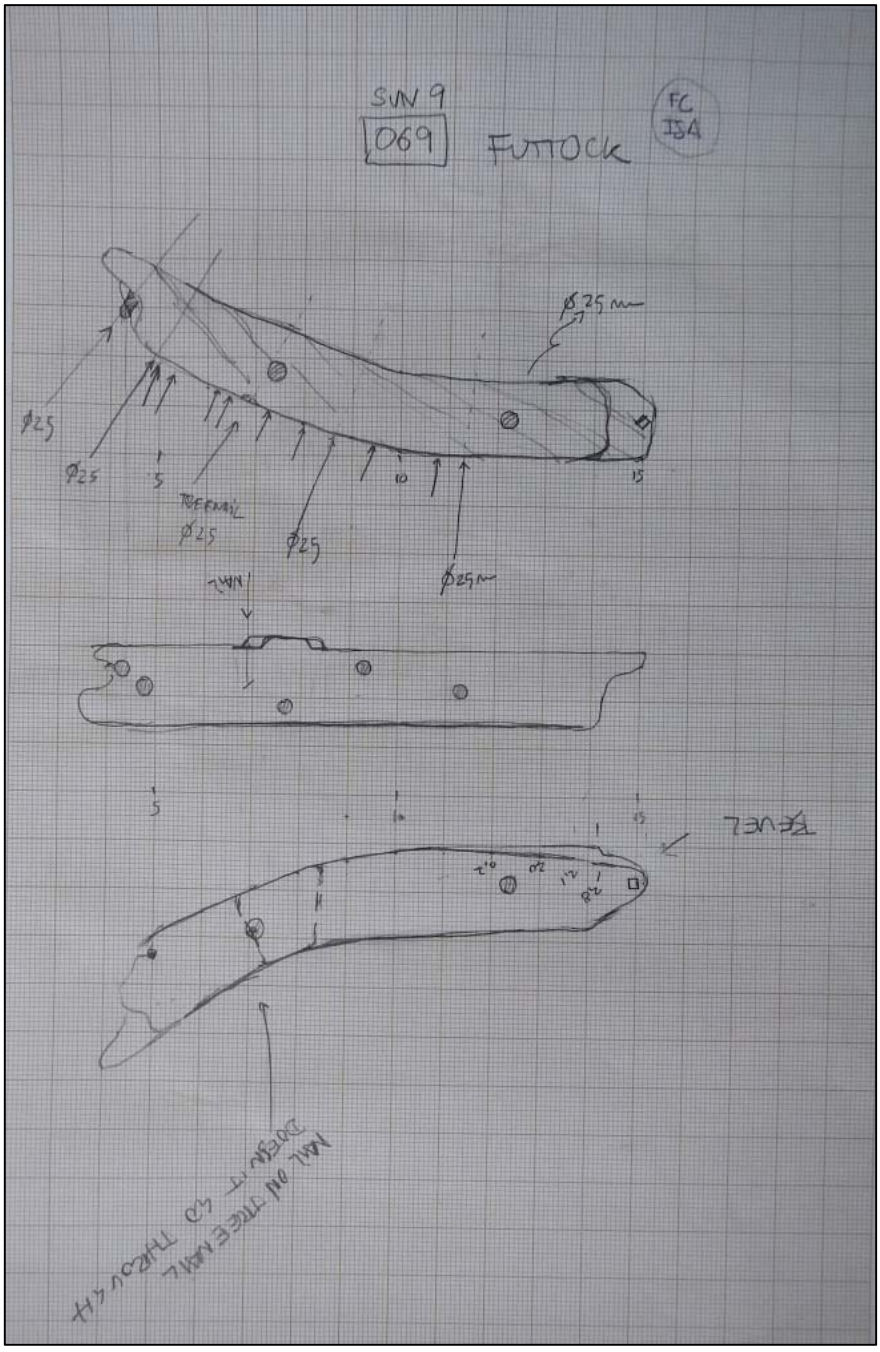


Figure 69.2 – Partially preserved step on the end of the timber.

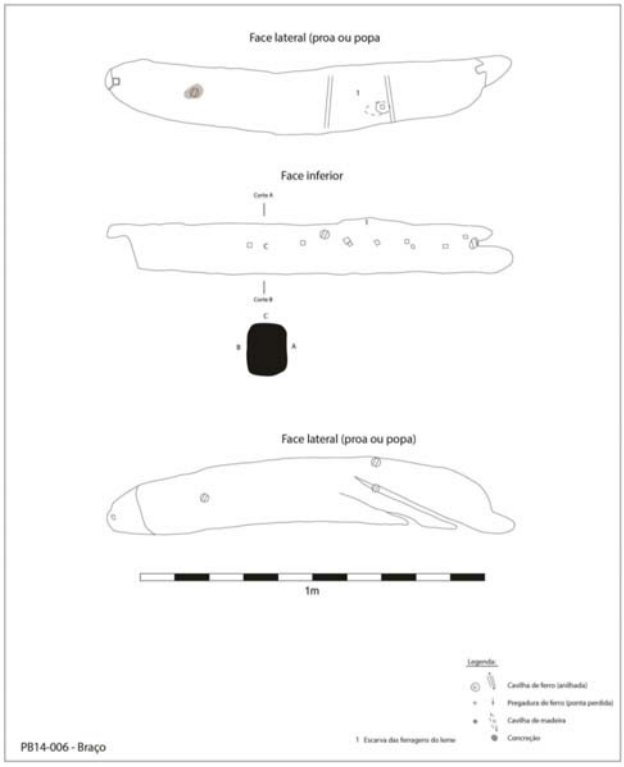


Figure 69.3 – Scarf and fasteners preserved.

1/10 Drawing:



CHAM Images:


Face lateral (proa ou popa
Face inferior
Face lateral (proa ou popa)
1m
PB14-006 - Braço


CHAM
0
0.5 m
PB14-006 - Braço

Timber: Frame fragment	No. 034W



Figure 34.1 – Photomosaic of the timber (not to scale).

Length preserved: 112 cm.

Section: sided 16 cm, molded 19.5 cm.

Bottom bevel: Not apparent.

Conversion: The grain rains across the piece in this area.

Tool Marks: All surfaces eroded. Two parallel lines on one of the faces may be design lines, although it seems that one of the lines passes over a broken treenail, in which case the lines could have been done somehow in the process of recovery.

Fasteners: Planks fastened with treenails (27 mm and 22 mm) and iron nails (10 mm).

Joinery: Dovetail scarf, salient, 10-24 cm, 2 treenails, 2 nails.

Comments: The salient dovetail scarf may indicate this is part of a futtock. One of the sides shows a stepped, pronounced reduction of the floor timber section.

Recording: 1/10 (FC).

Details:



Figure 34.2 – Photomosaic of the upper face, showing the step



Figure 34.3 – The wood grain pattern in this extremity of the timber is curved against the timber shape and has large knots.

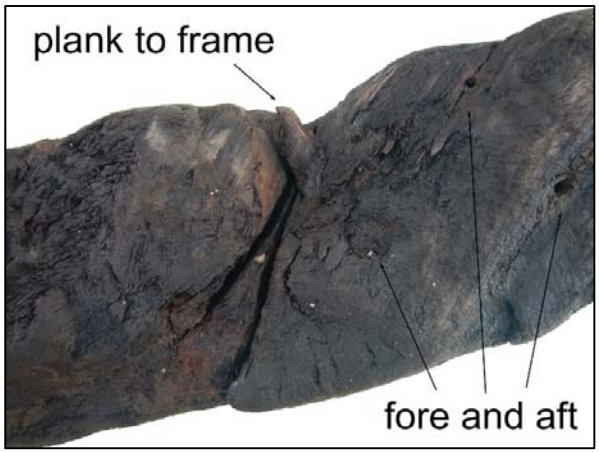


Figure 34.4 – Wood grain and fasteners: the treenail connecting the planking to the frame runs through the treenail connecting the floor and futtock, indicating the presence of pre-assembled frames.



Figure 34.5 – Lines scratched on the side face of timber 034W.

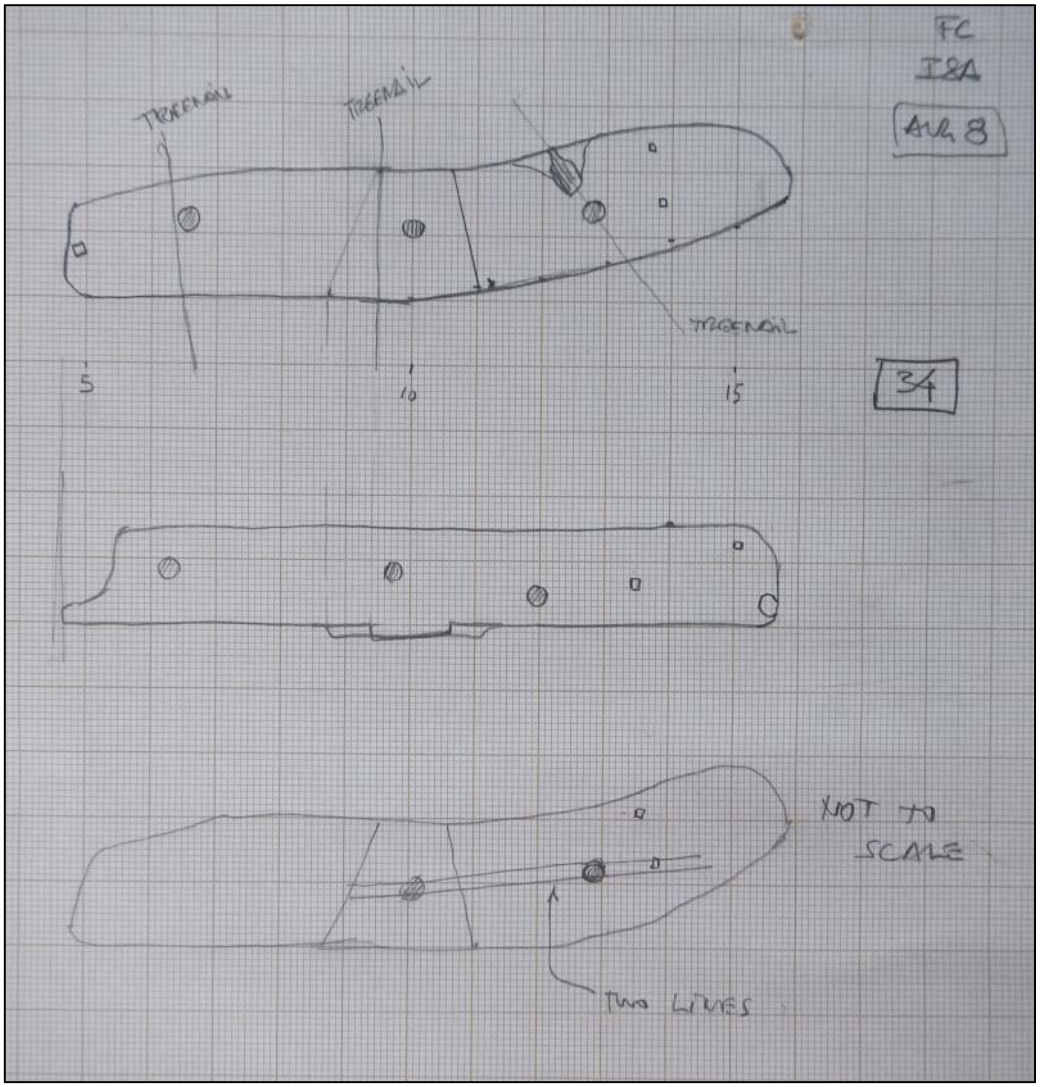


Figure 34.6 – Detail of the parallel lines.



Figure 34.7 – Another detail of the parallel lines, showing the broken treenail section where, under certain light angles, it seems that the lines may go over it.

1/10 Drawing:



Timber: Frame fragment No. 035W



Figure 35.1 – Photomosaic of the timber (not to scale).

Length preserved: 102 cm.

Section: sided 18 cm, molded 16 cm.

Bottom bevel: Not apparent.

Conversion: The grain is not parallel to the timber.

Tool Marks: All surfaces eroded. There are two spoon auger holes unfinished on the bottom face.

Fasteners: Planks fastened with treenails (27 mm and 22 mm) and iron nails (11 mm).

Recording: 1/10 (FC).

Details:



Figure 35.2 – The two blind holes on the lower face of timber 035W.



Figure 35.3 – Blind hole near a through hole on the upper face of timber 035W.

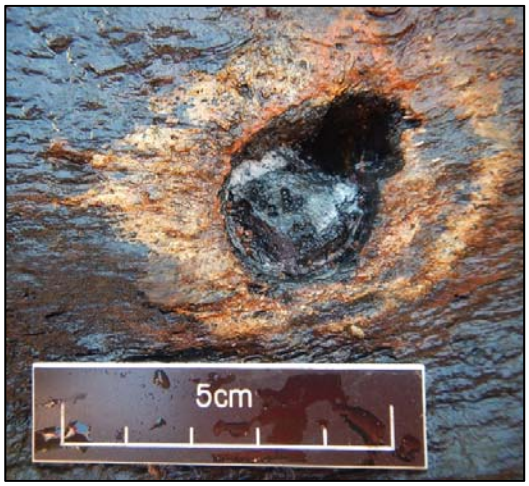


Figure 35.4 – Nail hole over a treenail on the upper face of timber 035W.

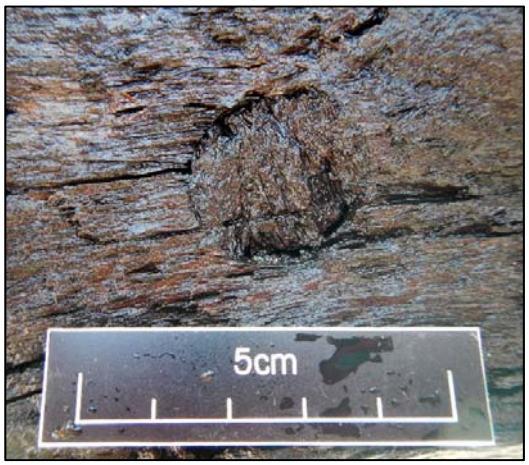
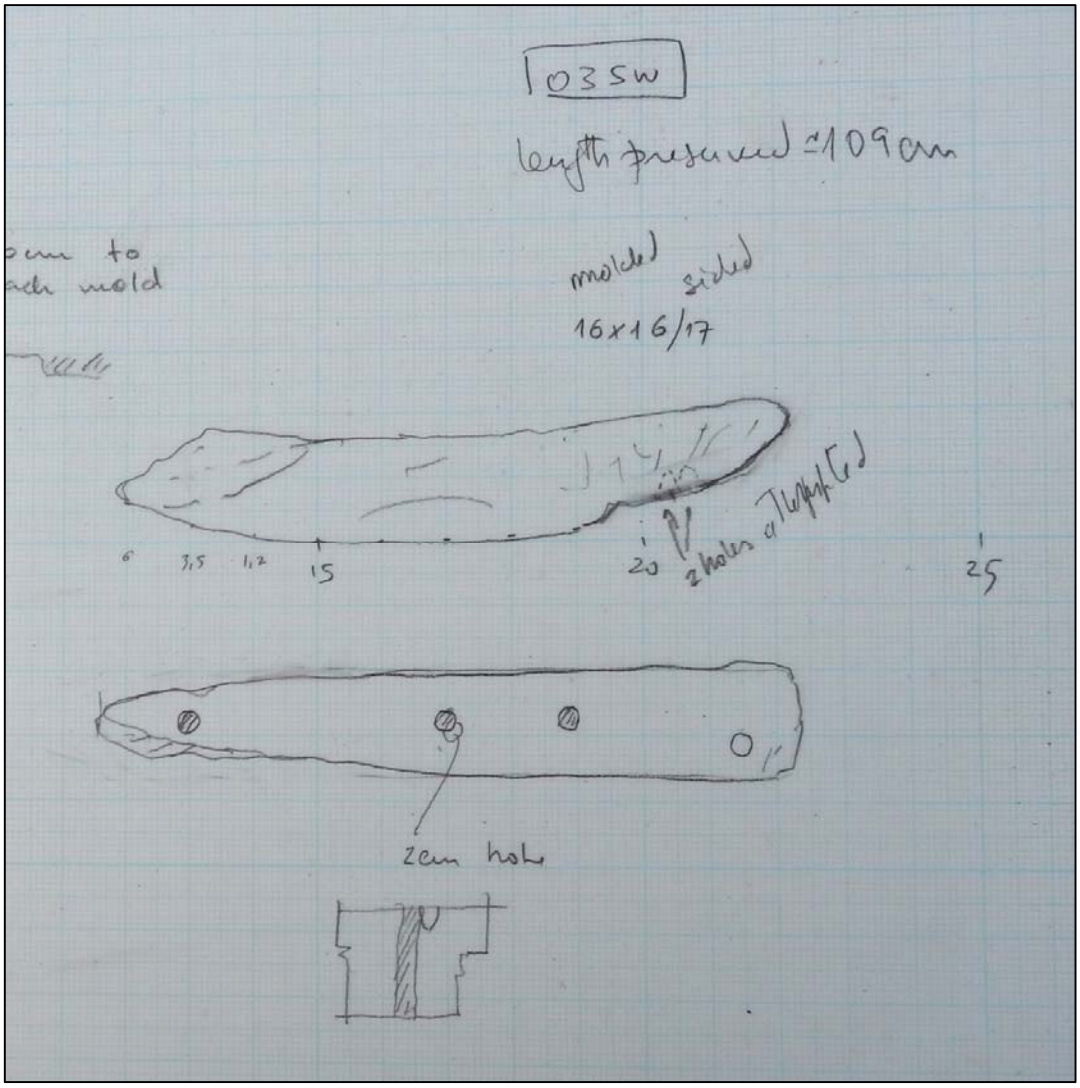


Figure 35.5 – Broken treenail section with vestiges of a scratch line, like the ones observed on timber 034W.

1/10 Drawing:


1035w
length preserved ≈109cm
molded
sided
16x16/17
6
3,5
1,2
15
20
25
2cm hole
2cm hole

Timber: Deck knee	No. 038W



Figure 38.1 – Photomosaic of the timber (not to scale).

Length preserved: 153 cm.

Section: sided 22 cm, molded 20 cm.

Bottom bevel: None.

Conversion: It is a standing tree, with the roots on one side and the branches on the other. Sapwood is mostly missing.

Tool Marks: All surfaces eroded.

Fasteners: Planks fastened to the top surface with and iron nails (10 mm). Two large fore and aft iron nails (20 mm) fastened this timber to the deck beams (?) and an iron bolt (25 mm) fastened it diagonally to the frames/wales (?).

Joinery: Very eroded. A small notch could correspond to the position of a clamp.

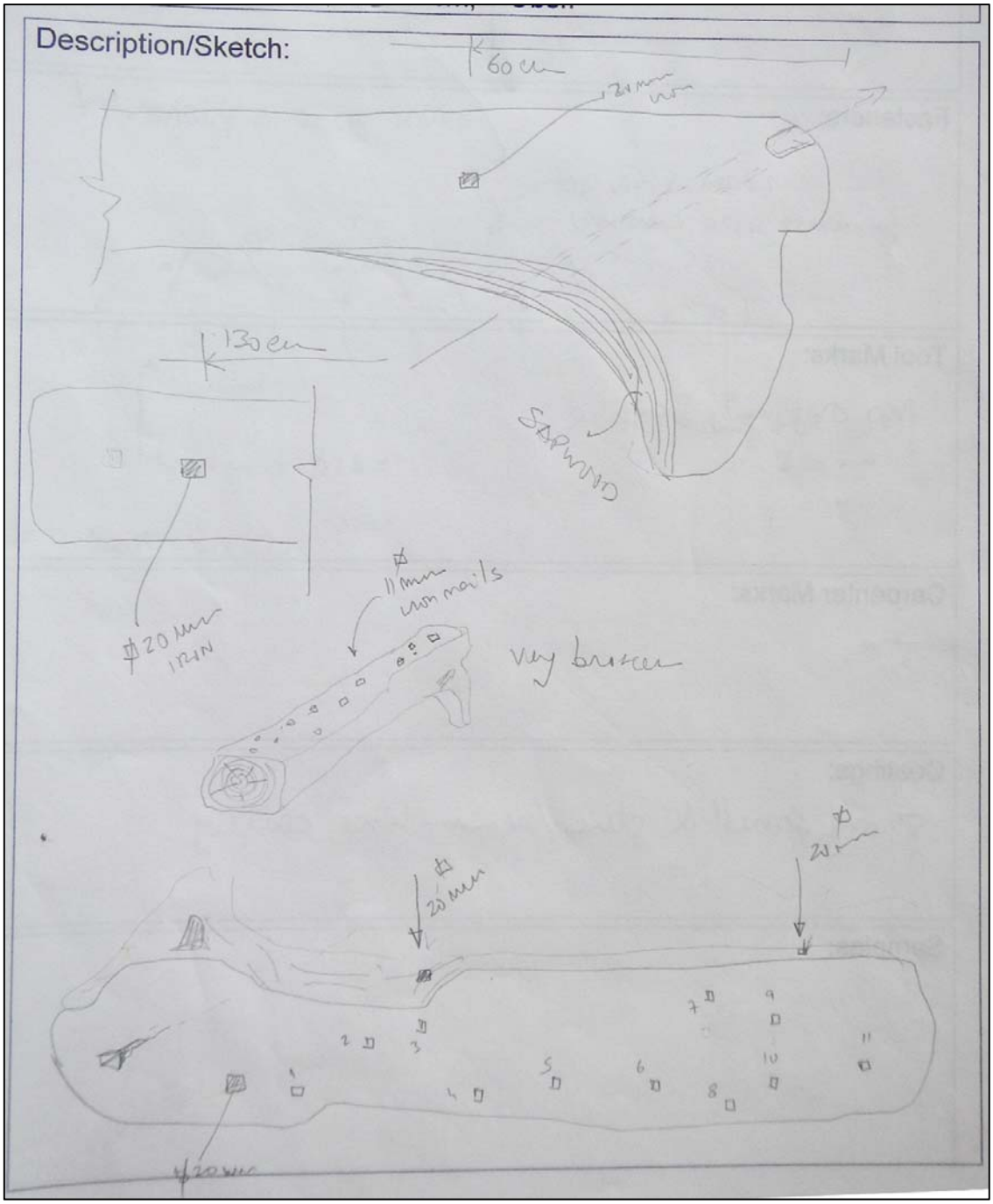
Recording: 1/10 (FC).

Details:

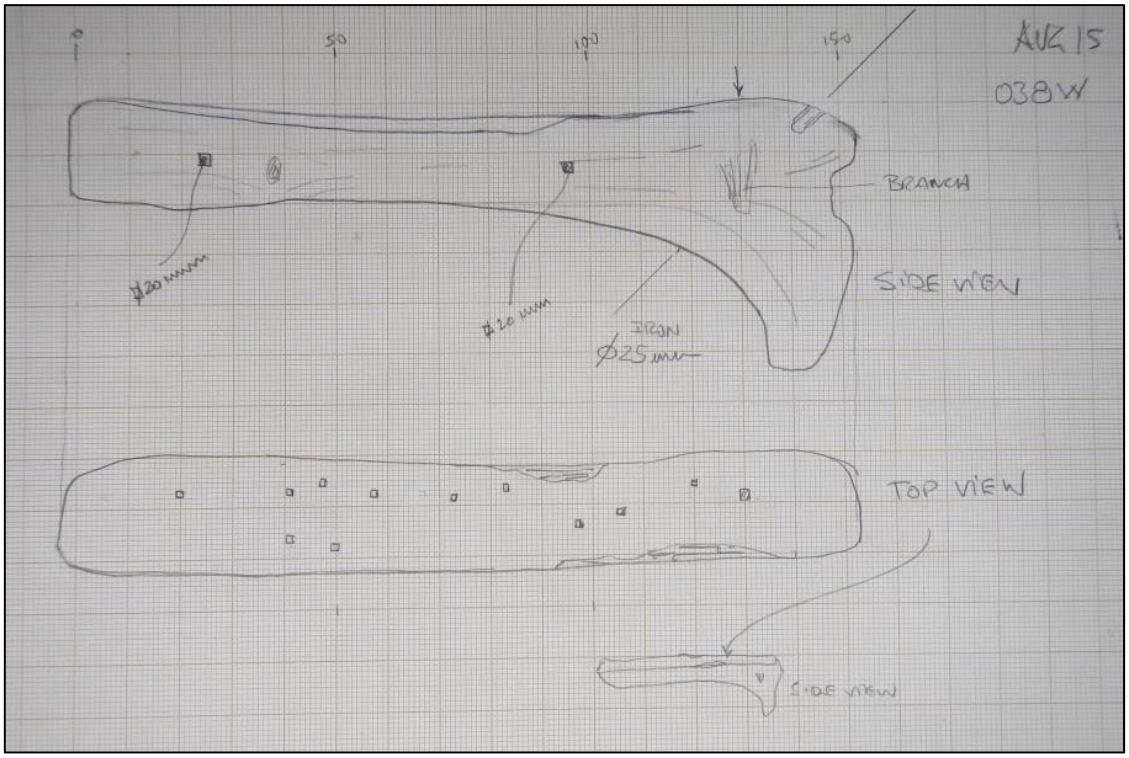


Figure 38.2 – Angle of the bolt that presumably connected this timber to the ship hull.

Sketch:



1/10 Drawing:


0
50
100
150
AUG 15
038W
BRANCH
SIDE VIEW
IRON
TOP VIEW
SIDE VIEW

Timber: Deck knee	No. 047W



Figure 47.1 – Photomosaic of the timber (not to scale).

Length preserved: 134 cm.

Section: sided 21 cm, molded 23 cm.

Bottom bevel: Not preserved.

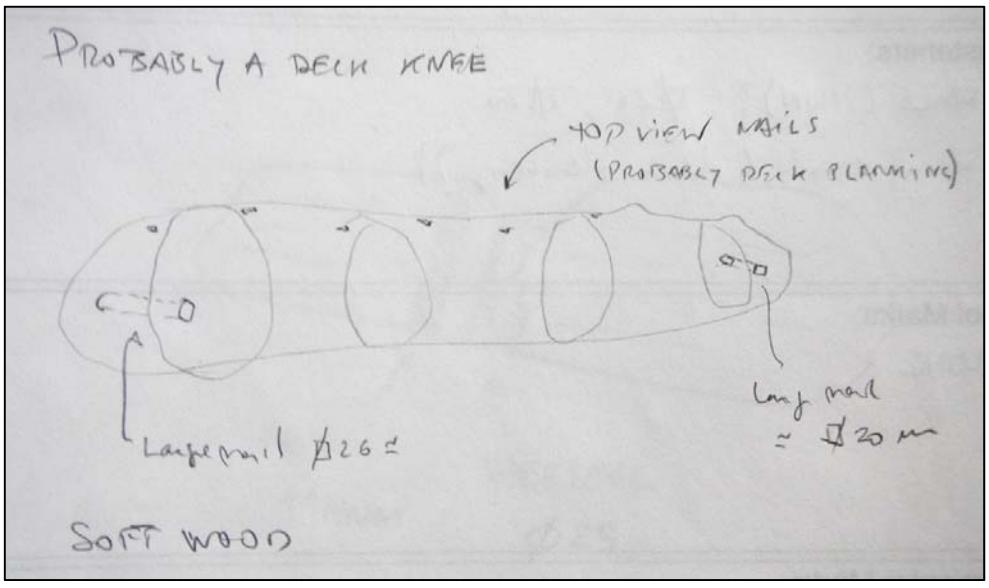
Conversion: It is a log with a branch. Sapwood is mostly missing.

Tool Marks: All surfaces eroded.

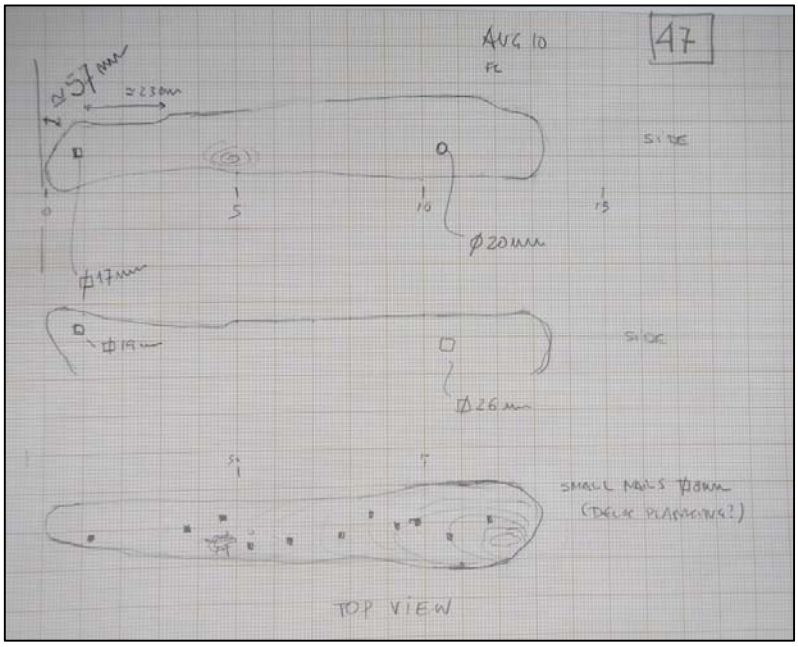
Fasteners: Planks fastened to the top surface with and iron nails (10 mm). Two large iron nails (20 mm) fastened this timber to the deck beams (?) and an iron bolt (25 mm) fastened it diagonally to the frames/wales (?).

Recording: 1/10 (FC).

Sketch:



1/10 Drawing:



Timber: Fragment of transversal timber	No. 014W



Figure 14.1 – Image of the timber.

Length preserved: 40 cm.

Section: not preserved.

Bottom bevel: Not preserved.

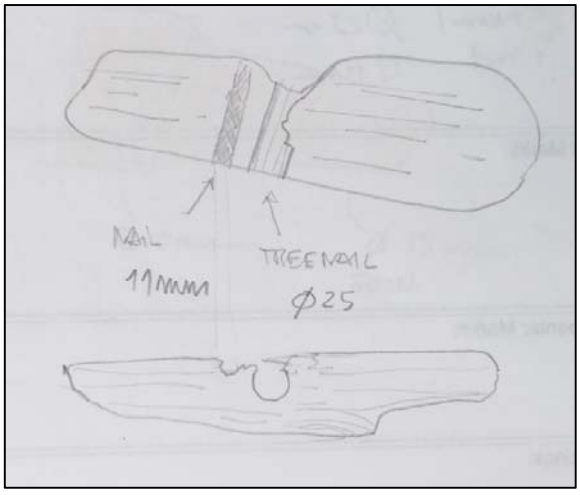
Conversion: Too small a fragment to allow retrieval of much information.

Tool Marks: All surfaces eroded.

Fasteners: Iron nails (10-11 mm) and treenails (25 mm).

Recording: Photographed and sketched.

Sketch:



Planking

Waterway 049

Portside plank w/ stern hood 057

Portside plank w/ stern hood 054

Portside plank w/ stern hood 055

Starboard plank w/ stern hood 059

Starboard plank w/ stern hood 060

Starboard plank w/ stern hood 056

Starboard plank w/ stern hood 053

Plank fragment 050

Plank fragment 052

Plank fragment 004

Plank fragment 061



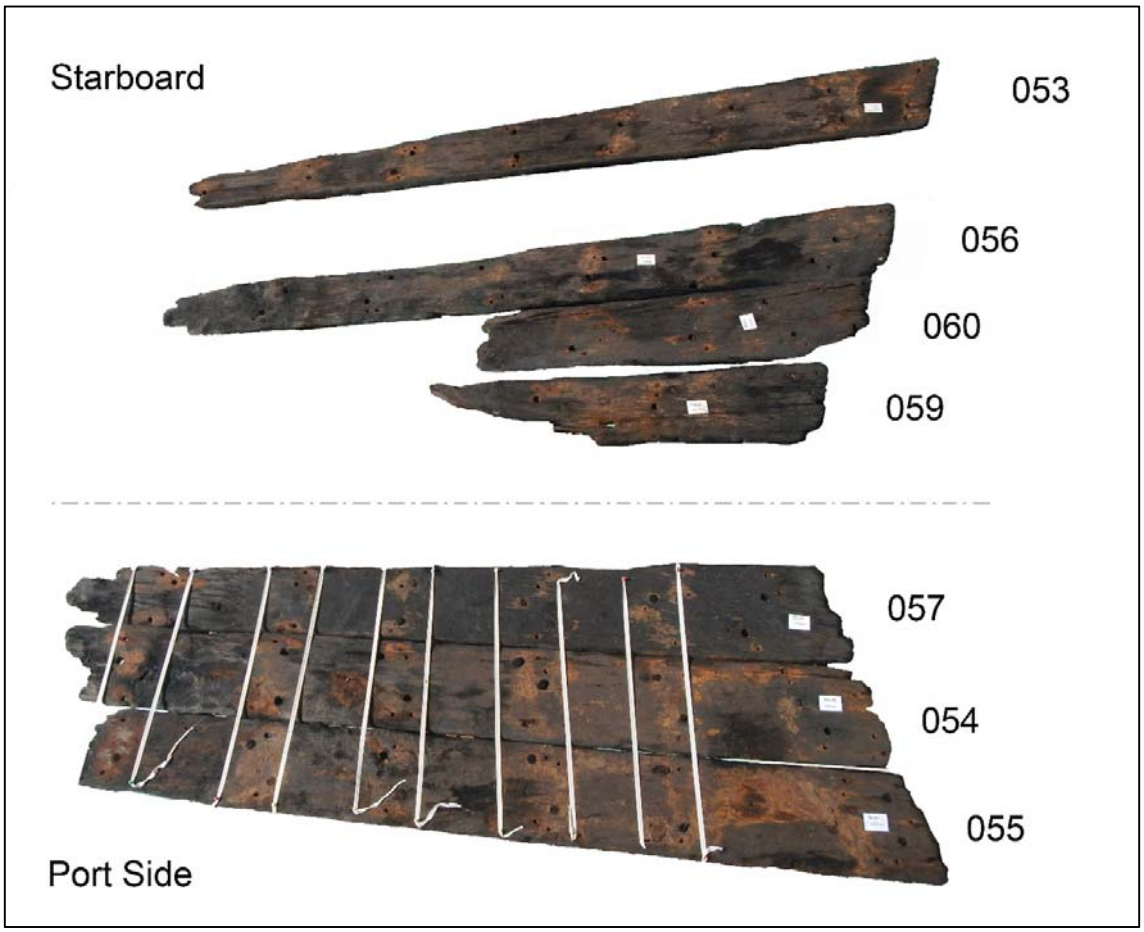
Stern timbers, positioned after analyzing the fastener's marks near the hoods and on the sternpost.



Tentative arrangement of the port side planking, matching the fastener's holes near the plank hoods to those on the preserved section of the sternpost.



Same tentative arrangement of the starboard side planking.



Preserved planks and their tentative positions.

Timber: Waterway	No. 049W



Figure 49.1 – Photomosaic of the timber (not to scale).

Length preserved: 396 cm.

Section: sided 16 cm, molded 10 cm.

Bottom bevel: None.

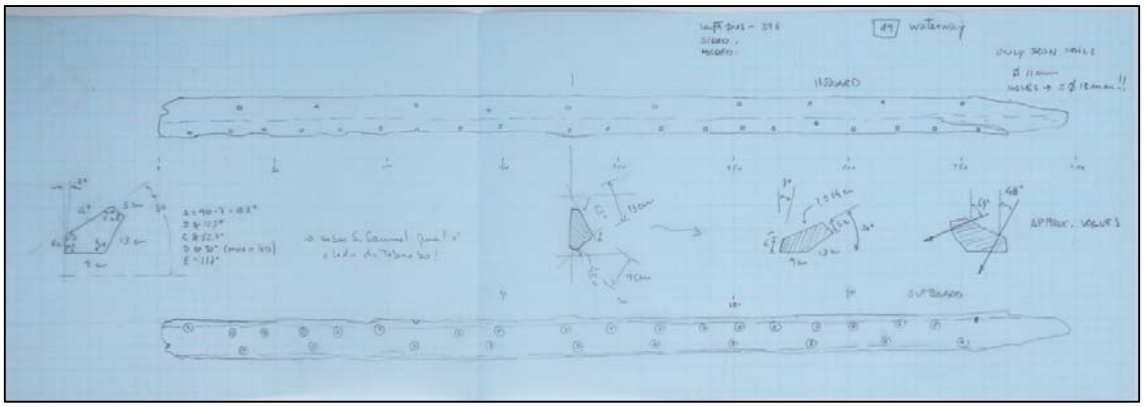
Conversion: Straight grain. Sapwood is missing.

Tool Marks: All surfaces eroded.

Fasteners: Fastened with iron nails (10 mm). Fastening pattern probably one nail // 15 cm on the planking, and // 30 cm to the side.

Recording: 1/10 (FC).

1/10 Drawing:



Timber: Plank Port Side	No. 057W



Figure 57.1 – Photomosaic of the timber outboard (not to scale).

Length preserved: 275 cm.

Section: sided 34 cm, molded 7 cm.

Bottom bevel: edges eroded.

Tool Marks: Deep (1-2 cm) grooves carved on the outboard surface, together with triangles.

Fasteners: Patterns vary, mostly in the sternpost area. There are several clusters of close spaced nails, sometimes in pairs, as observed in the sternpost and elsewhere. In the extension preserved the pattern is, counting from the sternpost: 2 treenails / 4 nails; 1 treenail / 7 nails; 1 treenail / 3 nails; 2 treenails / 3 nails; 3 nails; and 3 nails. There are two nails closely placed in between the positions of two y-frames, perhaps indicating the presence of a first futtock.

Sheathing: Small (4 mm) nails, probably used to secure lead sheathing (lead straps were found on the site).

Recording: 1/10 (FC).



Figure 57.2 – Photomosaic of the timber inboard with the fastening pattern (not to scale).

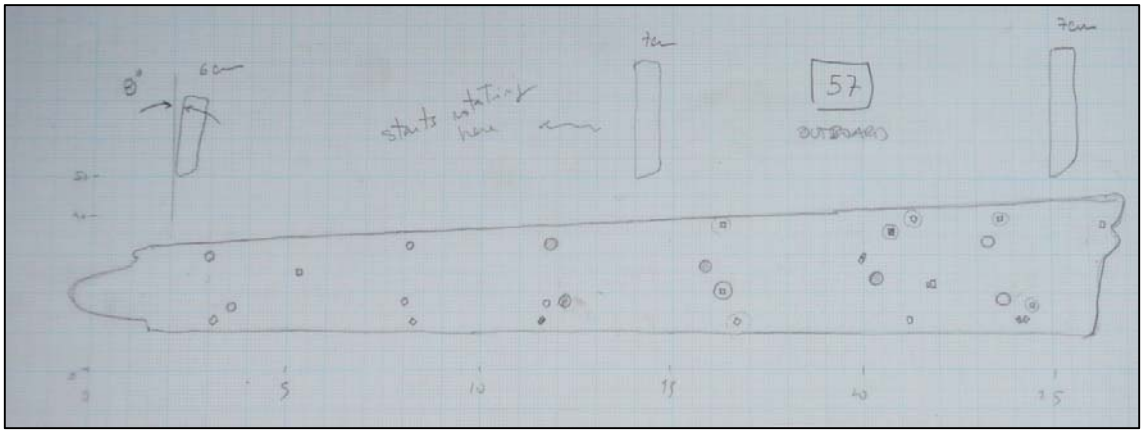


Fig. 57.3 – Grooves and triangles carved on the outer surface of the hull planks.



Fig. 57.4 – Saw marks on the outer surface of the hull planks.

1/10 Drawing:



Timber: Plank Port Side	No. 054W



Figure 54.1 – Photomosaic of the timber (not to scale).

Length preserved: 280 cm.

Section: sided 31 cm, molded 6.5 cm.

Bottom bevel: edges eroded.

Tool Marks: Deep (1-2 cm) grooves triangles carved on the outboard surface. We decided not to clean this plank and sample the coating for analysis.

Fasteners: Treenails (27 mm) and nails (10 mm). Countersink holes (50 mm) in every nail head. Patterns vary, mostly in the sternpost area. There are several clusters of close spaced nails, sometimes in pairs, as observed in the sternpost.

Sheathing: Small (4 mm) nails, probably used to secure lead sheathing (lead straps were found on the site).

Recording: 1/10 (FC).



Fig. 54.4 – Detail of the outboard surface, the chisel marks made to wedge a treenail.



Fig. 54.2 – Detail of the outboard surface, showing the grooves and triangular notches carved on the outer surface of the hull planks.

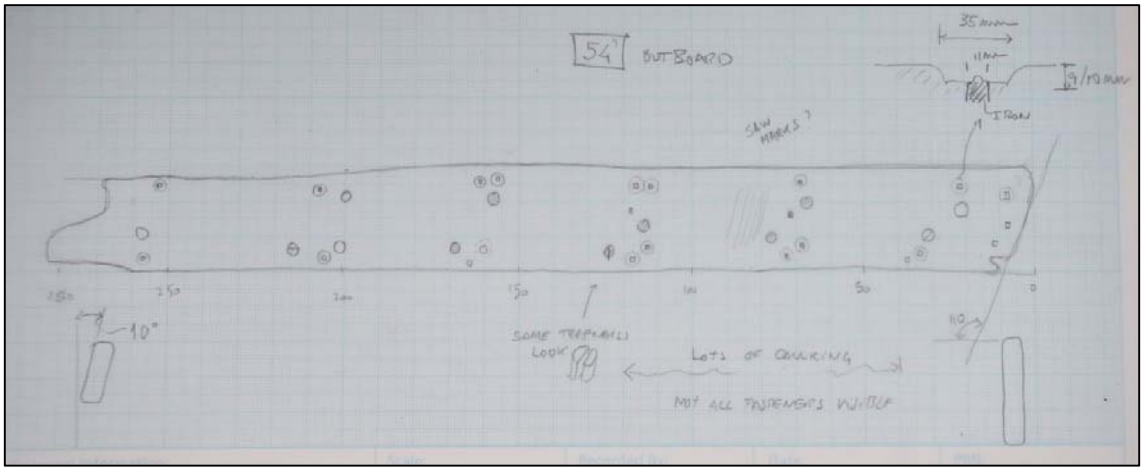


Fig. 54.3 – Detail of the outboard surface, showing saw marks.



Fig. 54.5 – Detail of the outboard surface, showing the treenail hole with the original treenail shape. Treenails were probably made with an ax and did not have circular sections.

1/10 Drawing:



Timber: Plank Port Side	No. 055W



Figure 55.1 – Photomosaic of the outboard face of the timber (not to scale).

Length preserved: 280 cm.

Section: sided 30.5 cm, molded 7 cm.

Bottom bevel: edges eroded.

Tool Marks: Deep (1-2 cm) grooves triangles carved on the outboard surface and possible saw marks.

Fasteners: Patterns vary, mostly in the sternpost area. There are several clusters of close spaced nails, sometimes in pairs, as observed in the sternpost.

Sheathing: Small (4 mm) nails, probably used to secure lead sheathing (lead straps were found on the site).

Recording: CHAM 005; 1/10 (FC).



Fig. 55.2 – Inboard surface of plank 055 (mosaic, not actual picture).



Fig. 55.3 – Grooves and triangular notches carved on the outer surface of the hull planks and full of a thick white coating.

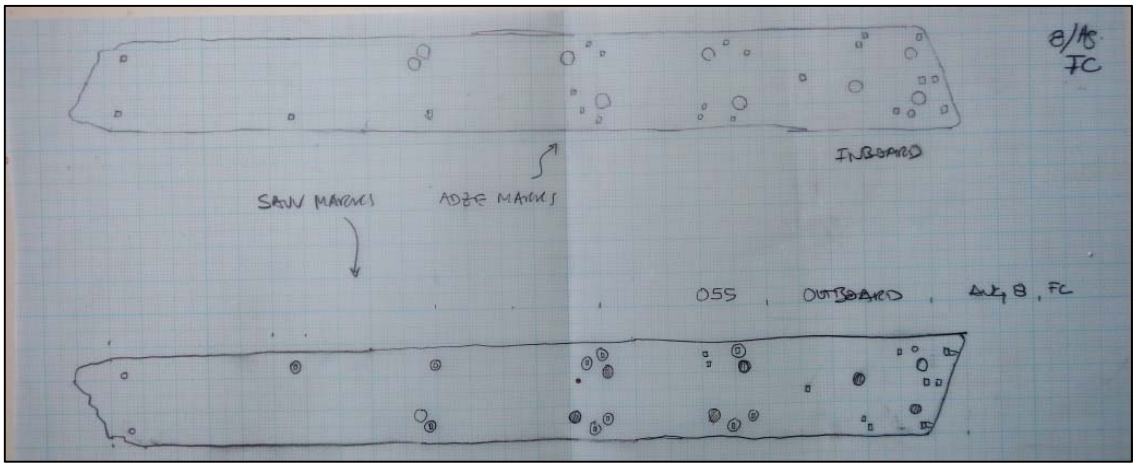


Fig. 55.4 – Possible saw marks on the outboard face of the plank.

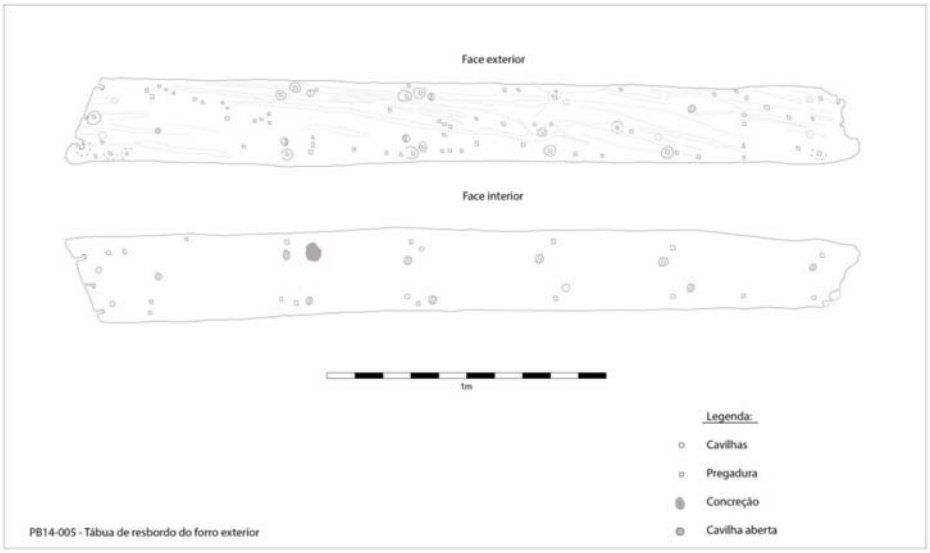


Fig. 55.5 – Sheathing nail holes preserved.

1/10 Drawing:



CHAM Images:


Face exterior
Face interior
1m
Legenda:
Cavilhas
Pregadura
Concreção
Cavilha aberta
PB14-005 - Tábua de resbordo do forro exterior


CHAM
0
0.5
1 m
PB14-005 Tábua

Timber: Plank Starboard No. 059W



Figure 59.1 – Photomosaic of the timber (not to scale).

Length preserved: 146 cm.

Section: sided 31 cm, molded 6.5 cm.

Bottom bevel: edges eroded.

Tool Marks: Deep (1-2 cm) grooves carved on the outboard surface, together with triangles.

Fasteners: Treenails (27 mm) and nails (10 mm). Countersink holes (50 mm) in every nail head. Patterns vary, mostly in the sternpost area. There are several clusters of close spaced nails, sometimes in pairs, as observed in the sternpost.

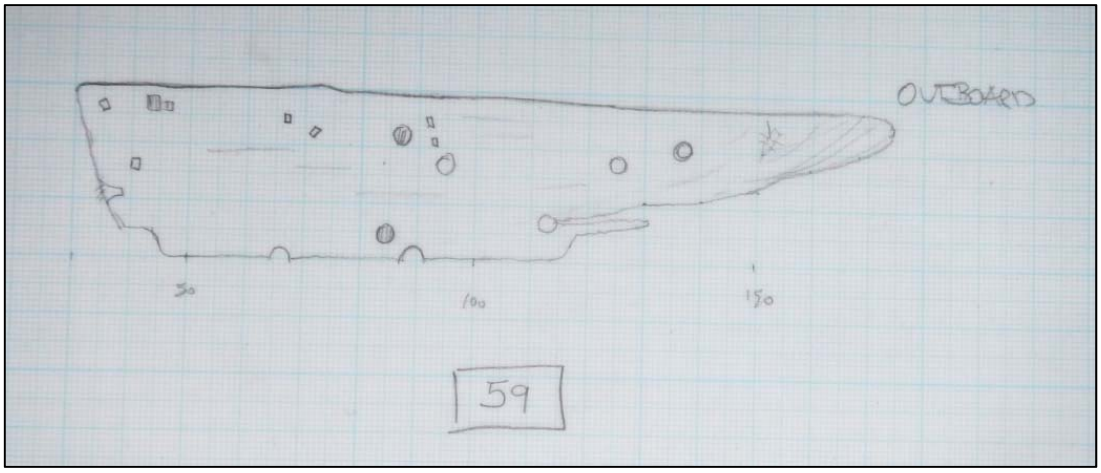
Sheathing: Small (4 mm) nails, probably used to secure lead sheathing (lead straps were found on the site).

Recording: 1/10 (FC).



Fig. 59.2 – Grooves and triangles carved on the outer surface of the hull planks.

1/10 Drawing:



Timber: Plank Starboard	No. 060W



Figure 60.1 – Photomosaic of the outboard face of the timber (not to scale).

Length preserved: 153 cm.

Section: sided 31 cm, molded 6.5 cm.

Bottom bevel: edges eroded.

Tool Marks: Deep (1-2 cm) grooves carved on the outboard surface, together with triangles.

Fasteners: Treenails (27 mm) and nails (10 mm). Countersink holes (50 mm) in every nail head. Patterns vary, mostly because only the sternpost area survived.

Sheathing: Small (4 mm) nails, probably used to secure lead sheathing (lead straps were found on the site).

Recording: 1/10 (FC).



Fig. 60.2 – Photomosaic of the inboard face of the timber (not to scale).



Fig. 60.3 – Groove near the countersink hole of the nail head. Similar grooves have been found on the frames of the Pepper Wreck. Their function or cause are unknown.



Fig. 60.4 – Nail hole plugged.

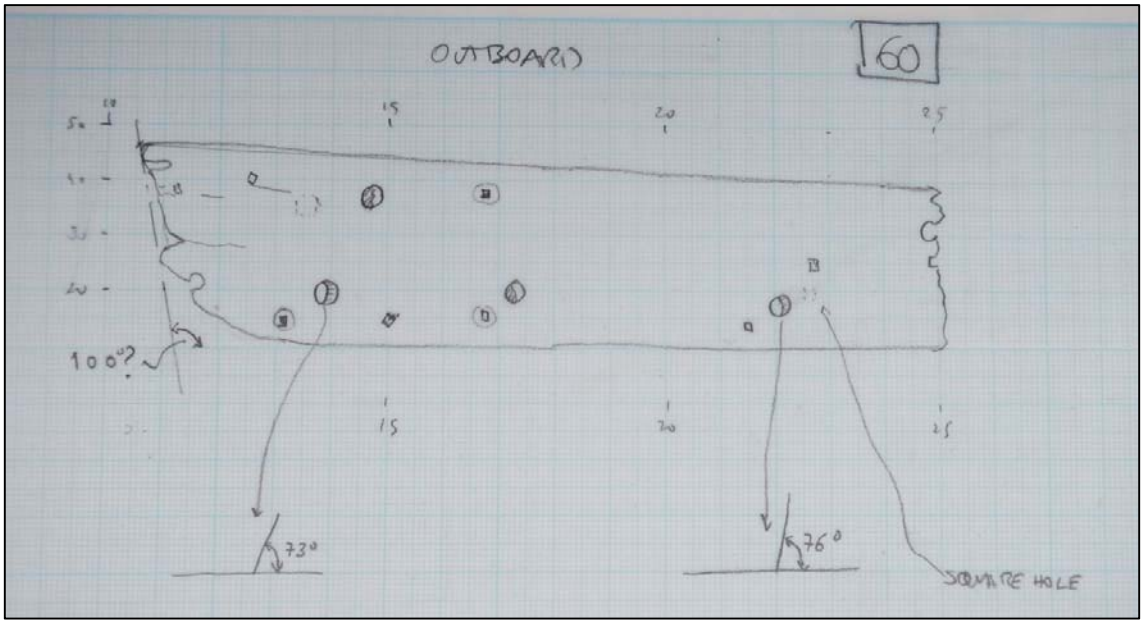


Fig. 60.5 – Square blind hole on the outboard surface of timber 060.



Fig. 60.6 – Another two square blind holes on the outboard surface of timber 060.

1/10 Drawing:



Timber: Plank Starboard	No. 056W



Figure 56.1 – Photomosaic of the timber (not to scale).

Length preserved: 301 cm.

Section: sided 35 cm, molded 6 cm.

Bottom bevel: edges eroded.

Conversion: Tangential.

Tool Marks: Deep (1-2 cm) grooves carved on the outboard surface, together with triangles.

Fasteners: Treenails (27 mm) and nails (10 mm). Countersink holes (50 mm) in every nail head. Patterns vary: 2 treenails and 2/3 nails.

Sheathing: Small (4 mm) nails, probably used to secure lead sheathing (lead straps were found on the site).

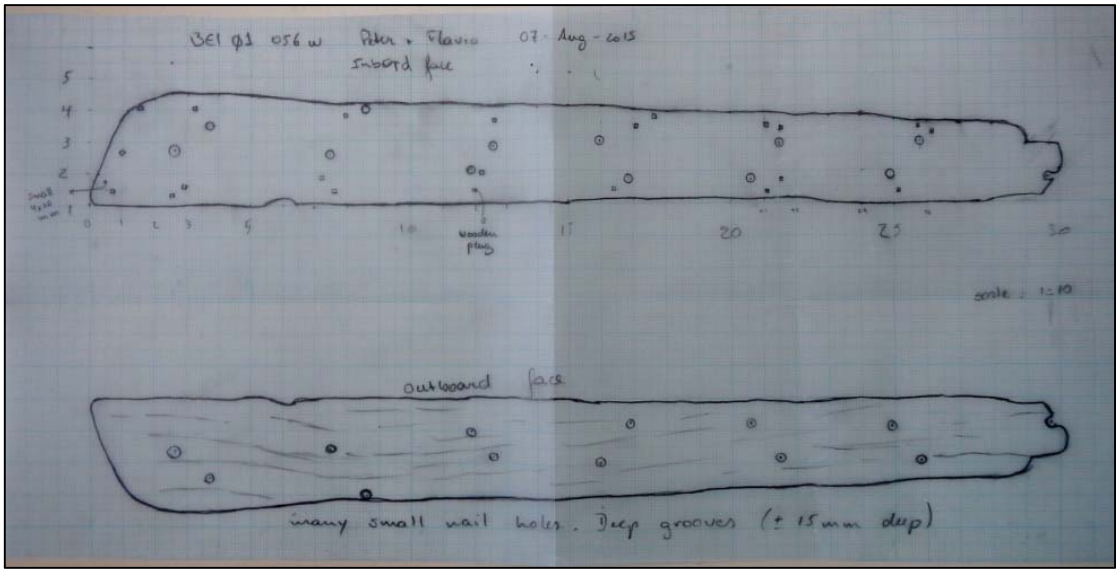
Coatings: White resinous substance inserted in all grooves and triangles (sampled).

Recording: CHAM 002; 1/10 (FC).



Fig. 56.2 – Pattern of the 4 mm square tacks used to secure the lead sheathing.

1/10 Drawing:



CHAM Image:



Timber: Plank Starboard	No. 053W



Figure 53.1 – Photomosaic of the outboard face of the timber (not to scale).

Length preserved: 332 cm.

Section: sided 37 cm, molded 7 cm.

Bottom bevel: Edges eroded.

Tool Marks: Deep (1-2 cm) grooves carved on the outboard surface, together with triangles.

Fasteners: Treenails (27 mm) and nails (10 mm). Countersink holes (50 mm) in every nail head. Patterns vary: 2 treenails and 2/3 nails. The fastening pattern in the first five frames is 2 treenails / 3 nails. As the sided dimension tapers towards the bow, the sixth frame is fastened with 1 treenail / 2 nails.

Sheathing: Small (4 mm) nails, probably used to secure lead sheathing (lead straps were found on the site).

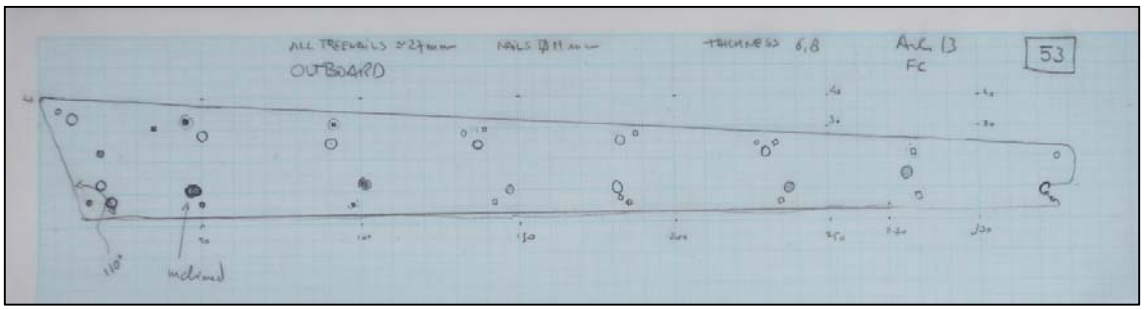
Coatings: White resinous substance inserted in all grooves and triangles (sampled).

Recording: CHAM 004; 1/10 (FC).

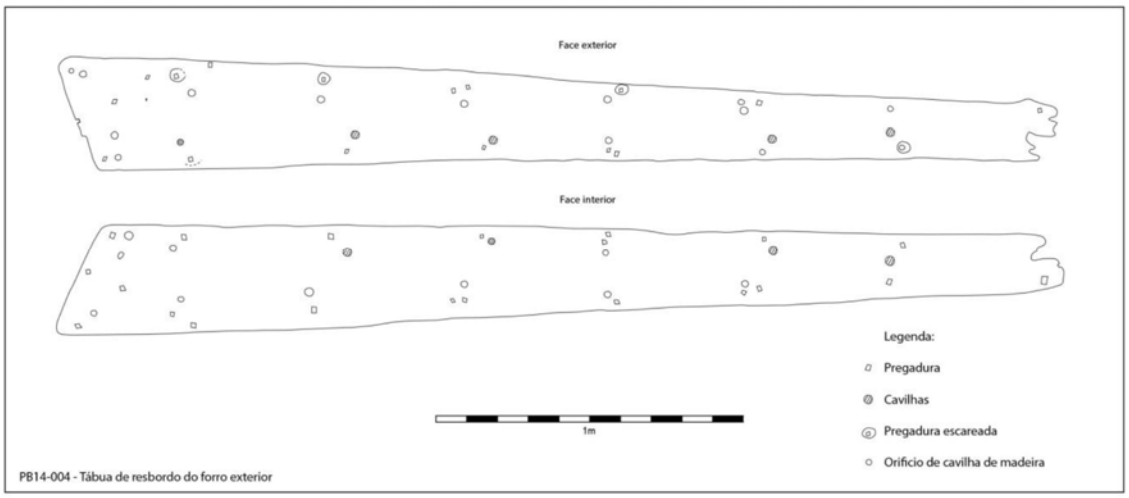


Fig. 53.2 – Photomosaic of the inboard face of the timber (not to scale).

1/10 Drawing:



CHAM Images:



Timber: Plank	No. 050W



Figure 50.1 – Photomosaic of the timber (not to scale).

Length preserved: 213 cm.

Section: sided 9 cm, molded 7 cm.

Bottom bevel: Edges eroded.

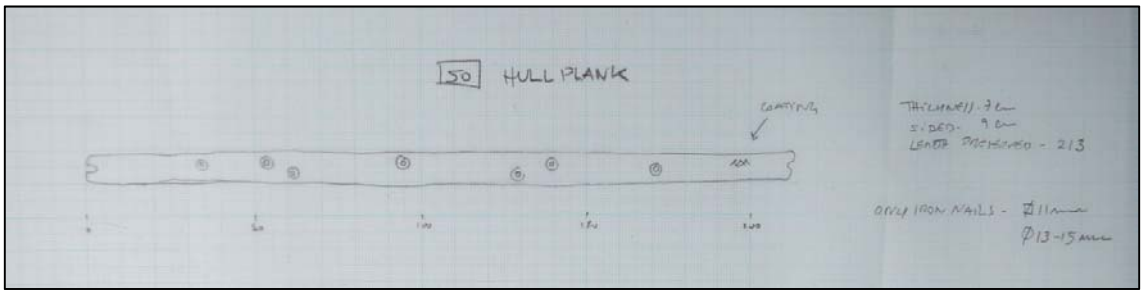
Conversion: Tangential.

Tool Marks: No grooves carved on the outboard surface, nor triangles.

Fasteners: Only nails (10 mm). Countersink holes (50 mm) in every nail head. Patterns vary: one or two nails per frame. Again, the nail holes seem bigger than the nail sections.

Recording: 1/10 (FC).

1/10 Drawing:



Timber: Plank fragment	No. 011W



Figure 11.1 – Photomosaic of the timber (not to scale).

Length preserved: 106 cm.

Section: sided 7.5 cm, molded 5 cm.

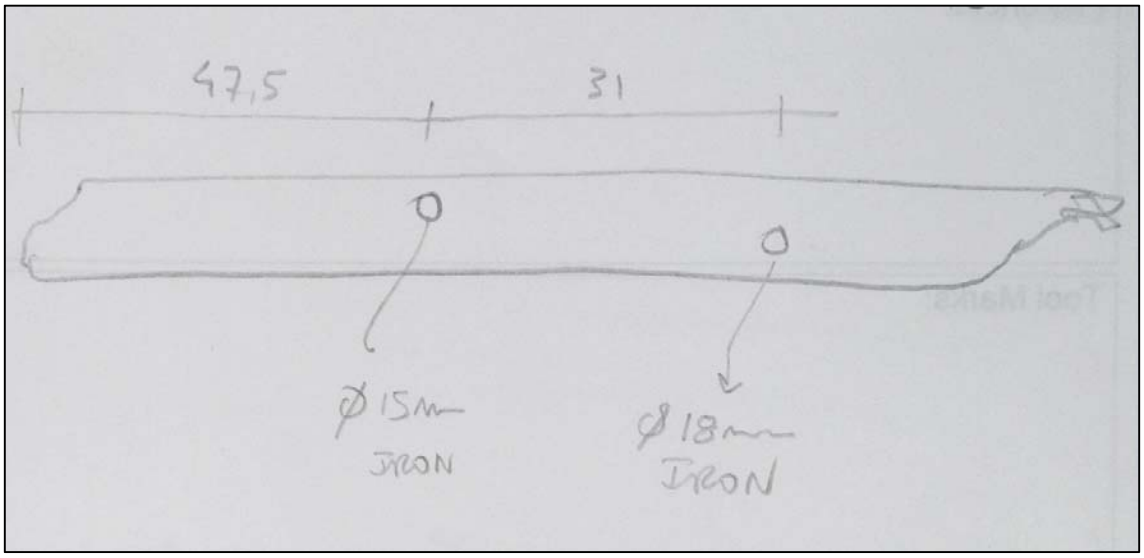
Bottom bevel: Edges eroded.

Tool Marks: No grooves carved on the outboard surface, nor triangles.

Fasteners: Only nails (10 mm). Countersink holes (50 mm) in every nail head. Pattern: one nail per frame. Again, the nail holes seem bigger than the nail sections.

Recording: Just pictures and sketch.

Sketch:



Timber: Plank fragment No. 052W



Figure 52.1 – Photomosaic of the inboard face of the timber (not to scale).

Length preserved: 333 cm.

Section: sided 24 cm, molded 6 cm.

Bottom bevel: Edges eroded.

Tool Marks: Too eroded. Vestigial grooves carved on the outboard surface, together with triangles.

Fasteners: Only nails (10 mm). Countersink holes (50 mm) in every nail head. Pattern seems to be 2 iron nails per frame.

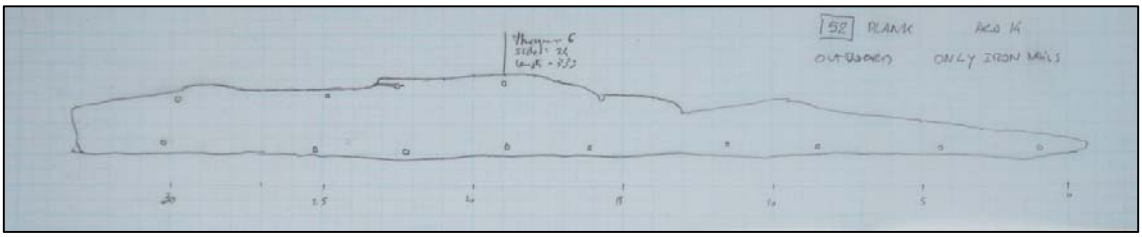
Sheathing: Small (4 mm) nails, probably used to secure lead sheathing (lead straps were found on the site).

Recording: 1/10 (FC).



Figure 52.1 – Photomosaic of the timber (not to scale).

1/10 Drawing:



Timber: Plank fragment No. 004W



Figure 40.1 – Photomosaic of the timber (not to scale).

Length preserved: 84 cm

Section: sided 44 cm, molded 6.5 cm (eroded).

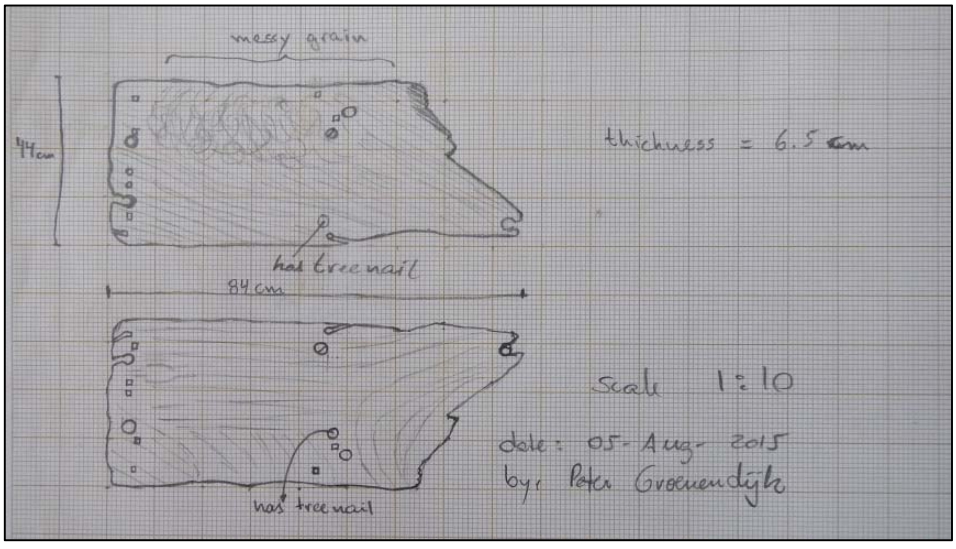
Shape: Hood, parallel edges.

Tool Marks: Deep (1/2 cm) grooves with traces of a white coating. Both surfaces eroded.

Fasteners: Treenails (25 mm) and iron nails (9-10 mm). No pattern discernable. Sometimes it seems that the holes are larger than the iron nails.

Recording: 1/10 Peter.

1/10 Drawing:



Timber: Plank fragment	No. 061W



Figure 61.1 – Photomosaic of the outboard face of the timber (not to scale).

Length preserved: 129 cm

Section: sided 41 cm, molded 6 cm (eroded).

Tool Marks: Deep (1/2 cm) grooves with traces of a white coating. Both surfaces eroded.

Fasteners: Treenails (27 mm) and iron nails (11 mm). No pattern discernable. Sometimes it seems that the holes are larger than the iron nails.

Samples: This timber was sampled for dendrochronology.

Recording: 1/10 FC.



Figure 61.2 – Photomosaic of the inboard face of the timber (not to scale).

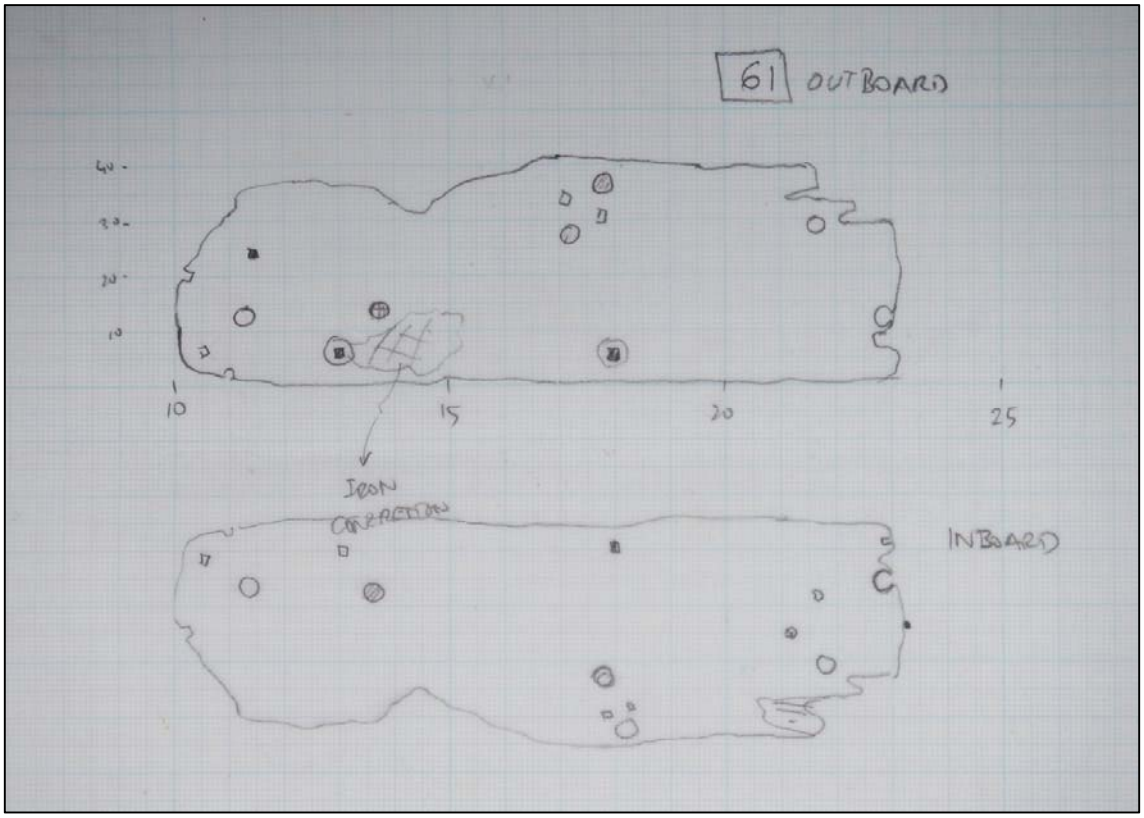


Figure 61.3 – Photomosaic of the outboard face of the timber (not to scale), showing the sample removed for dendrochronological analysis.



Fig. 061.4 – Grooves and triangles carved on the planks outboard face.

1/10 Drawing:



Planking Fragments

Plank fragment 002

Plank fragment 058

Plank fragment 005

Plank fragment 006

Plank fragment 007

Plank fragment 008

Plank fragment 009

Plank fragment 010

Plank fragment 012

Plank fragment 013

Plank fragment 015

Plank fragment 016

Plank fragment 017

Plank fragment 018

Plank fragment 019

Plank fragment 020

Plank fragment 021

Plank fragment 022

Plank fragment 023

Plank fragment 024

Plank fragment 025

Plank fragment 062

Plank fragment 064

Plank fragment 066

Plank fragment 029

Plank fragment 031

Plank fragment 033

Timber: Plank fragment No. 002W



Figure 02.1 – Photomosaic of the timber (not to scale).

Length preserved: 81 cm.

Section: sided 26 cm, molded 5 cm (eroded).

Shape: Only one edge preserved.

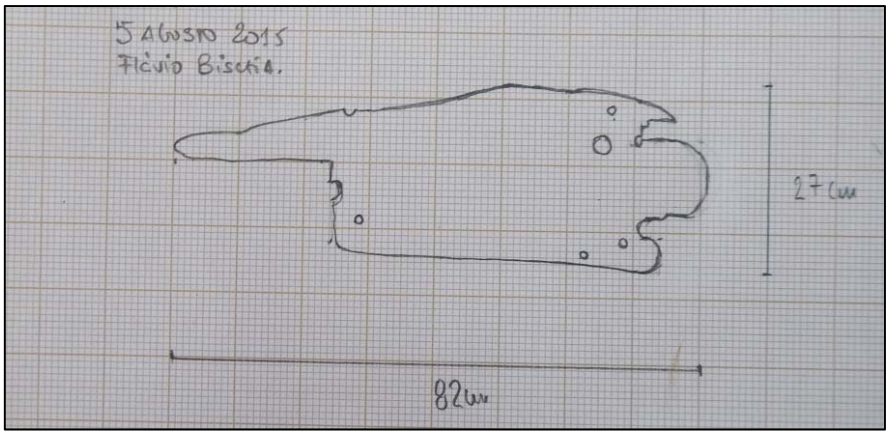
Conversion: Parallel lines, looks like a radial plank.

Tool Marks: Deep (1/2 cm) grooves with traces of a white coating. Both surfaces eroded.

Fasteners: Treenails (27 mm) and iron nails (9-11 mm). No pattern discernable. Sometimes it seems that the holes are larger than the iron nails.

Recording: 1/10 Flavio

1/10 Drawing:



Timber: Plank fragment	No. 058 W



Figure 58.1 – Photomosaic of the timber (not to scale).

Length preserved: 123 cm.

Section: sided 35 cm, molded 6 cm.

Tool Marks: All surfaces eroded. Deep (1/2 cm) grooves with traces of a white coating.

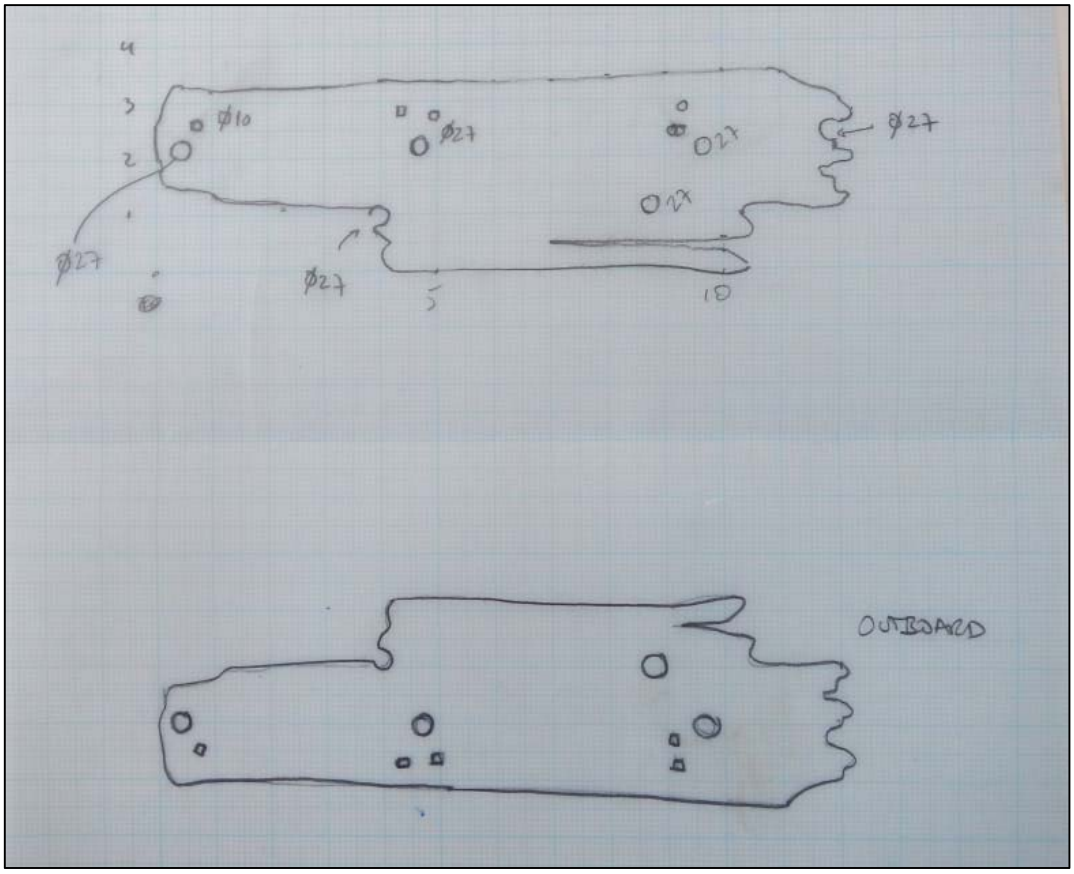
Fasteners: Planks fastened with treenails (27 mm and 22 mm) and iron nails (10 mm).

Recording: 1/10 (FC).



Figure 58.1 – Photomosaic of the timber with the caulking tacks marked (not to scale).

1/10 Drawing:



Timber: Plank fragment	No. 005W



Figure 05.1 – Photomosaic of the timber.

Length preserved: 117 cm.

Section: sided 14 cm, molded 7 cm.

Shape: No edges.

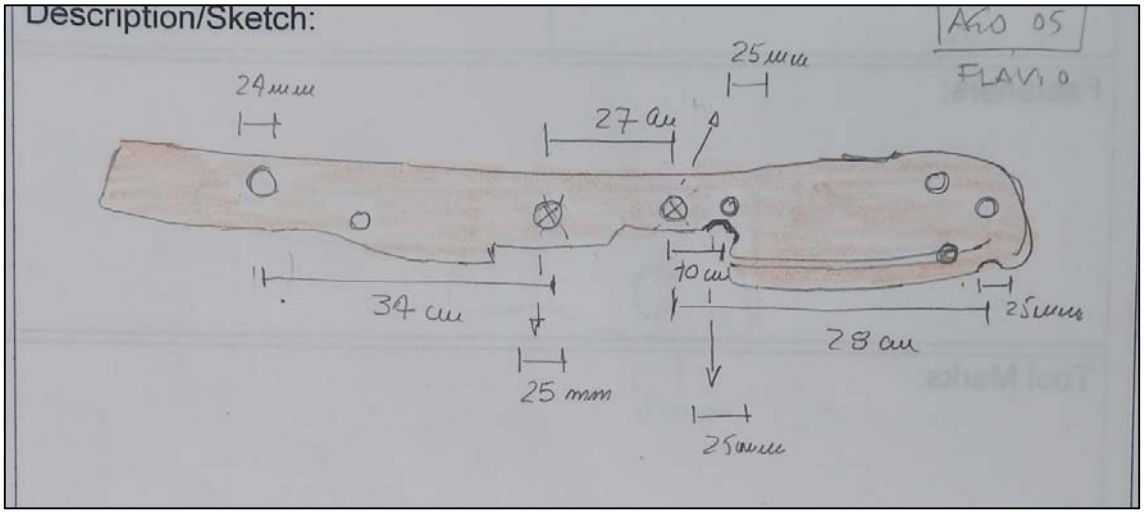
Conversion: Grain curved.

Tool Marks: Deep (1-2 cm) grooves with traces of a white coating.

Fasteners: Treenails (27 mm) and iron nails (11 mm). No pattern discernable. Sometimes it seems that the holes are larger than the iron nails.

Recording: Sketched

Sketch:



Timber: Plank fragment	No. 006W



Figure 06.1 – Photomosaic of the timber.

Length preserved: 40 cm.

Section: sided 14 cm, molded 7 cm.

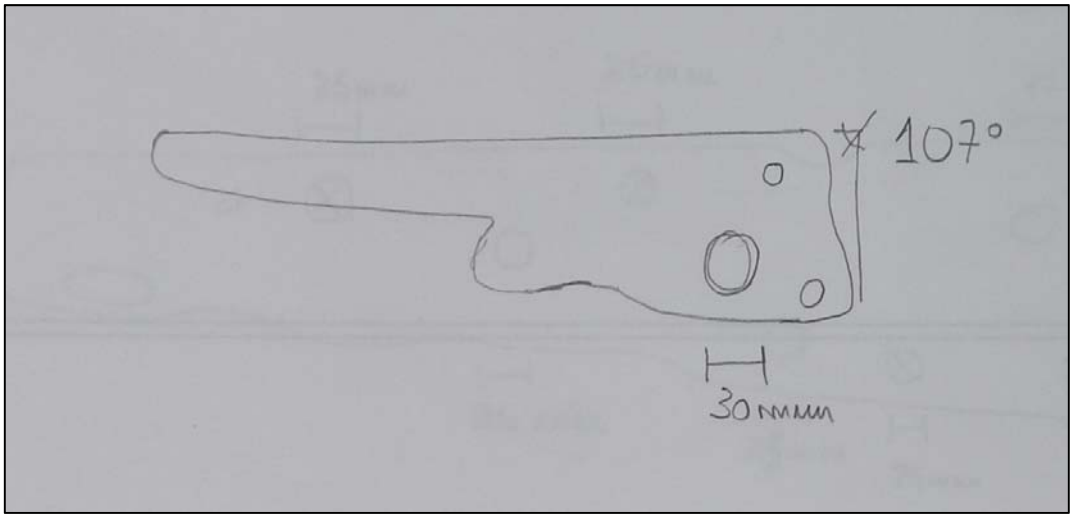
Shape: No edges.

Conversion: Grain curved.

Fasteners: Treenails (25-27 mm) and iron nails (10-11 mm).

Recording: Sketched

Sketch:



Timber: Plank fragment No. 007W



Figure 07.1 – Photomosaic of the timber.

Length preserved: 137 cm.

Section: sided 23 cm, molded 3.5 cm.

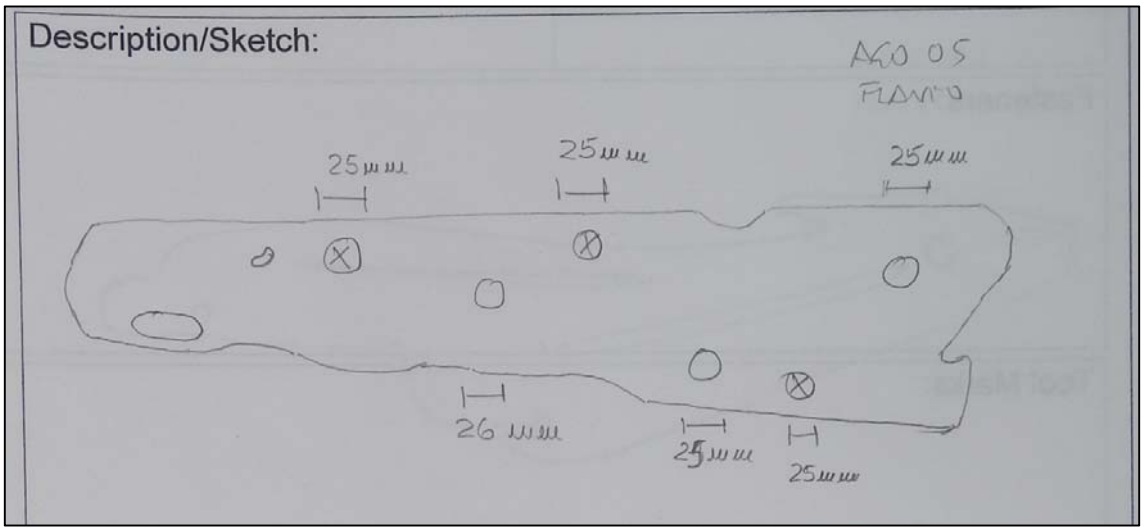
Shape: No edges.

Tool Marks: Deep (1-2 cm) grooves with traces of a white coating.

Fasteners: Treenails (25-27 mm) and iron nails (9-11 mm). No pattern discernable. Sometimes it seems that the holes are larger than the iron nails.

Recording: Sketched

Sketch:



Timber: Plank fragment	No. 008W



Figure 08.1 – Photomosaic of the timber.

Length preserved: 92 cm.

Section: sided 17 cm, molded 5 cm.

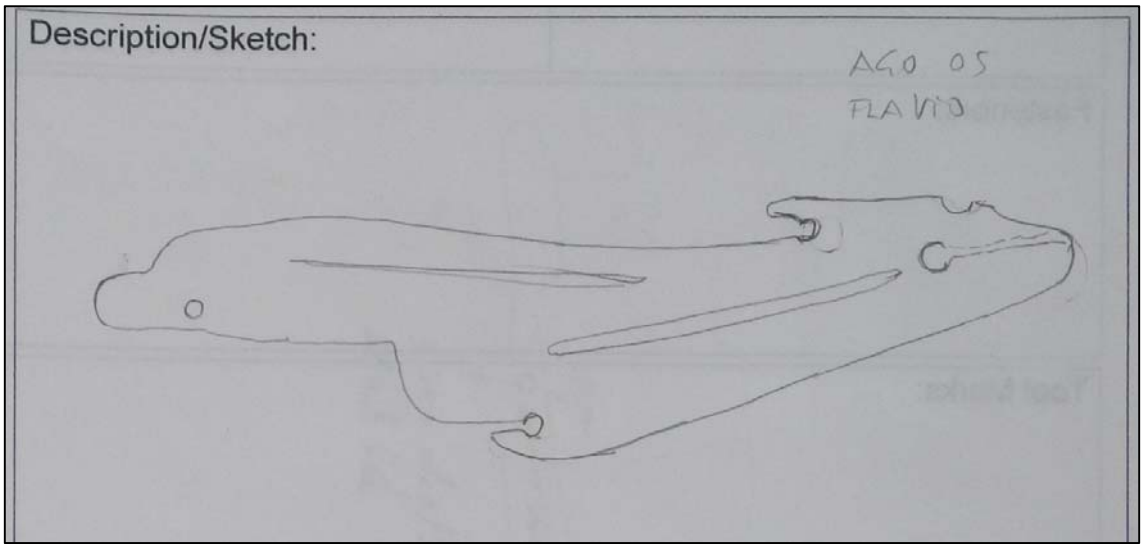
Shape: No edges.

Tool Marks: Deep (1-2 cm) grooves on outboard face.

Fasteners: Treenails (25-27 mm) and iron nails (9-11 mm). No pattern discernable.

Recording: Sketched

Sketch:



Timber: Plank fragment	No. 009W



Figure 09.1 – Photomosaic of the timber.

Length preserved: 106 cm.

Section: sided 10 cm, molded 5 cm.

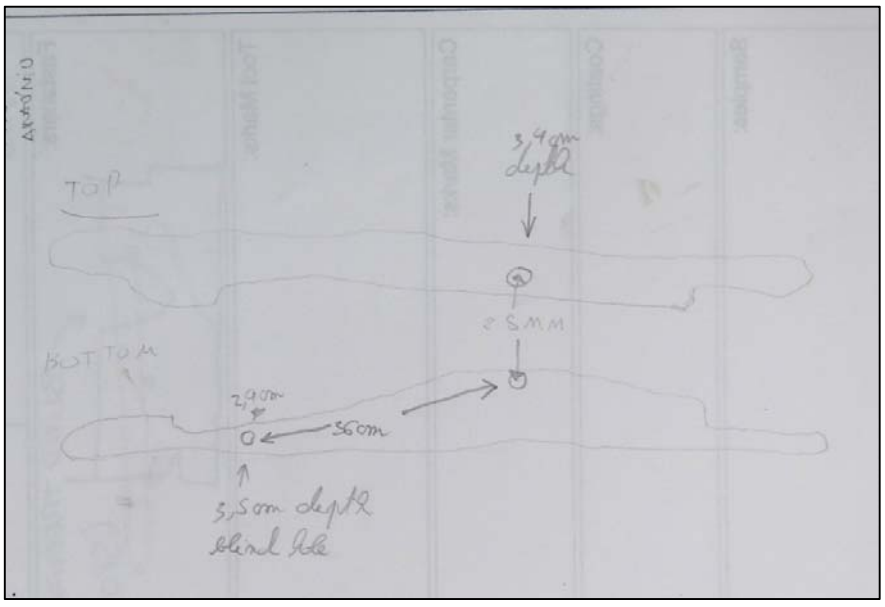
Shape: No edges.

Tool Marks: Deep (1-2 cm) grooves with traces of a white coating. Blind treenail hole in the shape of a spoon auger.

Fasteners: Treenails (25-27 mm) and iron nails (9-11 mm). No pattern discernable. Sometimes it seems that the holes are larger than the iron nails.

Recording: Sketched

Sketch:



Timber: Plank fragment	No. 010W



Figure 10.1 – Photomosaic of the timber.

Length preserved: 66 cm.

Section: sided 16 cm, molded 3 cm.

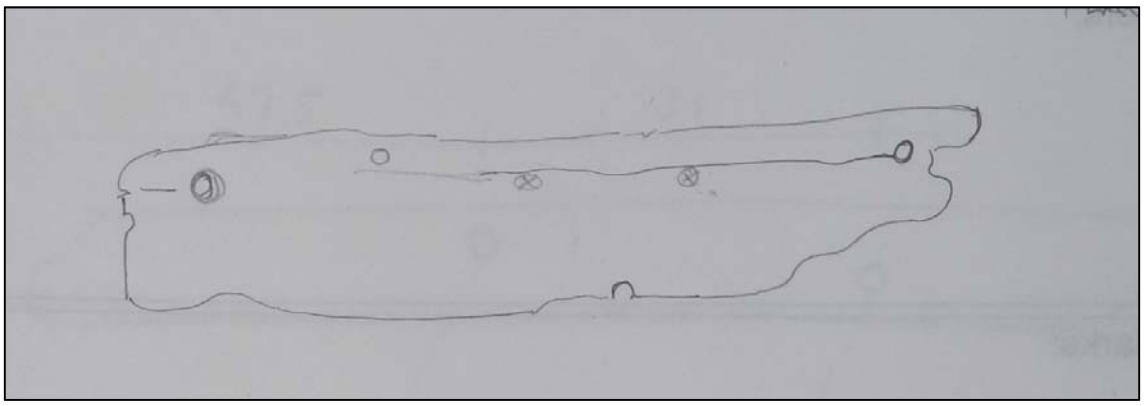
Shape: No edges.

Tool Marks: Deep (1-2 cm) grooves with traces of a white coating.

Fasteners: Treenails (25-27 mm) and iron nails (9-11 mm). No pattern discernable. Sometimes it seems that the holes are larger than the iron nails.

Recording: Sketched

Sketch:



Timber: Plank fragment	No. 12W



Figure 12.1 – Photomosaic of the timber.

Length preserved: 26 cm.

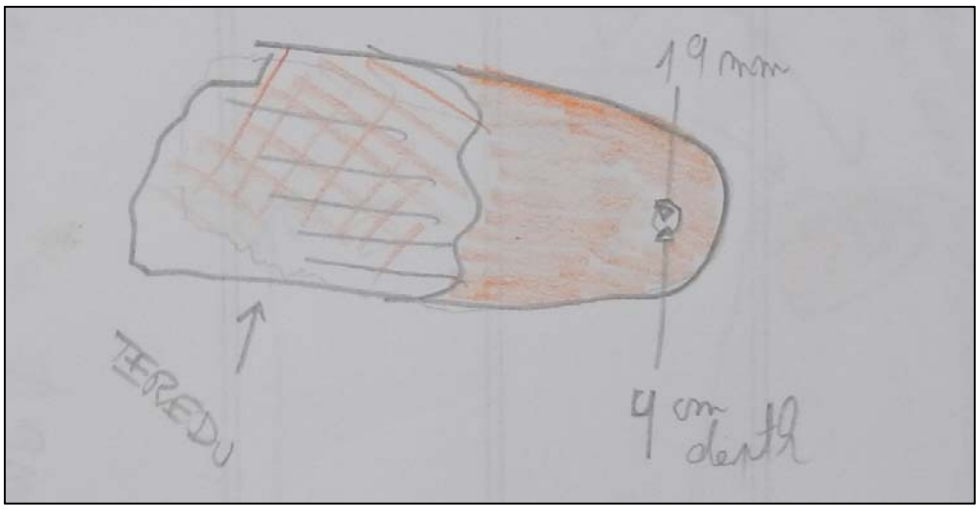
Section: sided 13 cm, molded 5 cm.

Shape: No edges.

Fasteners: Iron nail (19 mm). No pattern discernable.

Recording: Sketched

Sketch:



Timber: Plank fragment No. 013W



Figure 13.1 – Photomosaic of the timber.

Length preserved: 38 cm.

Section: sided 12 cm, molded 6.5 cm.

Shape: Looks like a repair.

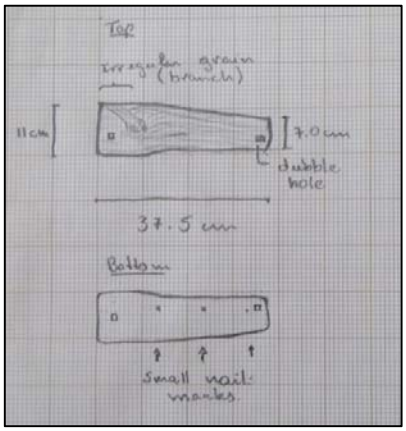
Tool Marks: Countersink holes for nail heads.

Fasteners: Two iron nails (9-11 mm). No pattern discernable. Sometimes it seems that the holes are larger than the iron nails.

Recording: Sketched.

Samples: Sampled for dendrochronology.

1/10 Drawing:



Timber: Plank fragment	No. 015W



Figure 15.1 – Photomosaic of the timber.

Length preserved: 22 cm.

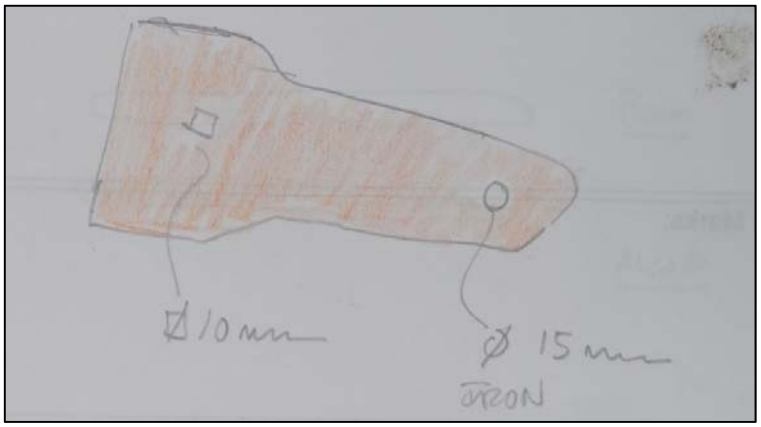
Section: sided 9 cm, molded 2.5 cm.

Shape: No edges.

Fasteners: Iron nails (9-11 mm). No pattern discernable. It seems that the holes are larger than the iron nails.

Recording: Sketched

Sketch:



Timber: Plank fragment	No. 016W

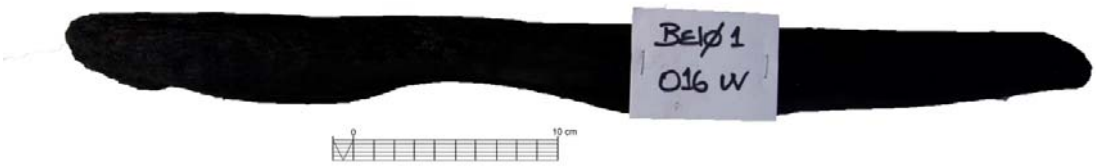


Figure 16.1 – Photomosaic of the timber.

Length preserved: 50 cm.

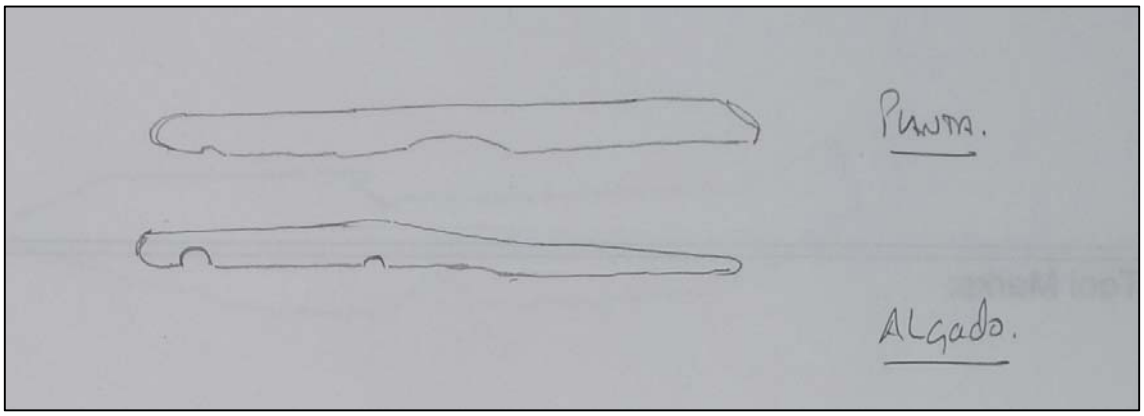
Section: sided 5 cm, molded 4.5 cm.

Shape: No edges.

Fasteners: Treenails (25-27 mm) and iron nails (9-11 mm). No pattern discernable.

Recording: Sketched

Sketch:



Timber: Plank fragment	No. 017W



Figure 17.1 – Photomosaic of the timber.

Length preserved: 71 cm.

Section: sided 9.5 cm, molded 3 cm.

Conversion: Curved grain.

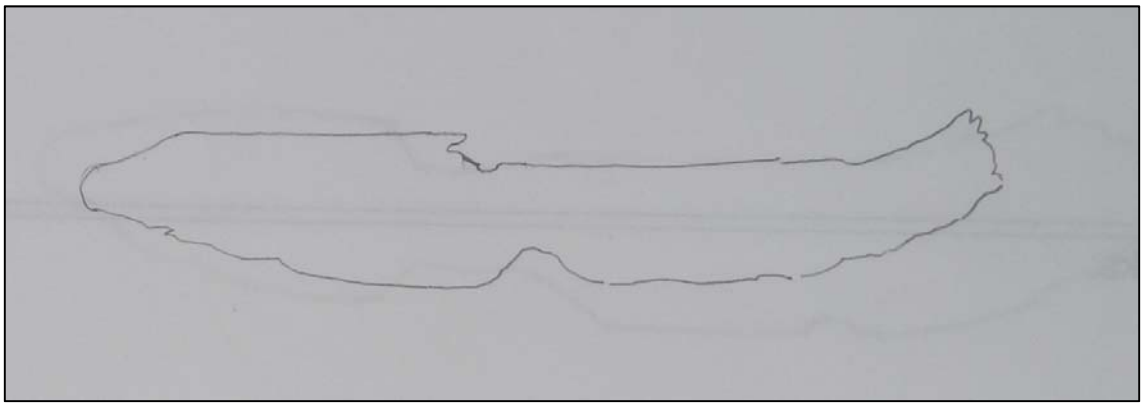
Shape: No edges.

Tool Marks: Deep (1-2 cm) grooves with traces of a white coating.

Fasteners: Treenails (25-27 mm).

Recording: Sketched

Sketch:



Timber: Plank fragment No. 018W

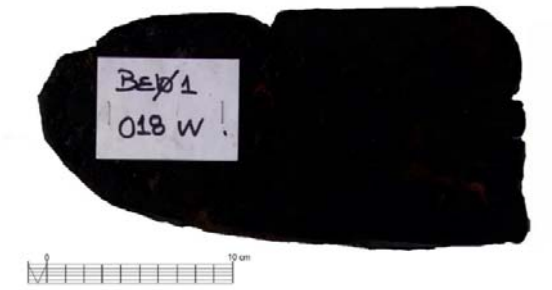


Figure 18.1 – Photomosaic of the timber.

Length preserved: 24 cm.

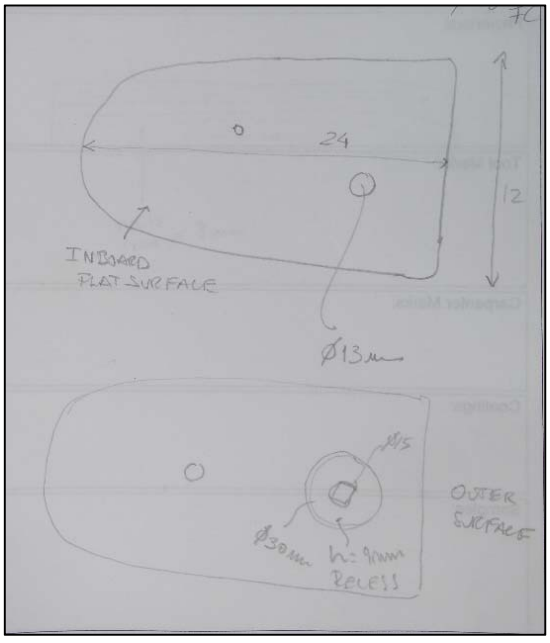
Section: sided 12 cm, molded 3.5 cm.

Shape: One edge preserved.

Fasteners: Iron nails (9-11 mm). No pattern discernable. Sometimes it seems that the holes are larger than the iron nails.

Recording: Sketched

Sketch:



Timber: Plank fragment No. 019W



Figure 19.1 – Photomosaic of the timber.

Wood: Soft wood.

Length preserved: 38 cm.

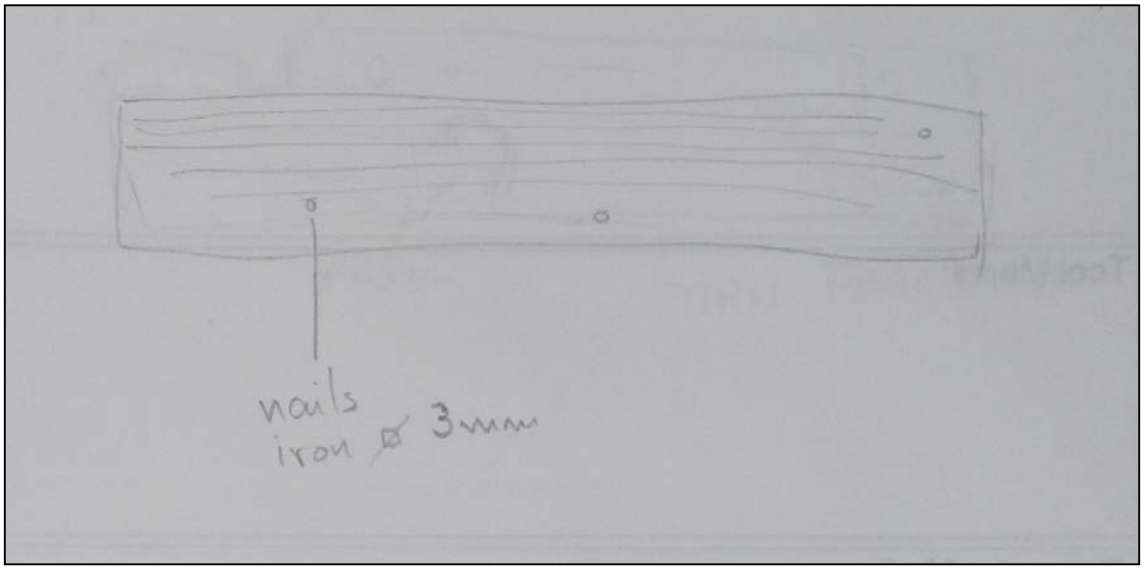
Section: sided 6.5 cm, molded 2 cm.

Shape: No edges.

Fasteners: Iron nails (3 mm). No pattern discernable.

Recording: Sketched

Sketch:



Timber: Plank fragment No. 020W



Figure 20.1 – Photomosaic of the timber (not to scale).

Length preserved: 41 cm.

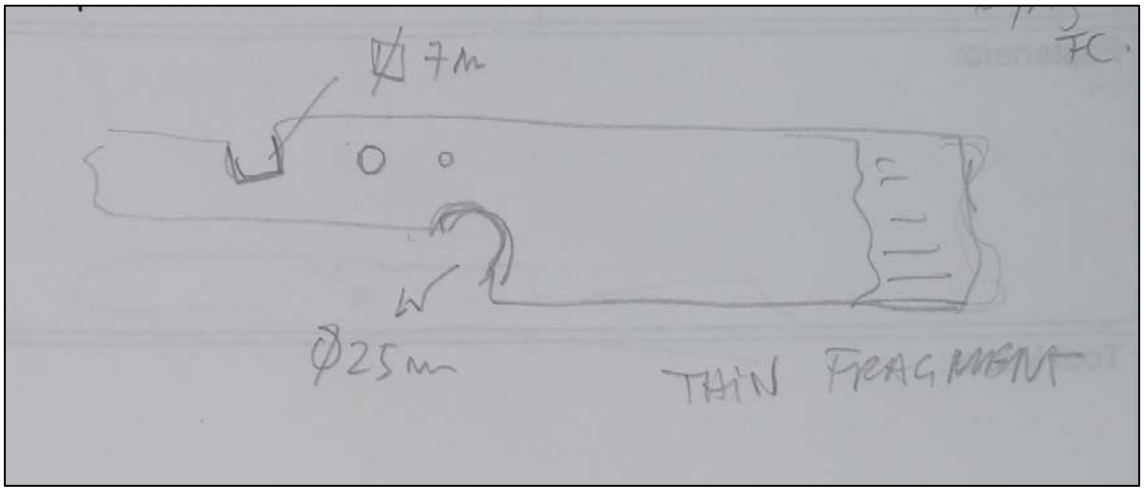
Section: sided 5 cm, molded 2.5 cm.

Shape: No edges.

Fasteners: Treenails (25 mm) and iron nails (9-11 mm). No pattern discernable. Sometimes it seems that the holes are larger than the iron nails.

Recording: Sketched

Sketch:



Timber: Plank fragment	No. 021W



Figure 21.1 – Photomosaic of the timber (not to scale).

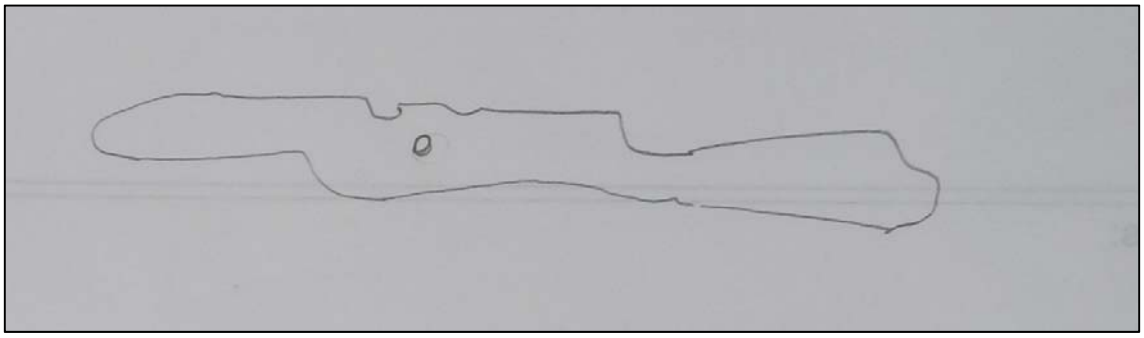
Length preserved: 52 cm.

Section: sided 7.5 cm, molded 3 cm.

Shape: No edges.

Recording: Sketched

Sketch:



Timber: Plank fragment	No. 022W



Figure 22.1 – Photomosaic of the timber (not to scale).

Length preserved: 19 cm.

Section: not preserved.

Shape: No edges.

Timber: Plank fragment	No. 023W



Figure 23.1 – Photomosaic of the timber (not to scale).

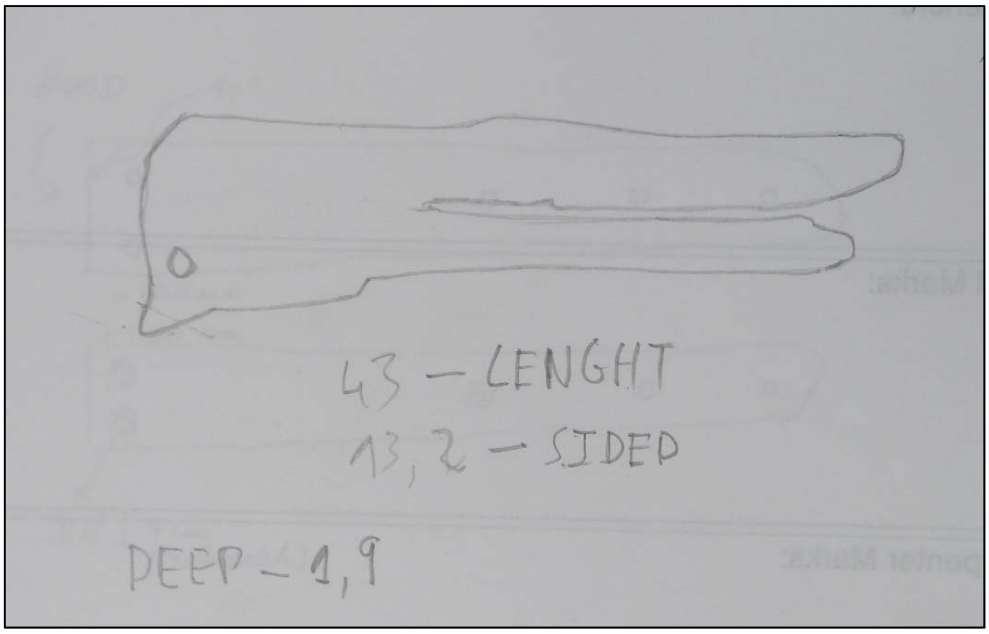
Length preserved: 43 cm.

Section: sided 13 cm, molded 2 cm.

Shape: No edges.

Recording: Sketched

Sketch:



Timber: Plank fragment No. 024W



Figure 24.1 – Photomosaic of the timber (not to scale).

Length preserved: 77 cm.

Section: sided 13 cm, molded 6.5 cm.

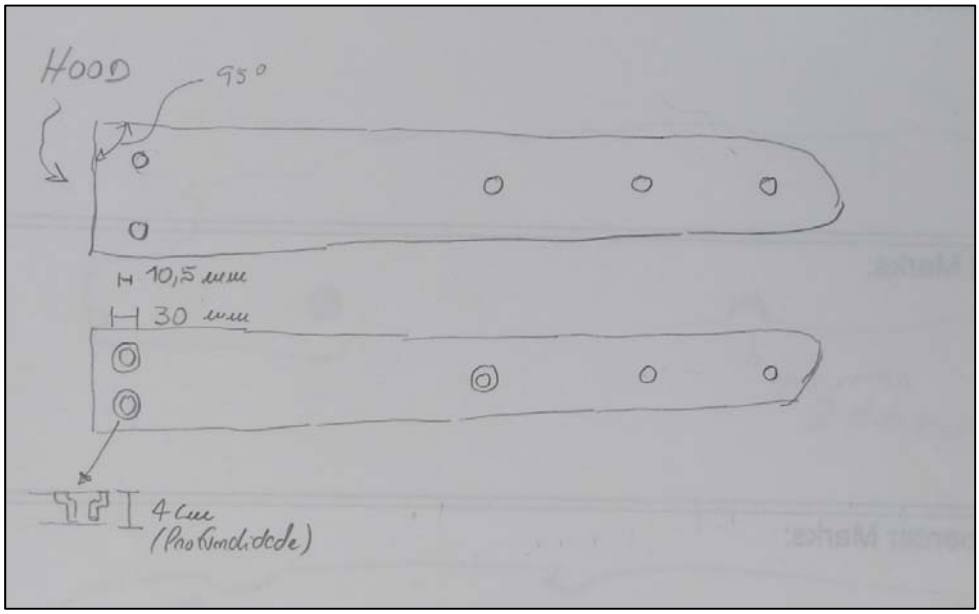
Shape: Hood, angle 95º.

Tool Marks: Deep (1-2 cm) grooves with traces of a white coating.

Fasteners: Iron nails (9-11 mm): two near the hood, one, one, one.

Recording: Sketched.

Sketch:



Timber: Plank fragment	No. 025W



Figure 25.1 – Photomosaic of the timber (not to scale).

Length preserved: 128 cm.

Section: sided 18 cm, molded 5 cm.

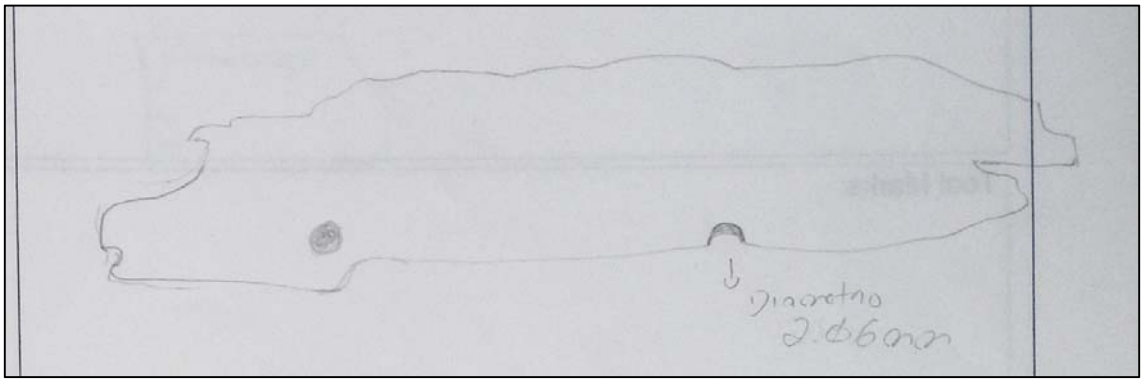
Shape: No edges.

Tool Marks: Deep (1-2 cm) grooves with traces of a white coating.

Fasteners: Treenails (25-27 mm) and iron nails (9-11 mm). No pattern discernable.

Recording: Sketched

Sketch:



Timber: Plank fragment No. 062W



Figure 62.1 – Photomosaic of the timber (not to scale).

Length preserved: 127 cm.

Section: sided 22 cm, molded 4.5 cm.

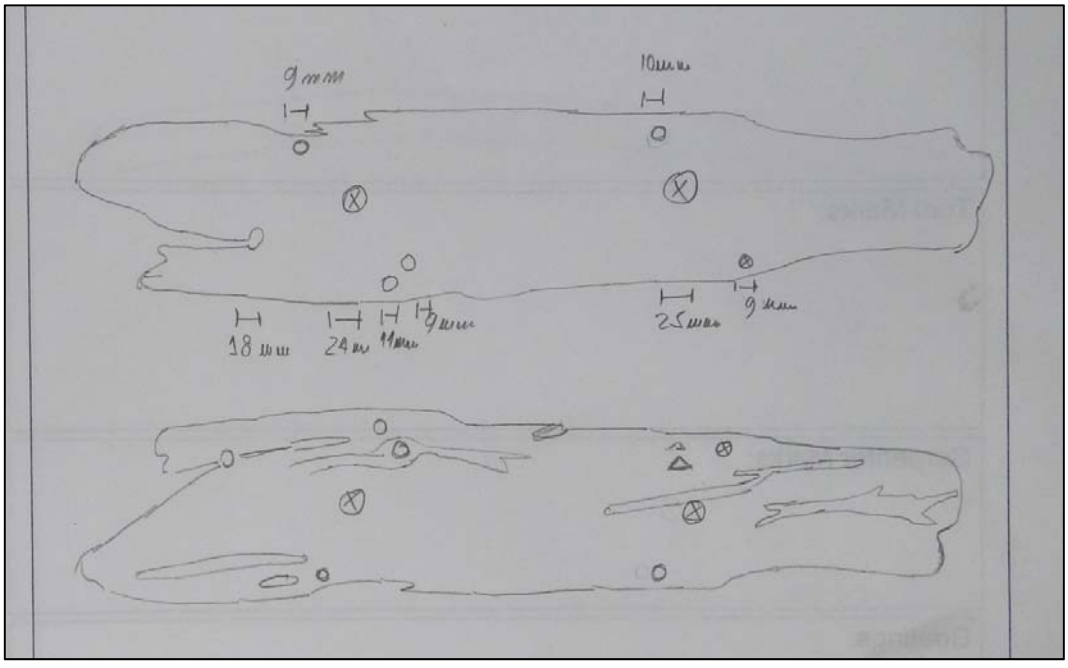
Shape: No edges.

Tool Marks: Deep (1-2 cm) grooves with traces of a white coating.

Fasteners: Treenails (25-27 mm) and iron nails (9-11 mm). No pattern discernable. Sometimes it seems that the holes are larger than the iron nails.

Recording: Sketched

Sketch:



Timber: Plank fragment No. 064W



Figure 64.1 – Photomosaic of the timber (not to scale).

Length preserved: 93 cm.

Section: sided 19 cm, molded 4.5 cm.

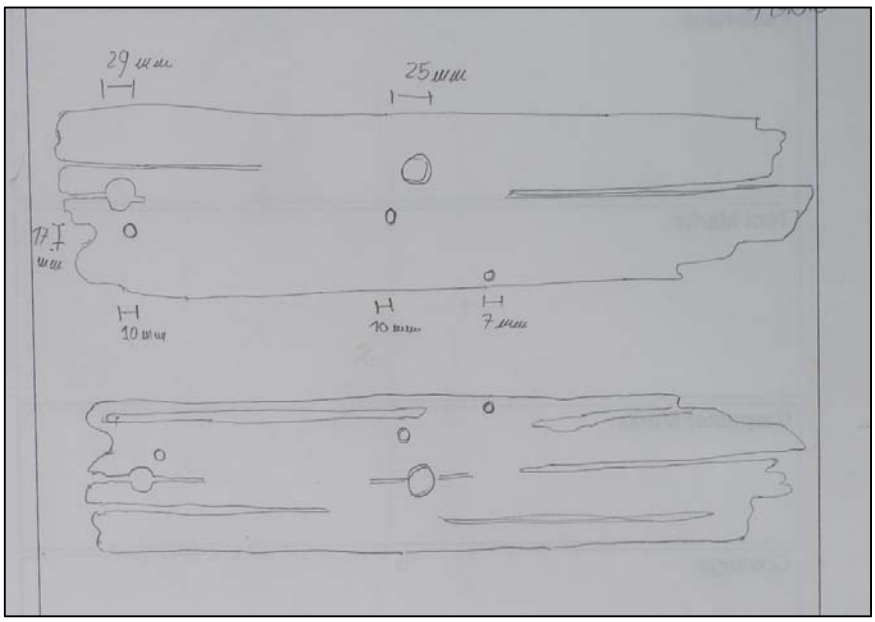
Shape: No edges.

Tool Marks: Deep (1-2 cm) grooves with traces of a white coating.

Fasteners: Treenails (25-27 mm) and iron nails (9-11 mm). No pattern discernable. Sometimes it seems that the holes are larger than the iron nails.

Recording: Sketched

Sketch:



Timber: Plank fragment No. 066W



Figure 66.1 – Photomosaic of the timber (not to scale).

Length preserved: 190 cm.

Section: sided 19 cm, molded 5 cm.

Shape: No edges.

Tool Marks: Deep (1-2 cm) grooves with traces of a white coating.

Fasteners: Treenails (25-27 mm) and iron nails (9-11 mm). No pattern discernable. Sometimes it seems that the holes are larger than the iron nails.

Recording: Sketched

Sketch:



Timber: Plank fragment No. 029W



Figure 29.1 – Photomosaic of the timber (not to scale).

Length preserved: 63 cm.

Section: sided 20 cm, molded 6 cm.

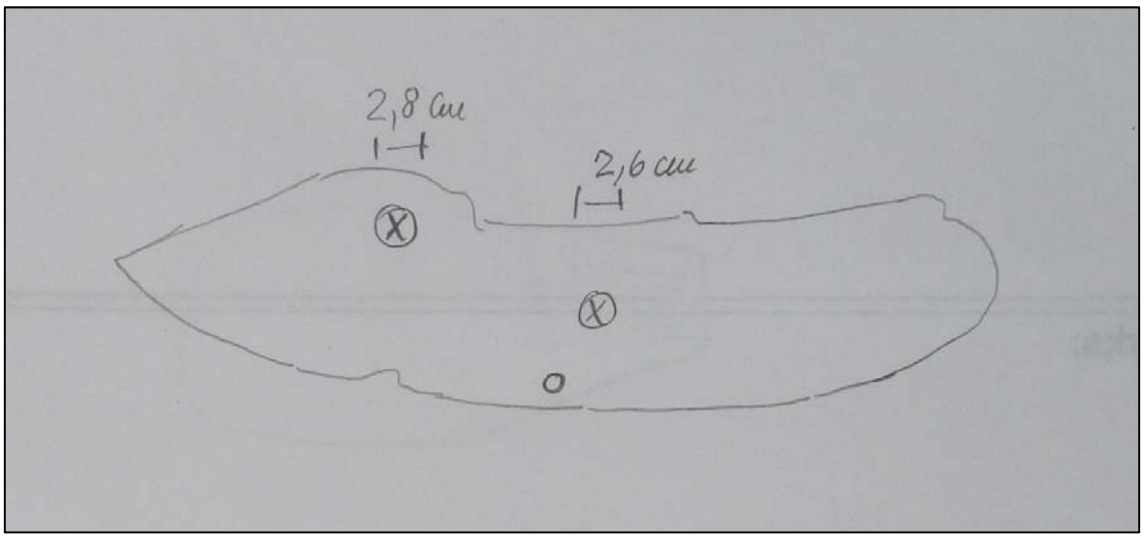
Shape: No edges.

Tool Marks: Deep (1-2 cm) grooves with traces of a white coating.

Fasteners: Treenails (25-27 mm) and iron nails (9-11 mm). No pattern discernable. Sometimes it seems that the holes are larger than the iron nails.

Recording: Sketched

Sketch:



Timber: Plank fragment No. 031W



Figure 31.1 – Photomosaic of the timber (not to scale).

Length preserved: 59 cm.

Section: sided 37 cm, molded 5 cm.

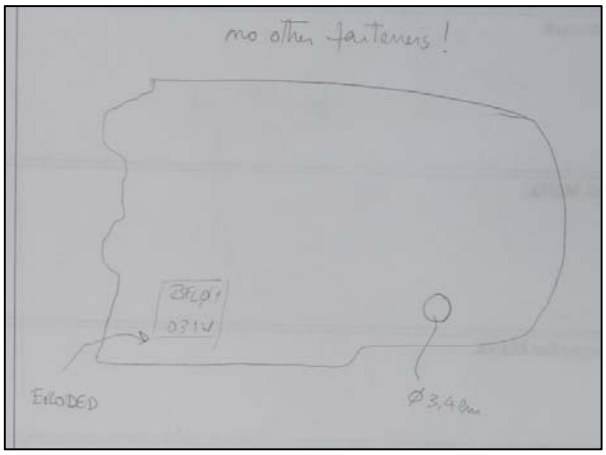
Shape: No edges.

Tool Marks: Deep (1-2 cm) grooves with traces of a white coating.

Fasteners: Treenails (25-27 mm) and iron nails (9-11 mm). No pattern discernable. Sometimes it seems that the holes are larger than the iron nails.

Recording: Sketched

Sketch:



Timber: Plank fragment No. 033W



Figure 33.1 – Photomosaic of the timber (not to scale).

Length preserved: 140 cm.

Section: sided 20 cm, molded 4 cm.

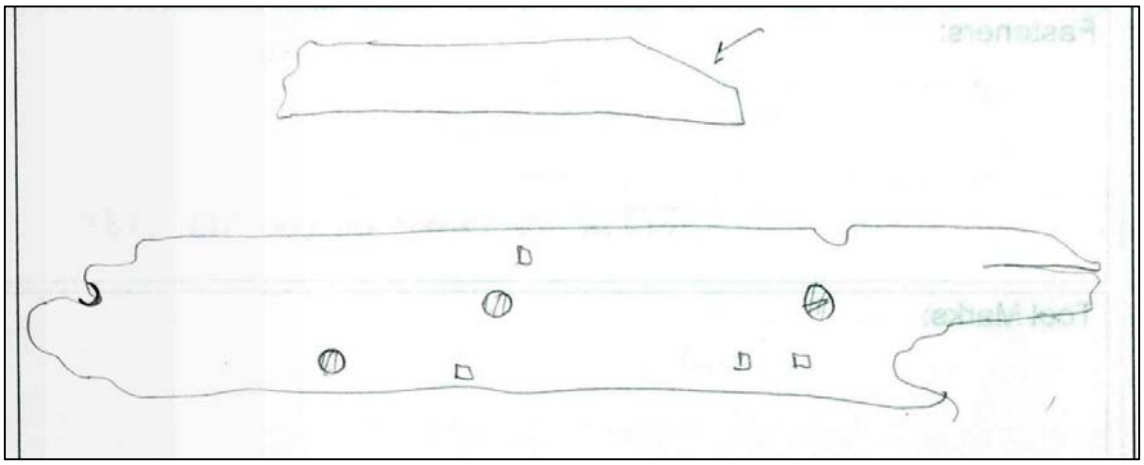
Shape: No edges.

Tool Marks: Deep (1-2 cm) grooves with traces of a white coating.

Fasteners: Treenails (25-27 mm) and iron nails (9-11 mm). No pattern discernable. Sometimes it seems that the holes are larger than the iron nails.

Recording: Sketched

Sketch:



Wood Fragments

Wood fragment 026

Wood fragment 027

Wood fragment 028

Wood fragment 030

Wood fragment 067

Wood fragment 068

Wood fragment 070

Wood fragment 065

Wood fragment 063

Wood fragment 048

Wood fragment 046

Timber: Wood fragment	No. 026W



Figure 26.1 – Photomosaic of the timber (not to scale).

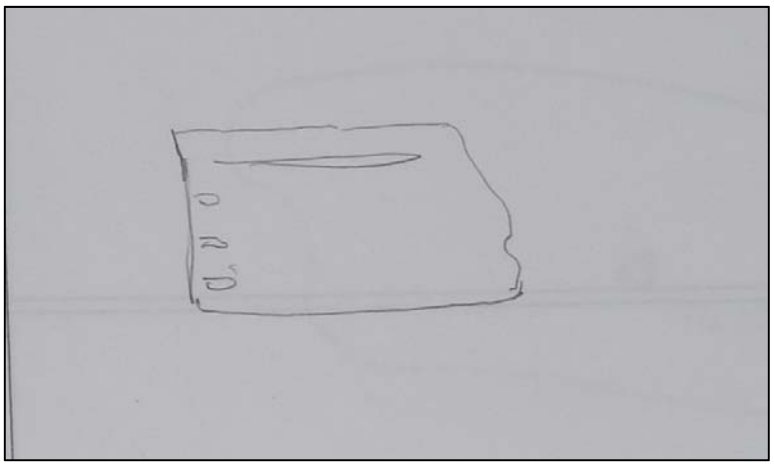
Length preserved: 23 cm.

Section: sided 14 cm, molded 6 cm.

Shape: No edges.

Recording: Sketched

Sketch:



Timber: Wood fragment	No. 027W



Figure 27.1 – Photomosaic of the timber (not to scale).

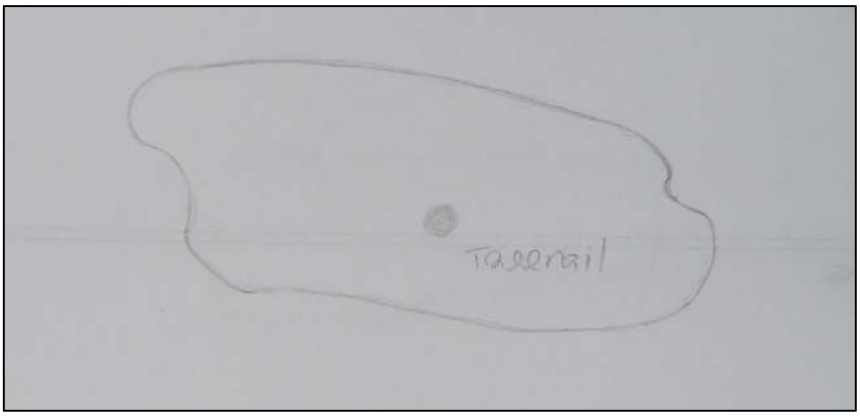
Length preserved: 23 cm.

Section: sided 14 cm, molded 11 cm.

Shape: No edges.

Recording: Sketched

Sketch:



Timber: Wood fragment	No. 028W



Figure 28.1 – Photomosaic of the timber (not to scale).

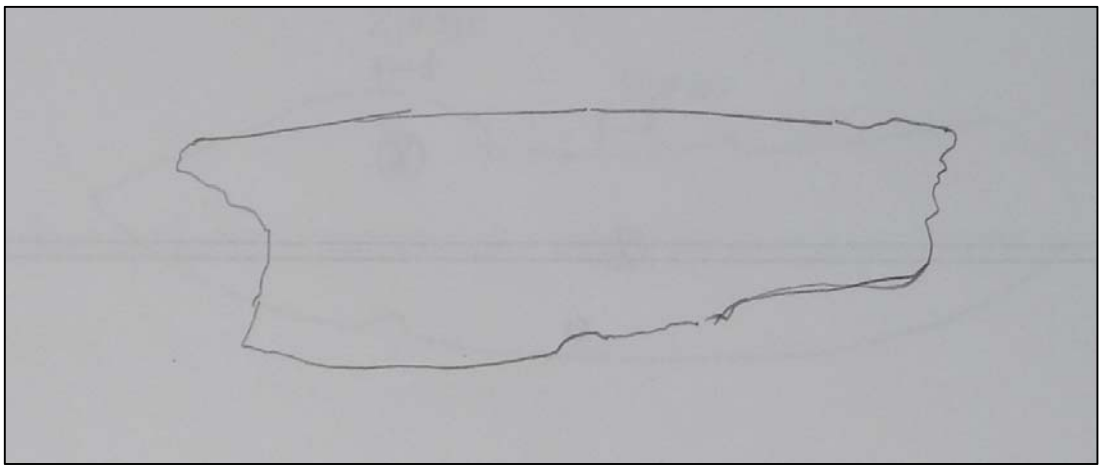
Length preserved: 30 cm.

Section: sided 12 cm, molded 3.5 cm.

Shape: No edges.

Recording: Sketched

Sketch:



Timber: Wood fragment	No. 030W



Figure 30.1 – Photomosaic of the timber (not to scale).

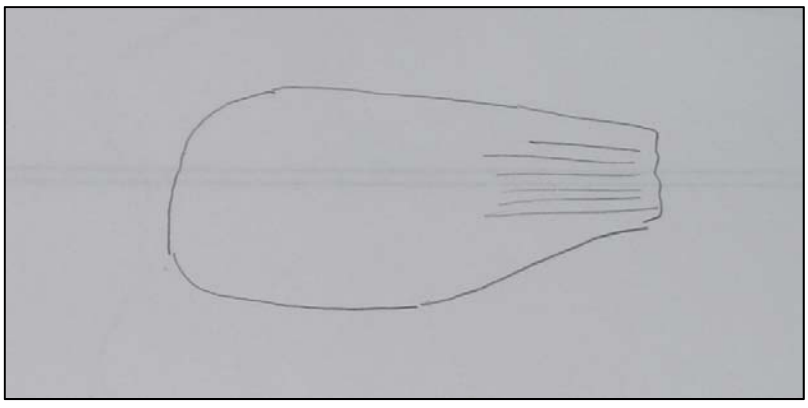
Length preserved: 26 cm.

Section: sided 12 cm, molded 5 cm.

Shape: No edges.

Recording: Sketched

Sketch:



Timber: Wood fragment	No. 067W



Figure 67.1 – Photomosaic of the timber (not to scale).

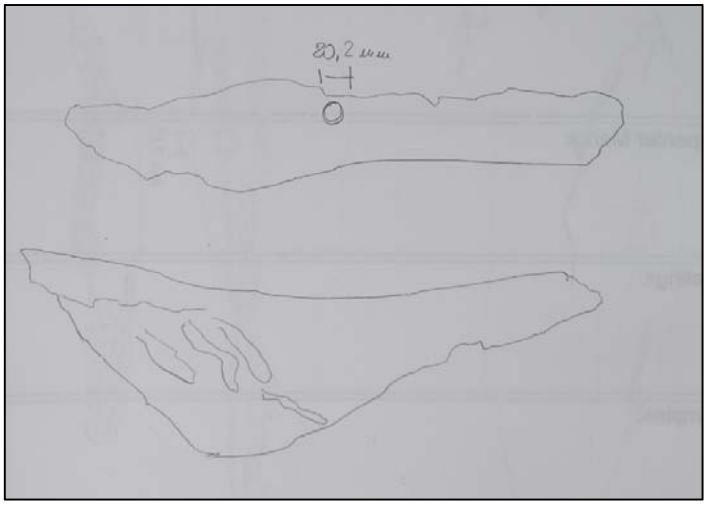
Length preserved: 61 cm.

Section: sided 20 cm, molded 14 cm.

Shape: No edges.

Recording: Sketched

Sketch:



Timber: Wood fragment No. 068W



Figure 68.1 – Photomosaic of the timber (not to scale).

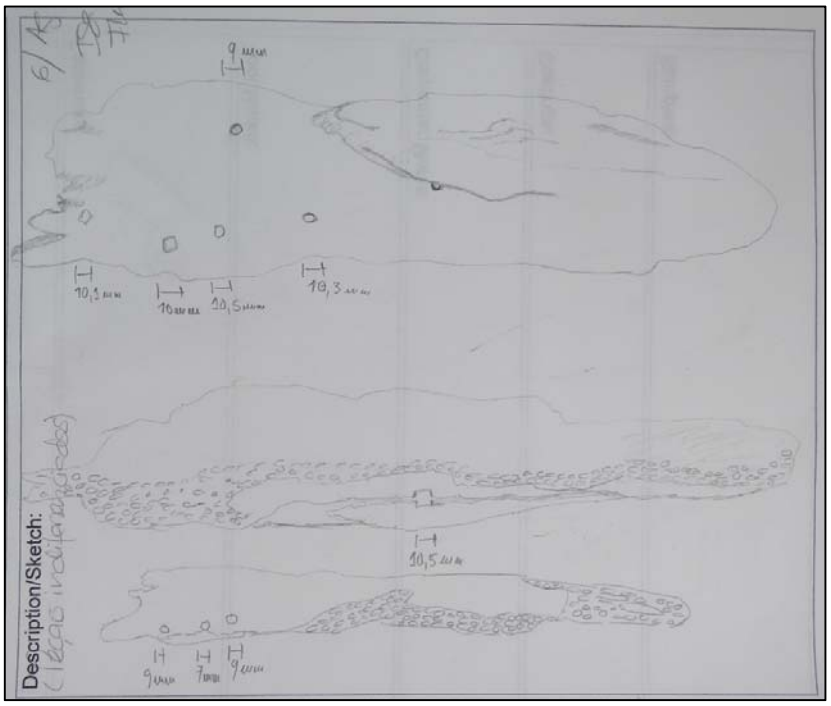
Length preserved: 80 cm.

Section: sided 17 cm, molded 10 cm.

Shape: No edges.

Recording: Sketched

Sketch:



Timber: Wood fragment	No. 070W



Figure 70.1 – Photomosaic of the timber (not to scale).

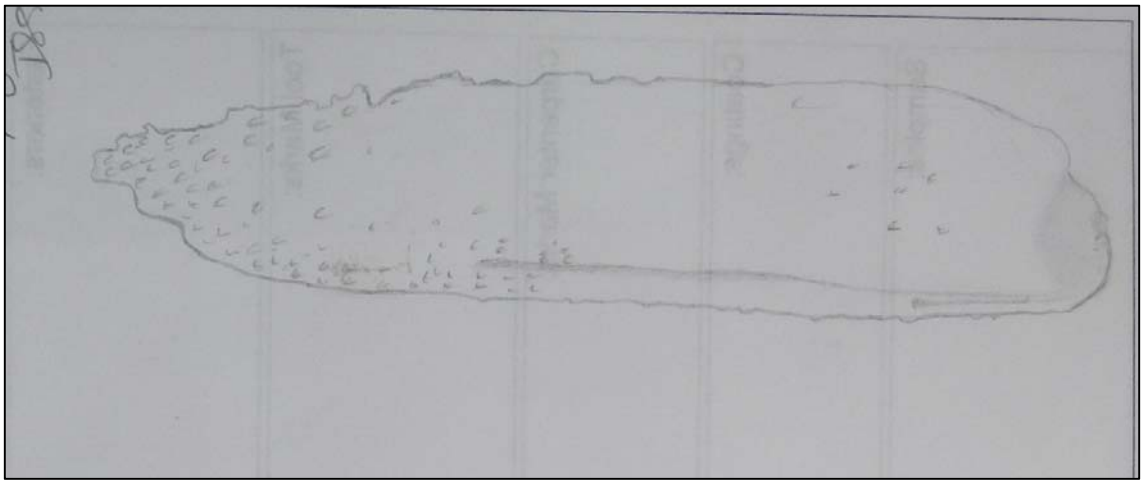
Length preserved: 57 cm.

Section: sided 14 cm, molded 14 cm.

Shape: No edges.

Recording: Sketched

Sketch:



Timber: Wood fragment No. 063W



Figure 63.1 – Photomosaic of the timber (not to scale).

Length preserved: 208 cm.

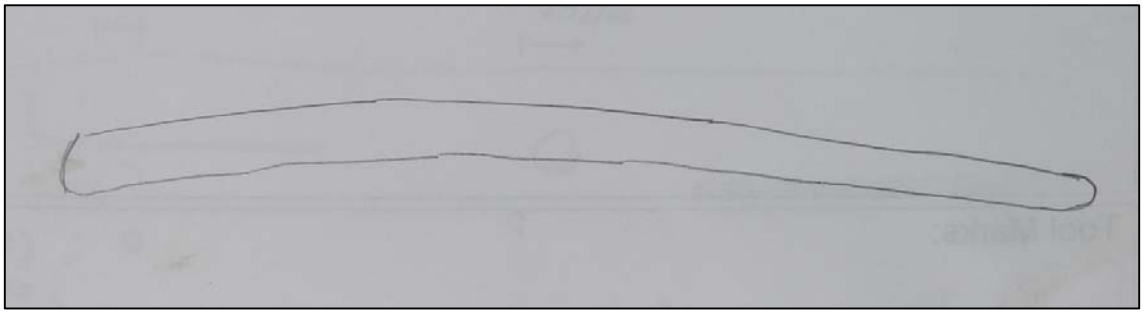
Section: sided 8 cm, molded 7 cm.

Shape: No edges.

Fasteners: None.

Recording: Sketched

Sketch:



Timber: Wood fragment	No. 065W



Figure 65.1 – Photomosaic of the timber (not to scale).

Length preserved: 130 cm.

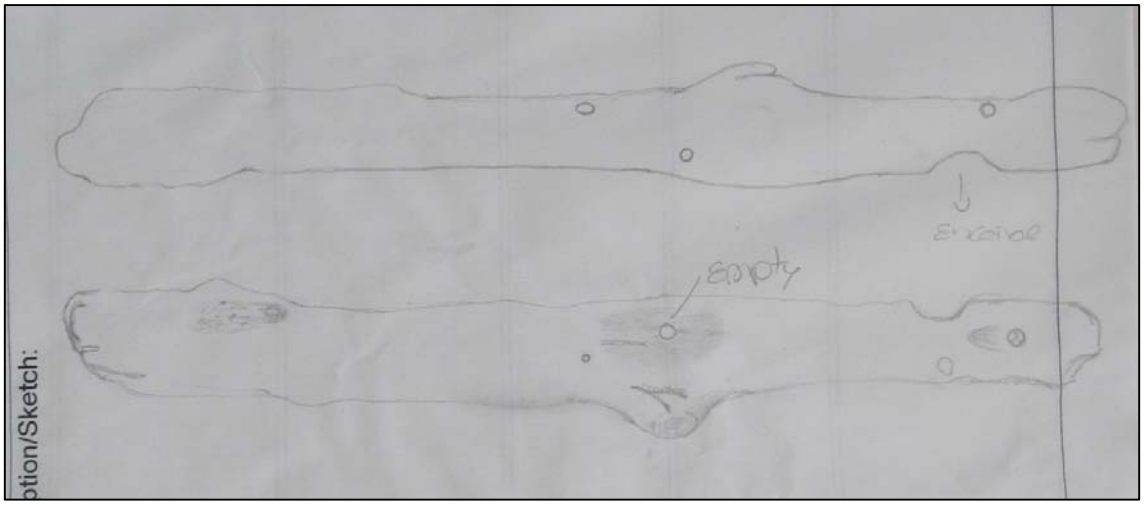
Section: sided 13 cm, molded 8 cm.

Shape: No edges. Could be a stanchion.

Fasteners: Iron nails.

Recording: Sketched

Sketch:



Timber: Wood fragment	No. 046W



Figure 46.1 – Photomosaic of the timber (not to scale).

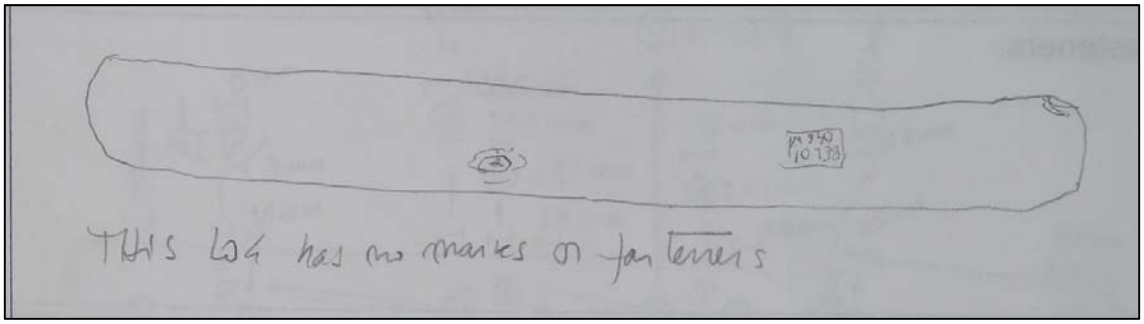
Length preserved: 139 cm.

Section: sided 14 cm, molded 16 cm.

Shape: No edges.

Recording: Sketched

Sketch:



Timber: Wood fragment	No. 048W



Figure 48.1 – Photomosaic of the timber (not to scale).

Length preserved: 158 cm.

Section: sided 18 cm, molded 27 cm.

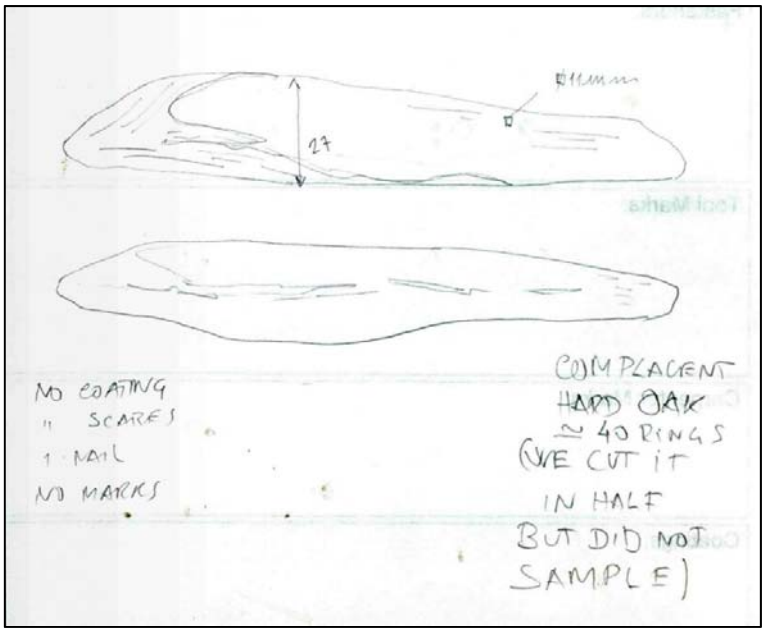
Shape: No edges.

Fasteners: Only one nail hole.

Recording: Sketched.

Samples: sampled for dendrochronology.

Sketch:





Belinho1: Timber Recording and Sampling Project Design

Version 0.6, July 2015

Compiled by the
ForSEAdiscovery Project

Principle Contact: Adolfo Martins

a.martins@uwtsd.ac.uk

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Document Control Grid

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Approval	
This project design has been prepared in accordance with MoRPHE guidelines (English Heritage 2006, Reissue date v1.2 01-04-2015 © Historic England)	

Summary Description

This project seeks to record and characterize an assemblage of ship timbers (and associated artefacts under parallel work) washed ashore on the foreshore close to Esposende in northern Portugal. The project aims to enhance understanding of the shipwreck which produced this material, presumably through natural erosion of an *in situ* shipwreck offshore, and provide training and enhanced awareness of aspects of maritime archaeology to ForSEAdiscovery researchers and the wider community.

Background

This project focuses on the recording and characterization of a specific ship timber assemblage. The approaches being employed and the project objectives need however to be seen within the wider aspirations of the Marie Curie ForSEAdiscovery project.

The project provides a case study for the development of techniques which both provide appropriate documentation of ship timbers of presumed Iberian origin, and also facilitate analysis of the relationship between supplied wood (parent trees) and its usage in the manufacture of ship timbers of suitable shape, strength etc. This meets the ForSEAdiscovery aspirations of both a particular PhD study (ESR6) and wider objectives in the development of protocols for best practice in ship timber documentation and sampling for a range of wood science analyses.

ForSEAdiscovery is a Marie Curie Initial Training Network. This project will provide fieldwork and post-excavation training for WP2 (and WP3) fellows. For the second Work Package (nautical archaeology and shipbuilding) Early Stage Researchers ESR6, 7 and 8 will be able to develop their experience in recording methodologies which may be useful within their own personal research, and provide employability skills for the future. There will also be an opportunity for WP3 (wood science) fellows to learn more about documentation processes, particularly with reference to the supply of samples from recorded timbers for analysis by WP3 fellows.

The project also seeks to provide outreach and dissemination through engagement with the regional archaeologists and community volunteers who have, and continue to be central to the curation and understanding of this ship assemblage.

Site Description and Archaeological Investigations

The place where the ship timbers where brought ashore is known as Praia de Belinho (Beach of Belinho), situated in the city of Esposende, district of Braga in the north of Portugal. As a natural reserve and linked to the sea, the area is under the protection of the Harbour Master of Viana do Castelo and the Natural Reserve of the Northern Littoral:

Praia de Belinho:

Lat/Long WGS84 Coordinates: 41º 35’ 02.27’’N / 008º 48’ 17.69’’W.

The northern coast of Portugal has being suffering by accelerated erosion events and climate change over the last 40 years. These processes appear to have caused significant variations in the landscape and seabed. During extreme winter storms in 2013 and 2014, natural erosion brought ashore an exceptional group of artefacts that comprises more than 70 ship timbers, 200

pewter plates, and others items apparently dated to the 15th and/or 16th centuries. Since the first artefacts were declared in January 2014 to the Portuguese authorities, the inventory has being increasing after storms. The local archaeologists Ana Almeida and Ivone Magalhaes are conducting periodical surveys in the area and recording as well as recovering new finds related to the presumed ship wreck.

Some recording of individual timbers was undertaken in May 2014 by members of CHAM. Records comprising notes, photographs and 1:1 non-contact tracings were apparently compiled. These are not presently available to this project group.

The local archaeologists have curated the timbers through production of an inventory, and wrapping of timbers in clingfilm. Subsequently, following author's advice, a water tank has been constructed to hold the timbers.

As part of community engagement, the finder Joao Sa, has taken part in the team as a volunteer, for the survey and recovering of the artefacts.

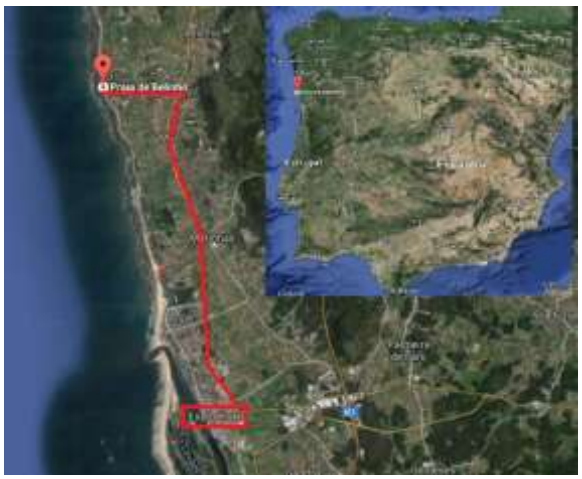


Figure 1. Location of the find spot, and storage location of timbers. Copyright Google

Research Aims, Objectives

Project Aims

The project has two key aims:

Aim 1: To characterize the nature of the shipwreck material recovered from the foreshore in the presumed vicinity of the *in situ* wreck.

Aim 2: To develop the skills and experience of ForSEAdiscovery researchers and regional archaeologists through involvement in archaeological recording and analysis.

Project Objectives

Within these aims there are a number of objectives:

Objective 1: To enhance understanding of the Belinho 1 shipwreck through recording of recovered ship timbers

Objective 2: To enhance understanding of the Belinho 1 shipwreck through wood science studies of selected samples from recovered ship timbers including microscopic wood anatomy, dendrochronological analysis and geochemical analyses

Objective 3: To provide training opportunities for ForSEAdiscovery early stage researchers, regional archaeologists, and volunteers

Objective 4: To develop understanding of the importance of timber assessment and sampling within maritime archaeological investigations

Business Case

The merits of this project can be seen from a number of perspectives. As an aspect of the ForSEAdiscovery Project, this programme of research can help to deliver outcomes identified in that project's research design. Similarly, there is overlapping research interest in development of Iberian shipbuilding technology through Texas A&M Nautical Archaeology programme. In addition, the project aims to address the needs for appropriate recording and analysis of this assemblage to meet the heritage management needs of local (City of Esposende) and national heritage agencies (DGPC).

The ForSEAdiscovery Project (Forest resources for Iberian Empires: Ecology and Globalization in the Age of Discovery) is a Marie Curie Initial Training Network funded through the European Union Framework 7 program.

The aims of the project are:

- to consolidate a research line combining historical research, underwater archaeology, GIS and wood provenancing methods (dendrochronology, wood anatomy and geo/dendrochemistry);

- to increase the background and experience of trainees in the different research areas, by engaging the fellows in training courses and workshops aimed at developing their scientific, communication, and management skills; and
- to develop their transferable skills for future careers in academia or the private sector whilst advancing the research fields through the integration of research tools, development of reference datasets and new discoveries.

The project includes the following partners: Instituto de Historia, Consejo Superior de Investigaciones Cientificas (Spain); Universiteit Leiden (Netherlands); Rijksuniversiteit Groningen (Netherlands); University of Wales Trinity Saint David (UK); Universidade Nova de Lisboa (Portugal); University of Santiago de Compostela (Spain); Wageningen University (Netherlands); and Universite de Lorraine (France).

Associated partners are: Texas A&M University (USA), Dendro DDK (Denmark), Archeonauta S.L (Spain), Nicolaus Copernicus University (Poland), and Dixit International (Sweden).

Local Partners: Esposende City Council, Vila do Conde City Council, D. Diogo de Sousa National Museum, Jose Carmo (wooden shipbuilding designer for the Nau of Vila do Conde)

Project Scope

The project scope is limited to examination, and selective recording and analysis of the timber assemblage recovered from the foreshore at Praia de Belinho and presently held in store by the Council of Esposende. It is recognised that locating the *in situ* remains of the shipwreck from which this artefactual material has eroded would be a pertinent and potentially achievable research objective. This could potentially form a later staged of a more sustained and developed project should the outcome of this study indicate that the parent ship is both Iberian (Spanish or Portuguese built) and falls into the time frame of the ForSEAdiscovery project (15th-18th century). Other artefact types which may be derived from the same shipwreck will be examined in parallel with this project and are therefore mentioned in areas where pertinent (e.g. logistics).

Interfaces

In addition to the research project on the ship timbers themselves, other sub-projects within an overarching Belinho 1 Shipwreck Project could include:

Regional archaeologists Ana Almeida and Ivone Magalhaes and Rosa Varela Gomes ForSEAdiscovery project partner in Portugal

- Pewter plates and other artefacts pewter:
  - Rosa Varela Gomes, Tania Casimiro
- Dendrochronology and wood analysis:
  - ForSEAdiscovery WP3

A key project interface is with the ForSEAdiscovery program which is outlined above.

Additional interfaces include known or suspected Iberian shipwrecks:

- **16th Century Vessels off England**
  - ***Yarmouth Roads*** Protected Wreck.
  - ***Studland Bay*** Protected Wreck. Spanish Merchant Vessel from the 1520s-30s with an artefact collection numbering around 750 from excavation in the 1980s, the archive of which is held by Poole Museums. This is a directly comparable collection for Yarmouth Roads and has had recent work undertaken on it by Bournemouth University.
  - ***Cattlewater*** Protected Wreck. An early 16th century armed merchant ship (1530s), located in Plymouth Sound. Archaeological investigation and an associated artefact collection provide comparative material for Yarmouth Roads.
  - **Other relevant examples off England:** Church Rocks an Iberian merchant vessel (16th C), Bartholemew Ledges armed cargo vessel probably Spanish (1590s), St Anthony an armed merchant carrack from Portugal (1527), Brighton Marina (early 16th century), Dunwich Bank a Spanish or Dutch ship (16th century).
- **Comparative 16th century Iberian Trading Vessels Internationally**
  - There are a range of examples of Iberian trading vessels found internationally which require further research to determine which of those provide potential research links for Belinho1. A number of wrecks will be subject to sampling and analysis as part of the ForSeaDiscovery project.

- **Aveiro A**: This excavated in the beginning of the century was founded in 1992 by a fisherman. The hull remains are dated to the 15th century by (C14).
- **Corpo Santo:** 15th century (C14) shipwreck which its remains represent with extremely accuracy the Portuguese Treatises. Its remains mainly comprise the stern and hull outside planks.
- **Cais do Sodre:** shipwreck dated around 16th century (C14) was found and excavated during the construction of a Lisbon underground tunnel.

Communications

Provisional arrangements for the proposed recording programme have been made by Project Manager Adolfo Martins in discussion with regional archaeologists Ana Almeida and Ivone Magalhaes. Email discussions within the ForSEAdiscovery network led to a scoping meeting held at the LASA2015 meeting on 28 May 2015 (NN, AM, FC, PAM). Development of this project design in advance of the fieldwork will give team members the opportunity to comment and steer the direction and methodology of the research.

It is expected to have a kick-off fieldwork meeting with the presence of most of the research team. Additionally, further formal meetings may be necessary to adjust schedule and priorities.

The local archaeologists Ana Almeida and Ivone Magalhaes will be full time at work.

ForSEAdiscovery early stage researchers and established researchers not attending will be encouraged to contribute, particularly regarding selective sampling and documentation, remotely by any means available (Skype, etc).

The initial product of this project design will be a highlight report to meet the requirements of the DGPC as the national heritage agency providing permissions to undertake this project.

Project review

Describe how and when progress will be assessed: Give an estimated timetable for Review Points R3 (the review after each Execution Stage), and specify who will be involved;

Ongoing amendments to project design, timetable etc will be undertaken by the Project Manager (AM) with approval from the Project Executive (NN) and Consultant (FC). The Project Manager will maintain appropriate communications with local archaeologists and the hold of required permissions and authorizations from the Portuguese Heritage (Rosa Varela Gomes) to ensure compliance with all local and national heritage agency requirements.

The Project Manager will ensure that copies of all documentation required by REA (EC) to meet ethical requirements of the ForSEAdiscovery grant agreement have been provided to the ForSEAdiscovery Network Co-ordinator in advance of any fieldwork.

Resources and programming

Information in the following categories may change during any project re-planning.

Project Team structure

Describe the key roles and responsibilities of Project Management and any specialists. Include time commitments expected from those involved part-time.

Table 1. Project Team Participants

Name	Roles	Start Date	End Date	Time Commitment	Comment
Ana Almeida	Regional Archaeologist	01/08/15	23/08/15	23 days (fieldwork)	Archaeologist local Liaison
Ivone Magalhaes	Regional Archaeologist	01/08/15	23/08/15	23 days (fieldwork)	Archaeologist local Liaison
Carlos Almeida	Regional Consultant	01/08/15	23/08/15	23 days (fieldwork)	Archaeologist local
Nigel Nayling	Project Executive ForSEAdiscovery (WP2 Co-ordinator)	02/08/15	23/08/15	21 days (fieldwork)	Timber recording, sampling
Rosa Varela Gomes	Portuguese project coordinator , ForSEAdiscovery Partner	04/08/15	08/08/15	04 days (fieldwork)	Artefacts recording
Mario Varela Gomes	Portuguese project coordinator	04/08/15	08/08/15	04 days (fieldwork)	Artefacts recording
Adolfo Martins	Project Manager ForSEAdiscovery ESR (WP2)	02/08/15	23/08/15	21 days (fieldwork)	Timber recording, sampling
Filipe Castro	Nautical Archaeology specialist ForSEAdiscovery Associate Partner	04/08/15	21/08/15	17 days (fieldwork)	Timber recording, interpretation
Antonio Rocha Santos	Project Officer ForSEAdiscovery ESR (WP2)	04/08/15	12/08/15	09 days (fieldwork)	Timber recording, sampling
Koldo Monchet	Project Officer ForSEAdiscovery ESR (WP2)	04/08/15	08/08/15	04 days (fieldwork)	Timber recording, archives
Jemma Bezant	GIS and IT Consultant	02/08/15	12/08/15	10 days (fieldwork)	GIS, IT

Name	Roles	Start Date	End Date	Time Commitment	Comment
Maria Silva	Master Student Volunteer	02/08/15	23/08/15	21 days (fieldwork)	Timber recording, sampling
Chris Dostal	Conservator / curator	04/08/15	21/08/15	17 days (fieldwork)	Timber conservation
Tania Casimiro	Researcher	04/08/15	08/08/15	04 days (fieldwork)	Artefacts recording
Joana Goncalves	Researcher	04/08/15	08/08/15	04 days (fieldwork)	Artefacts recording
Alexandre Monteiro	Archives specialist? UNLA	10/08/15	16/08/15	07 days (fieldwork)	Shipbuilding techniques, archives
Marta Dominguez	Dendrochronology specialist ForSEAdiscovery ESR (WP3)	02/08/15	23/08/15	21 days (laboratory)	Dendrochronology
Peter Gronendijk	Dendrochronology specialist ForSEAdiscovery ER (WP3)	02/08/15	23/08/15	21 days (laboratory)	Dendrochronology

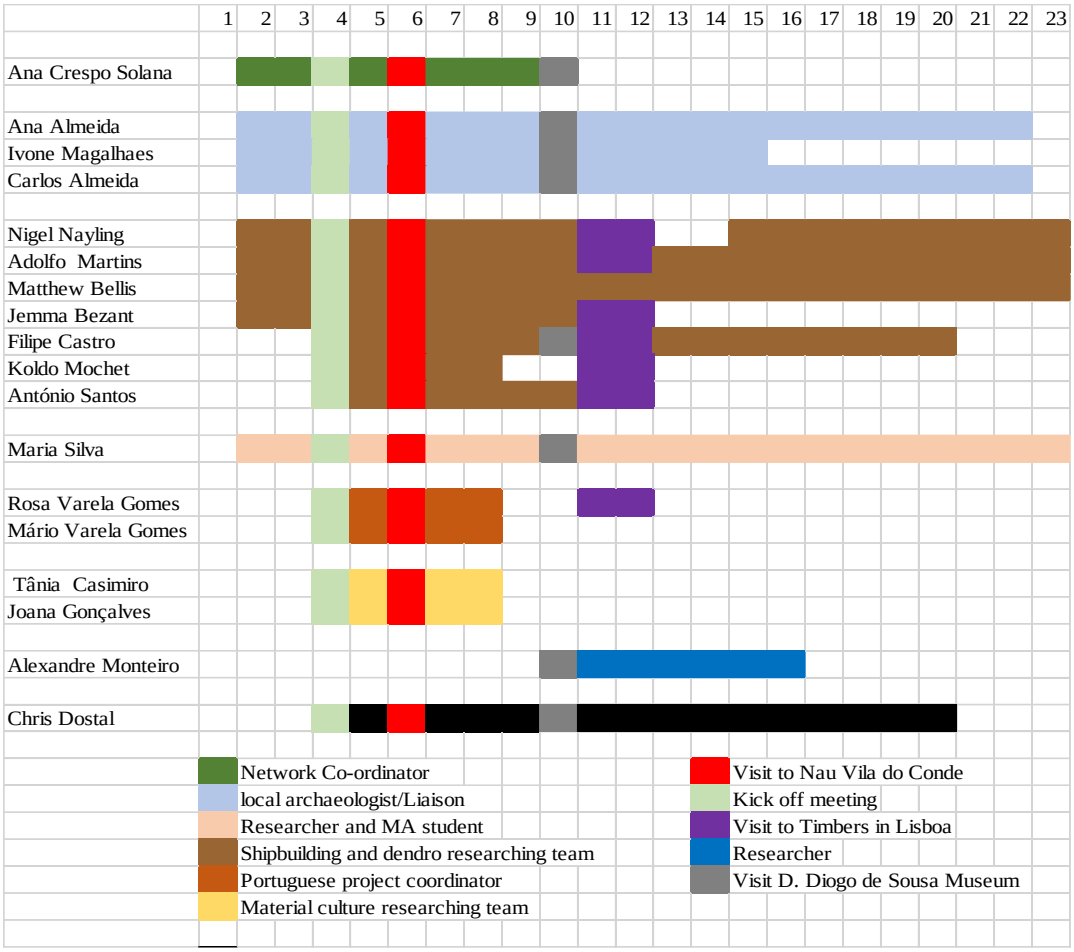


Figure 2. Project Participation Timetable

Methods statement

Detail how the research Aims and Objectives will be achieved. What techniques or approaches will be employed? How do these maximise the potential of the area of study to provide information? How will the results be archived and disseminated? Where appropriate, reference should be made to professional standards and guidelines, and to organisational procedures manuals.

The project focus is on efficient and effective ship timber documentation and sampling. The diagram below outlines a process for timber cleaning, selection, and documentation through use of timber record sheets, photography, 3D recording using Faro-Arm and Rhinoceros 3D software, and selective white-light scanning. The process of timber documentation will be informed by presently available guidance on best practice (Historic England Waterlogged Wood Guidelines https://content.historicengland.org.uk/images-books/publications/waterlogged-wood/waterlogged-wood.pdf/, Historic England Dendrochronology Guidelines https://content.historicengland.org.uk/images-books/publications/dendrochronology-guidelines/dendrochronology.pdf/, and the ship timber recording manual developed for the Newport Ship Project http://archaeologydataservice.ac.uk/archiveDS/archiveDownload?t=arch-1563-1/dissemination/pdf/Newport_Medieval_Ship_Project_Timber_Recording_Manual.pdf.

Indexes of assigned timber numbers, photographs, Rhino files, scans and samples will need to be collated within a single database which links to the ForSEAdiscovery project database and GIS. During fieldwork, temporary paper based indexes may be used but will need to be frequently and regularly entered into the Belinho1 project database (NN suggests daily at a minimum).

In the collection of data, project team members will need to be aware of current recommendations for sustainable file formats and file naming, and ensure collation of appropriate metadata to assist in the process of archive inception and submission. Further advice on these aspects is available at the Archaeology Data Service - http://guides.archaeologydataservice.ac.uk/.

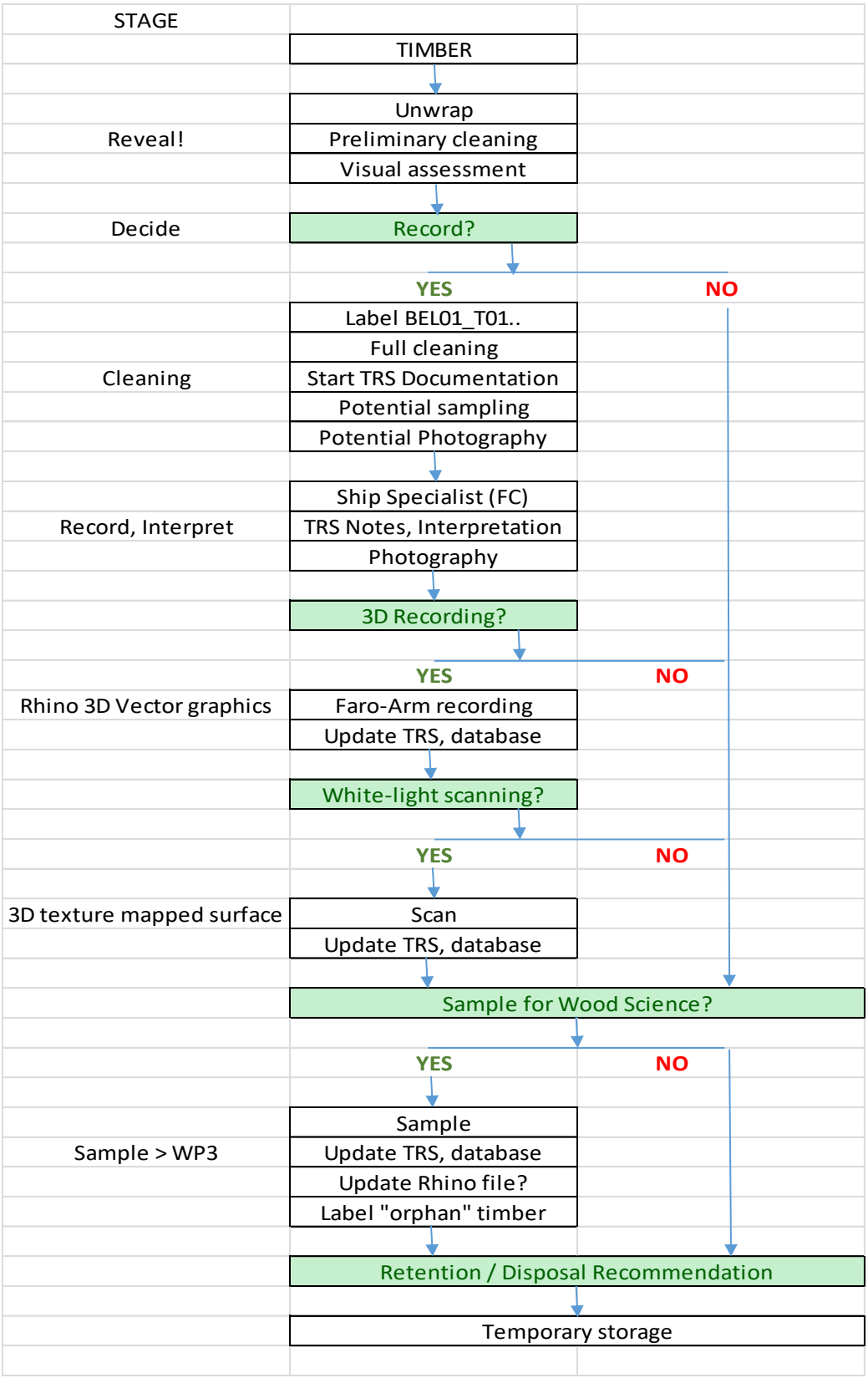


Figure 3. Timber recording process

Stages, Products and Tasks

Describe in detail how the project will proceed. Identify Stages, their Products and the Tasks needed to produce them. Typically these might be tabulated, with a reference number or name for each Product, who it is assigned to, and planned start and end dates for the Product. Detailed Product Descriptions can be appended to the project Design.

An estimated end date should be given for each Stage. If required, Tolerances (for completion before or after deadlines) may be included. Remember to schedule updates of project-management documents (Project Design, Risk Log and Issues Log) and to allow sufficient time for reviews.

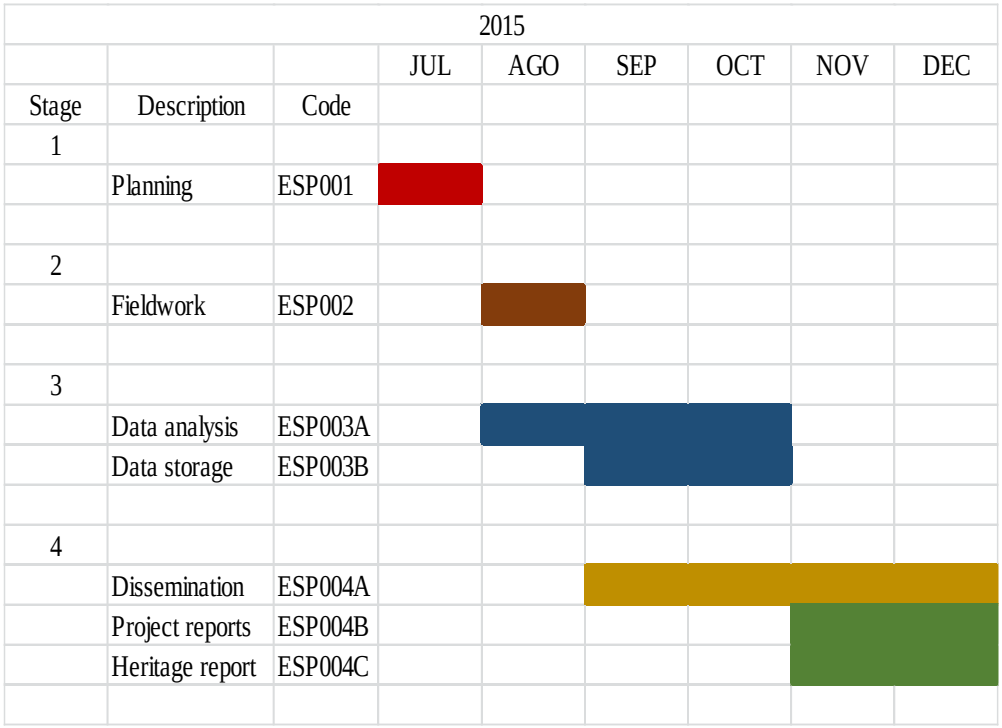


Figure 4. Products Timetable

For research-focused projects, specific reference should be made to the preparation of a project archive (including the policy for retention and disposal of archive material) and the dissemination of results or Products.

Project Stage	Task	Product Name	Product Code	Start Date	End Date
1	Prepare and finalise project design	Project Design	ESP001	28/05/15	30/07/15
2	Timber recording, sampling	Timber Dataset	ESP002	03/08/15	22/08/15
3A	Internal summary report. Commentary to project archive	Interim Report	ESP003A	23/8/15	31/10/15

Project Stage	Task	Product Name	Product Code	Start Date	End Date
3B	Prepare project archive (to Archaeology Data Service specifications?)	Project Archive	ESP003B	1/09/2015	31/10/15
4A	Papers, articles and monograph?	Dissemination	ESP004A. (NN - We need to discuss issues of authorship, responsibility, timetable etc etc. Need to be mindful of draft document from Ana C on Ethical Publishing for ForSEAdiscovery)	?	?
4B	ForSEAdiscovery internal reporting	Project Reports	ESP004B	?	?
4C	Production of interim report for DGPC	Highlight Report	ESP004C	23/08/15	31/12/15

Figure 5. Product Codes and Descriptions

Ownership

What legal agreements are proposed for the ownership of project Products and Archive material (for example, material remains from excavation, and intellectual-property rights for photography, written text and other works).

According to the Portuguese Law for the heritage among with the UNESCO Convention of 2001 for the underwater cultural heritage:

"Underwater cultural heritage" means all traces of human existence having a cultural, historical or archaeological character which have been partially or totally under water, periodically or continuously, for at least 100 years such as (UNESCO: 2001, 2):

- sites, structures, buildings, artefacts and human remains, together with their archaeological and natural context;
- vessels, aircraft, other vehicles or any part thereof, their cargo or other contents, together with their archaeological and natural context.
- Any artefacts considered as part of heritage are automatically property of Portugal, exception for flag ships sink in the Portuguese seabed, shore or other.

Risk Log

Append the project Risk Log as an annexe.

Budget

Set out the proposed budget, including estimates, for each financial year, of:

staff costs;

any contractor costs;

non-staff costs such as transport and office consumables;

overheads;

capital-equipment purchases;

estimated total cost of the project; any required Tolerance on total cost should be specified separately.

Risk Log

The Risk Log is a planning tool created at the Initiation Stage. It serves to document and assist in the monitoring of project Risks (uncertainties in outcome). It should be checked during reviews to assess whether the likelihood of each Risk has changed, and whether any anticipated Risks are in fact occurring. The Risk Log will generally take the form of a table with the following columns:

Risk number: For identification.

Description: Description of the Risk.

Probability: Probability of the Risk occurring (high, medium, low).

Impact: Likely impact of the Risk (high, medium, low).

Countermeasures: Agreed action(s) to avoid or reduce the impact or probability of this Risk.

Estimated time/cost: An estimate of time and cost for agreed countermeasures for each Risk; the sum of countermeasures for all Risks would be an estimate of the required Contingency. Contingency funds or agreed extensions to timetable are only accessed if an anticipated Risk occurs.

Owner: A member of the Project Team responsible for monitoring this Risk and notifying the Project Manager if it occurs. This should be someone 'close to the problem'.

Date this entry last updated: The Risk Log should be reviewed formally, at least at Review Point R3.

Product Description

Product Descriptions are in effect specifications for a piece of work. They are prepared during Initiation, or as soon as the need for a Product is identified. A compiled set of Product Descriptions should be appended to the Project Design. These will need to be updated as each Stage is planned or reviewed.

Product number: For identification.

Product title: For identification and reference; generally couched in terms of something completed or accomplished (for example, 'Edited text' or 'Survey drawing completed').

Purpose of the Product: What project Objectives will this Product satisfy?

Composition: What will the Product consist of?

Derived from: Identify the source(s) of the Product's components.

Format and presentation: Describe the product's appearance.

Allocated to: Who on the Project Team will undertake the work? Where this is not known, the required skills should be documented.

Quality criteria and method: How will the quality of the Product be checked? Quote relevant standards or guidelines.

Person/group responsible for quality assurance: Who on the Project team (or Stakeholders) will be involved in checking the quality of the Product? Person/Group Responsible for approval: Who on the Project Team will approve the final version of the Product?

Planned completion date: Estimated date or stage in the project for the first draft or prototype, and planned date for delivery or completion.

Highlight Report

Highlight Reports provide brief informative statements of progress. Their format, frequency and circulation should be set out in the Project Design. For example an approach useful when staff are receiving reports from many projects is the 'traffic-light' system, in which Schedule, Budget and Resources are noted as red (for immediate attention), amber (problem foreseen) or green (according to plan) with any accompanying notes.

Date: Report date.

Circulated to: Circulation list for this report.

Period covered: Normally since the last project meeting or last Highlight Report.

Schedule status: Is the overall project on schedule, ahead of schedule or falling behind?

Budget status: Is the overall project on budget, underspent or overspent?

Resources: Does the overall project have the resources (staff, time, equipment etc) it needs?

Products and Tasks completed during this period: i.e. since the last Highlight Report

Products and Tasks to be completed during the next period: i.e. before the next Highlight Report.

Project Risks: Have there been any changes in the status or likelihood of Risks documented in the Risk Log? Have any new Risks been noted?

Project Issues: Do any new Issues need attention? Include here any other project news.

End-of-Project Report

This report should be lodged in the project archive and presented to the Sponsor. Where key lessons learned may assist in the planning of future projects, they should be circulated more widely. It should include the following.

Project Closure date: The agreed date for the conclusion of the project.

Lessons learned: What useful lessons were learned during the project which might be applicable to similar projects in future? Which project-management processes, tools and techniques

worked well and which ones caused problems? What recommendations can be made? How can these be shared with other projects

Post-Project Evaluation Plan: How should the project be evaluated, and when will this be appropriate? The scale of the evaluation process should be consistent with the size of the project. Items to consider for future evaluation in the light of experience include:

- Did the project achieve the stated Aims and Objectives?
- Which project processes worked successfully and why?
- Which project processes encountered problems and why?
- Did quality-assurance procedures work well?
- Was the Project Team sufficiently skilled, trained and empowered?
- Were sufficient Risk strategies in place and managed?
- Were allocated time and resources sufficient?

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Dunkley, M., 2001, *The Yarmouth Roads Wreck: A Study in Interpretation*. Unpublished MA thesis, University of Portsmouth.

English Heritage. 2006. *Management of Research Projects in the Historic Environment*. London: English Heritage.

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How can we see trees in timbers? An approach to the Golden Age of shipbuilding

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Abstract

The most essential part of an excavation is the record, it will give us the tools to analyse the site formation, its chronology and many other aspects. However, this process may be done using different methodologies: in the traditional way by hand drawing timbers and artefacts on mylar or in other available support. At the opposite we may use specific hardware and software to draw automatically on the screen of a laptop the shapes and features of the material culture. Both are always an option, what really differs is the approach. In the next few words I will try to present my research project and, in what it consists. For that purpose first will be presented the basic concepts for the research and then will flow through the aspects of dendrochronology and maritime archaeology (shipbuilding methods). Finally, the purposed method for the Iberian ship timbers record.

Resumen

La parte más esencial de una excavación es el registro de datos, que nos proporcionará las herramientas para analizar la formación del yacimiento, su cronologia y muchos otros aspectos. Aún así, éste processo puede ser realizado utilizando diferentes metodologias. De la llamada tradicional forma de recoger los datos mediante el dibujo de maderas y artefactos en mylar o en outro tipo de formato de soporte. Por el contrario puede que usemos programas específicos tanto de software, como médios de hardware diversos para dibujar automaticamente en la pantalla de un portátil las formas y características de la cultura material. Ambas son siempre una opción, pero lo que de verdade difiere en dichos formatos, es el enfoque. En las próximas resumidas palabras trataré de presentar mi proyecto de investigación y en que consiste. Para éste propósito primero presentaré los conceptos básicos para la investigación y después discurriremos a traves de los aspectos dendrocronológicos y de arqueologia marítima (Métodos de construcción naval). Por último, se mostrará el método propuesto para el registro de maderas de los navios de tradición Ibérica.

1. Concepts

Man as part of Nature has been struggling against his need to cross boundaries and phenomenon, generated by the earth morphology and atmospheric events. However, the causes are not only related to the innate instinct for surviving, but also in large part to his need for achieving and / or to collect more and to understand what is behind the horizon. We may say, using our empirical experience of life that every man is different from the other, but as a team their strengths and beliefs are capable of generating the most marvellous piece of art, or the opposite, the worst catastrophes. These next words, paragraphs and pages, are related exactly to one of the most impressive achievements of mankind – the ability to build the means to, in a reasonably safe way, cross and return a large area of liquid matter. This technological advance may be clearly compared to the invention of the microchip, and maybe, it is not so far from the reality. The ingenius ability to choose a tree, shape its trunks and brunches and use them all together for sailing up the rivers or to follow the thin horizon line, give us nowadays a better understanding of our planet in several aspects.

This process obviously was not built in a constant rhythm, nor was it always successful, or even pacific in terms of diplomacy between countries. The learning process took ages for man to achieve the needed knowledge, to find an assertive way to combine four

major areas of expertise for purpose: - carpentry, navigation, physics and maths. This long process of tentative \ error had a remarkable stage for the advancement of the wooden shipbuilding technology in the early 16th century. From "now on" the knowledge has no boundaries and has led man on an intense and epic journey throughout the sea, known as the Golden Age of discoveries. New cultures, environments and goods were found, endorsing links between Europe and the most remote areas of the planet. The world started to be connected by maritime routes, which accelerated the decline of the millenary silk route. Providing for those who could buy exotic porcelains, smooth silk, black pepper and expensive furniture made by no less exotic wood coming from the Far East or the remote West. Nevertheless, the cultural exchange between all kinds of nations also promoted knowledge and increased the scientific understanding of botany, medicine, anthropology, trading, etc.

Behind all the challenges and risks undertaken by courageous men and women, comes Nature with the transformation of the basic substance CO2 into the essential by the chemical process of *photosynthesis* (Bartholomew: 2010, 124). This obviously provides, besides a healthy environment for every living organism on the face of the earth, all the tools that men need to carry on with his expectations, and allows him to have perfect raw material to build the magnificent wooden ships. However, these machines, as Steffy (1994, 3) said are "in reality, far more than a lifeless structure. It began as a desire for profit, a hope for victory, or a dream of exploration or conquest in the minds of its originators. The idea moved to the shipyard, where the efforts of shipwrights, carpenters, and smiths – who sometimes the marks of their tools or the signs of their ingenuity – converted hundreds of trees into a variety of shapes and joined them together."

Today much that archaeologists know about ships, shipbuilding methods, dockyards and maritime routes was brought to light from studies and underwater excavations undertaken all over the world. Theories, assumptions and essays have been done since already forgotten times when man under his scientific thoughts tried to understand how it could be possible to build such a highly complex machine capable of carrying in its interior a huge amount of goods, an enormous apparatus of provisions and guns, the crew and the passengers. Tons of timbers, nails, ropes and all the needed equipment was carried through seas and deserts of salt water.

Under this thematic area of expertise, this multidisciplinary research plan undertaken within the objectives of the Marie Curie Actions – ForSEAdiscovery Project aims to find answers related to the management, selection and usage of the trees used in shipbuilding from 16th to 18th centuries and which techniques man used to convert trunks and branches into timbers. The research plan baseline tries to combine three main areas of science under a maritime archaeology perspective, which are Archaeology, dendrochronology and History. The basilar structure for the research rests on the adoption of three basic concepts published by Steffy (1994), Schweingruber (1987) and Hocker (2004). The research project main tasks involve a self-critical analysis of the research main question: How can we see trees in timbers? The critical analysis of the previous researches in an attempt to rebuild theoretical hypothesis of the trees shapes based on ship timbers, which will converge into the PhD literature review. The development of digital techniques for 3D reconstruction of the growth pattern, age structure and morphology of parent trees employed in ship timbers in Iberian shipbuilding (16th to 18th centuries) from known Iberian shipwrecks, such as Belinho 1 (on lab, Portugal) and Ribadero 1, The Filipe II 1596 Armada, Madgdalena and Bayonaise (in situ, Spain). After the conclusion of the data analysis, all the results will be presented as a PhD thesis and published in open source.

The first challenges within the research plan are related to the dichotomy between the spatial traditional approaches for timber record used in the European northern countries and the southern. The developed research and studies by nautical archaeologists in the North, have undertaken research which integrates areas of expertise such as dendrochronology. However in the South (in Portugal and Spain as I am concerned), very few nautical archaeology publications touch on the importance of the wood as a material in shipbuilding. Even where attempts have been made to consider the shape of the timber in relation to the parent trees from which it was converted, this has been limited to two-dimensional drawings which do not synthesize all of the data available from the archaeological record and wood science. This means that most of the books and articles that we may read today about nautical archaeology in several languages, have a very professional interpretation about the site formation and a thorough timber record, but it does not tell us almost anything about the trees and where they came from or even how they were cut down. This

does not mean that there is a better or worst approach, or even that wrong methodologies exist. This means under a personal view point that all potential support from other areas of expertise are longed-for nautical archaeology research. Although, this paradigm may have an explanation based on the fact that the major part of maritime archaeologists in Portugal and Spain are truly focused on the shipbuilding methodology adopted by carpenters and disregard the forest management, the timber trade and tree shapes. Part of this explanation may also reside on the most used theoretical approach for dating the archaeological sites. The analysis of shipbuilding methods and artefacts located on shipwrecks sites are mainly used for dating a wooden ship, rather than using dendrochronology with an eventual combination with Radio-Carbon 14. Part of this explanation subsists in the theory that dendrochronology, as a discipline, cannot give a straight-forward answer for dating a shipwreck, because according to the archives the timbers should rest for several years in specific places on the dockyard before they can be used, which will give archaeologists wrong chronologies for the shipwrecks. Obviously all conjectures may be rejected or assumed, but they also mean a challenge for this research plan that intends to find specific answers for the way that man found to convert trees in timbers.

The major opportunities of the research plan are mainly the chance to use high resolution scan techniques, which includes hardware and software such as Faro-Arm and Rhinoceros. To gain a better understanding of contemporary forestry practice, the trees available for shipbuilding and the ways in which this raw material was converted, there is a need to make better use of the 3D digital techniques increasingly being used in nautical archaeology. The multidisciplinary structure of the For-SEAdiscovery Project is also an added-value for the research. The project comprehends three groups directly related to the three major areas of science to find specific answers to the question of timber supply for shipbuilding in the Age of Discovery and European expansion. Historical Wood Supply and Dynamic Trade Networks (WP1), Nautical Archaeology and Shipbuilding (WP2) and Wood Provenance (WP3) – Research Working Packages which will promote 15 individual sub-projects called ESR (1 to 15) – Early Stage Research (Fellow). In this specific research plan undertaken within the WP2/ESR6 aims to contribute for the application of ring-width analysis to recovered dendrochronology samples and delivery of data, samples and sub-samples to be analyzed by the ESRs of WP3.

The research plan also includes secondment especially for training sessions or fieldwork in Portugal, Spain and United Kingdom. As a Marie Curie Actions project is essential and compulsory to gain experience in different areas of research. In the particular case of the ESR6 is expected to participate in training sessions in the dendroarchaeology laboratory for sample recording, wood anatomy analysis and dating. Archaeology laboratory sessions for 3D CAD timber recording by using existing high resolution techniques, in order to collect and identify existing potential data for the research plan purposes. Underwater activities are essential in the research plan to improve skills, the existing techniques and the perception of potential data in already excavated wooden shipwrecks identified as part of Iberian shipbuilding tradition.

The major expectation for this research plan follow Hocker (2004, 2) words on his book 'we seek to create one of those departure points, a general theoretical statement on the process of shipbuilding, the most essential of maritime technologies. This is not meant to be definitive or final - in fact, the contrary. It should be noted that the authors do not always agree, and this divergence of view-points is an essential part of the book [In The philosophy of Shipbuilding]. It is meant to show both how far we have come and how far we have yet to go, what the major outlines are and where the gaps are. It intended to provoke discussion, to encourage our colleagues to come up with better ideas. If we have done our jobs well, this volume may still have some use in a «History of Archaeology» classroom in fifty years' time, but it should be rendered technically and theoretically obsolete long before then".

The following pages attend to promote separately the discussion of the matter and aims of the research plan on a path throughout that begins from the raw material – the trees to the basic concepts for shipbuilding and ships, the timber recording techniques and available technology. Ending on theoretical multidisciplinary approach of the research purpose.

2. ANATOMY OF TREES: UNDERSTANDING THE FOREST

Scheingruber (1987, 7) refers to Weizsäcker to express his understanding of the need for a multidisciplinary approach with the following words: "Barriers erected

between the different branches of knowledge are at the root of many of our problems. One specialized science is not able to provide a complete global picture which, in the complexity of our modern existence, would give us something firm to hold on to. This is why we are looking for a synthesis; we want a comprehensive view". This proposed analogy in fact explains wisely the need of a wide-open view, which is absolutely essential in archaeological research, but as the author demonstrates, also for any other sciences. By one definition, the theoretical meaning of the act of research resides in a subject or point that is under discussion or open to controversy, or in a proposition brought up for consideration by an assembly. Either way, the research baseline should involve any support from different sciences that might help to find conclusions. Apparently these words sound trivial to every researcher; however, regarding the previous studies related to wooden shipwrecks and shipbuilding techniques, in more than just a few cases there are breaches. As mentioned in the introduction of this article, a very professional and thorough approach toward the remains of a ship, does not meant that all the existing data on the archaeological site is being analysed. A researcher begins his work by defining which answer he wants to find, which at the beginning will define the entire research, by assuming this risk and because it is not expected that a human being will know about every matter. This chapter does not intend to focus the anatomy of trees under the scope of a wooden sciences expert, but under the perspective of a maritime archaeologist. The existing reason for this chapter resides not only in the consequent need to understand the trees and their behaviour, but also to find what the trees can tell us about themselves. These living beings, widespread over all the continents, have many applications, especially for building the means to support man's will. From experienced carpenters to common workers, finding the needed shapes for the building process requires a certain amount of experience. To cut a tree without purpose could represent in the past or even in the present a waste of raw material and cause a serious impact on the environment and economy. This common judgment is not a new expression, according to Devy-Vareta (1985, 1986 and 2002). In the 16th century the constant need for wood as a material was incredible, balanced with the enlargement of the urban areas and the shipbuilding (Devy-Vareta: 1986, 5). Forest management soon become part of the countries' strategic interests and considered as essential for progress. Cities with privileged locations near the shore, influenced by the mercantilist interests were transformed in large enterprises where could be found private, local and sovereignty consortiums. The quest for wood as a raw material brought profound changes in society. The wanton consumption of trees without the required time for renewal of the forest's integrity, generated claims from the merchants and manifest from farmers to keep their rights of exploitation and usage of the forests (Devêze: 1965, 605). To face this problem, countries adopted a progressive royal control on the forests in general, which ended the degradation of forests by unbridled exploitation of this natural resource, even in countries such as France and some German states, where rules or forestry codes were enacted during the fourteenth century (Devy-Vareta: 1986, 6). Nonetheless, in the Southern European countries, where the ecological environment was already weakened by farmers considerably to extend the crops and pastoral work necessities. Furthermore, during the previous centuries, the Mediterranean trade and along the Atlantic coast promoted the extinction of forests to assure needs of this raw material for shipbuilding as never before, especially in Italy and in the Iberian Peninsula. In these countries, depending on the geographic location and morphology of their cities, were established, in many cases, one of the largest consumers of wood – the dockyards. In these places, where the knowledge was passed from master to apprentice, was in fact when the trunks and brunches gained specific shapes for shipbuilding usage. How were these men able to fulfil their objectives? Archaeologists and historians already have some conclusions, by analyzing treatises and performing excavations and studies related to shipbuilding. But regarding the understanding of trees and shapes, archaeologists still have a long journey ahead. A naval carpenter can be compared to an artist, by analogy. A carpenter possesses the ability to look at a tree, just like a sculptor looks at a rock and observes a fine and magnificent shape. The incoming knowledge related to the trees theoretically comes from successive action – reaction in order to achieve the purpose of "The shipbuilding [has] processes that preceded and may have influenced the development of Iberian shipbuilding are numerous and varied. Essentially, the subject encompasses the history of shipbuilding technology as it evolved throughout the Mediterranean region and northern and western European coasts and rivers over a period of more than ten millennia" (Steffy: 1994, 49). "We can only guess at the origins of watercraft in these two great maritime theaters. Certainly there were reed boats and animal skins and rafts of various

sorts, but eventually wood became the most widely accepted material for hull construction; it remained the material of choice for most ship and boat builders until the last century. From a practical standpoint, formal shipbuilding technology began when two or more pieces of wood were assembled to produce a displacement vessel. It, too, was a process that originated thousands of years ago and continues to evolve to this day" (Steffy: 1994, 49).

To understand how those brilliant men, the master carpenters, chose different kinds of trees and shapes is essential to uncovering the veil of an empirical knowledge passed from generation to generation. Therefore, by observing a tree under the perspective of dendroarchaeology as any other living being we may find answers on their structure and how they are influenced by the environment: geographic location, landscape morphology, astronomic cycles and atmospheric events.

2.1 Tree anatomy. From the empirical wisdom to the scientific approach

Trees tend to grow vertically, disregarding the shape of the soil in order to capture the sun essential for photosynthesis. Depending on different types of rocky soil or sandy, the roots have the imperative mission to find and gather water from underground (Schweingruber: 1988, 11) and also help to purchase and react to the stimuli promoted by earth movement and wind. Her vertical shape is also influenced by spatial environment where they live. By observing the differences between trees that live in a dense forest or at the opposite, in open areas, we will be able look in the first case at high trunks with confined canopies at the top and, small trees with large canopies in the second. These differences may be also observed in cut trees, by the length of the trunk and the knots' main concentration, which means that a tree that lives with less space and energy provided by the sun will have consequently bigger trunks and far more concentrated knots at the top.

The growth process will record different patterns depending on the altitude, temperature and location on the planet. As Schweingruber (1998, 6) has said "A tree is a stationary living thing. Its crown, trunk and roots are capable of receiving to environmental factors: some parts of the tree receive signals from the surrounding while others react to them. (…) This ability to integrate is reflected in many different kinds of tree characteristics, such as geographical distribution, tree crown and tree rings. In the course of evolution plants have developed on every site, being best adapted to the particular conditions obtaining there". Directly related to the growth patterns is the reaction time, where measurements of any environmental conditions are reflected in the tree rings and expressed in a very complex way in the annual ring. Within the growth process another influence caused by the environment is the tilting of the earth's axis, the gestation periods depending on the hemispheres trees growth in different occasions of the year. Between June and September in the northern latitudes is when the trees are receiving more energy and consequently growing, but this process is only observed on the southern part of the equatorial line during the months of December and March. It is precisely this process that provides by itself a very specific data for dendrochronology, archaeology and climatology. However, these facts cannot be seeing as a rule for every tree or any other "thing" that carries a growths pattern. Stones (i.g. agate), shells (i.g. freshwater mussel) and bones (i.g. mammoth tooth) or even some species of trees have astronomic cycles. Although, the most popular trees used for shipbuilding are oaks (*Querqus* – *Angiospermae* family - broadleaf that form tension wood) and pines (*Pinaceae* – Gymnosperm family - conifers that produce compression wood) (Schweingruber 1998, 10; Mitchel: 1984, 15).

The *Quercus* tree family is classified as part of the hardwood and comprises approximately 600 known subspecies. These groups of trees possess large cells also called vessels. Oaks in cross-section, "the wood shows rings of large cells separated by rings of small cells. Such woods are called *ring-porous*. In some other trees, such as beech and birch, the vessels are similar, rather small of mixed sizes throughout the season. These are called *diffuse-porous* timbers. The difference between these two types is easily seen and is the first important feature used in determining the genus of the tree from which a sample of wood is derived. Hardwood timber contains two other kinds of cells. The *fibres* are usually thick-walled, narrow, sharp-ended cells found fairly uniformly trough the annual ring. The *parenchyma* are thin-walled brick-walled cells which are mainly arranged in radiating *medullary rays*. It is these that give the «figure» or graining in timbers like oak, where they are very large, and are most prominent on the face which is parallel to the rays, that is, the radial face" (Mitchel: 1984, 19).

On the other hand, conifers or softwood timbers only have two kinds of cell – the vessels and fibres. These cell are "united in an intermediate form cell, the *tracheid* which combines the functions of the two kinds, and the *parenchyma"* (Mitchel: 1984, 19) which are much similar to the broadleaf trees.

To understand the structure of these trees, Mitchel (1984, 19) has said that "the *vessels* and *tracheids* are conducting tissues forming long, wide tubes joined end to end. Vessels have large plates at the ends with perforations to permit the flow of sap, or sometimes they are joined with end-plates at all. Tracheids are joined by a long overlap and their side-walls communicate by rows of holes. The fibres of hardwoods are entirely for strengthening, allowing the vessels to be thin walled for better conduction of sap. In softwoods there are no fibres and the tracheids have to be strong and thick walled as well as good conductors of sap, hence a long overlapping arrangement and small pits in their walls are necessary to permit the flow of sap through thick-walled, rigidly joined cells. The *parenchyma* is storage tissue, holding reserves of nutrients during the winter when the sap is scarcely flowing, ready for the time of greatest need, in spring when growth must start before the new leaves and roots are functioning".

This chemical process is continually generating new rings year after year as long as the tree still keeps receiving all the nutrients that it needs to be alive. Although, we may observe another chemical reaction in the tree structure, promoted by the cells when they become lignified. This process applies from the pith (core) to the bark and is in a straight line related to the death of the cells. Generating the heartwood which is much darker, stronger and durable and gives the necessary strength to the structure to allow the tree to growth vertically. At the opposite the sapwood has a pale colour, less strength and is much more permeable.

2.2 Tree shapes. Management versus natural growth

To obtain the shapes of timbers for the purpose of shipbuilding, trees must also have the needed shape for the futtock, keel and any other part of the ship. To achieve that combination between the needed timber with the hardiness and natural grain, the master carpenter had to have in his mind a clear view of what he wanted to find. As mentioned before, he needs to understand how the trees behave and which properties they must have.

According to Rackham (2003, 3) trees form part of four existing traditions of land-use, which are: the plantations where we may find a significant number of trees belonging to the same species and having approximately the same age; woods which are a combination of different species, ages and might have been intentionally planted; wood pastures wherein its growth is directly influence by the grazing animals; and, finally the non-woodland communally used to separate fields in different counties, such as United Kingdom and in some parts of the northern Portugal and Spain. However, regarding the carpenters need to found specific natural angles, sizes and shapes, there were only two ways to achieve the purpose. By pollarding or lopping which "is the practice of cutting a tree at between 6 and 15 feet [182, 88 cm and 457, 2 cm] above the ground, leaving a permanent trunk called a bolling (…). This sprouts in the same ways as a coppice stool, but at a height where animals cannot reach the spring, and yields and indefinite succession of crops of poles" (Rackham: 1976, 9; Rackham 2003, 3). A variant of this forest management type is shredding, in which side-branches are continuously cut off, leaving the tuft at the top of the tree, which provides correct shapes to convert the tree into timber and also helps to feed animals (cattle). The second tradition to manage forests were coppicing and suckering, which consisted of cutting the tree on the lower part of the trunk. However, because the animal interaction with the left roots these areas could not be unprotected from the absence of boundaries and security.

2.3 Finding the timbers on a tree

From a tree independently, if it is from the trunk or the branches, there are four distinct parts: the pith, heartwood, sapwood, bark edge (*libri (Charles: 1919, 7)*) and the bark. Besides all of them have an important function on a living tree, when the purpose is to have ship timbers some tree components are disregarded. From the viewpoint of a shipbuilder, the pith gives the exact understanding of the natural grain and shape of the tree to convert in the timbers. The densest and strongest part: the heartwood. The softest part is the sapwood, where new cells are still open allowing the sap to flow through the filaments, which makes it more vulnerable and permeable. The bark edge is the part that divides the sap-

wood from the bark and defines the limits of a trunk or branch for the shipbuilding purposes. By understanding different wood characteristics, carpenters may obtain the timbers that they need to use for building a ship. Another fundamental aspect was: which moment was the correct to cut a tree? This may varies from country to country, location to location or even from dockyard to dockyard, and was directly related to the astronomic cycles. Which means for instance that in the temperate areas of Portugal some carpenters chose to cut the trees in late autumn immediately after the leaves fall (Castanheira: 1991, 1). Other carpenters ("Mestres carpinteiros do antigo Arsenal do Alfeite" – Master carpenters from the old nay dockyard, Ribeira das Naus, Lisbon Portugal) preferred the month of August, especially for the pine (*pinus pine* and *pinus pinastre*), and the oaks (*Quercus Suber*) between October and February when the sap is less active (Valente: 1948, 52). Nevertheless, they could not disregard that "the size and fine growth of a tree is not an infallible sign of goodness of quality in the wood. The connection of the age of a tree with its development and the nature of the soil in which it grew, ought to be inquired into to enable a judgment to be formed of the quality of the wood" (Desmond: 1919, 8). This means that characteristics such as durability, uniformity of substance, straightness of fibre, strength and elasticity are fundamental for shipbuilding. But, another challenge exists: there are no such things as perfect trees to convert in perfect timbers. The carpenter still needed to find the place in the available raw material where the knots and cross-grained could be avoided. These kinds of "imperfections" usually represented weak points in the timber structure, especially because it interrupts the natural grain of the trunk or branch and, in case of being subjected to high pressures, may generate cracks or even worse, the promotion of holes caused by natural extraction of it.

2.4 The storage and converting process: Converting trees into timbers using an axe or saw

After the trees are cut, the growth process is completely interrupted leaving the timber exposed to all environmental events and it will inevitably start the degradation process. Therefore, if proper storage was disregarded, timbers could naturally split in case of fast dehydration, if they suffer high temperatures, it will initiate fermentation, which will be followed by loss of consistence and consequently attacked by worms. To avoid the loss of these precious raw materials, the timbers had a special place to be stored in the dockyards known by "a peculiar odor" (Desmond: 1919, 9), where they were piled by using two basic rules: to pile timber by shape and reduce the contact between them at all cost (this procedure helps the circulation of air and the fixation of harmful microorganisms). Another technique used to store timbers was to bury them in an anaerobic area "nas proximidades da embocadura de um rio e num ponto em que a mistura da agua doce do rio com a salgada do mar seja em quantidade a não deixar sobreviver o taredo / nearby a river where the fresh and salty water meet and avoid the presence of *teredo navalis* (shipworm) ". However, in any of the adopted storage criteria the display of the timbers should be organized by its special characteristics, size and function, which means that in general at the shipyards should exist a place where the timbers were separated by – hull timbers, rigging, paus direitos, curves (Castanheira: 1991, 30) until needed.

Once the carpenters needed the timber they could split them into several parts using an axe or saw. These processes mainly depend on the shipbuilding tradition. For instance, in Portugal, the trunks and branches were first converted into timbers with gross forms and when needed they were finally shaped with the exact measurements to fit its place in the ship frame. This final shaping could be done by using saws or other special tools in the shipyards. Another possible method consisted in first identifying the natural cracks in the tree and using them to split in the needed part by using an axe.

3. Anatomy of ships: basic concepts for box to sail

Either for boats and ships, there are three basic concerns: buoyancy, gravity and stability (Steffy: 1994, 8). Buoyancy is an inevitable need when the purpose is to carry something safely through water from one place to another (Pomey: 2001, 26). When used in direct proportion with gravity, it allows one to combine available space with increased weight. Furthermore, by joining this rule with balanced shapes and proper raw material (strength), the shipbuilder achieves the stability. "Whatever the degree of elaboration or complexity, from the most basic boat to the most sophisticated ship, the construction of a vessel is never an act of chance. It is a response to a demand and to specific needs" (Pomey: 2001, 26).

The ForSEAdiscovery Project objectives are centred in the reconstruction of the past Iberian Peninsula forestry and shipbuilding between the 16th and 18th centuries. This chronological period represents the so-called Age of Discoveries, the Golden Age of Shipbuilding, or any other to expression to represent one of the most significant periods for the advance of knowledge in humankind.

In these chapters related to shipbuilding, the next few words may be considered absolutely justified when looking at the main objectives for the WP2 / ESR6 objectives. The search for answers related to the main question: How did the carpenters see timbers in trees, needs to centre on a close view of the time (chronology) and place (geography) of the subject. Which leads us automatically into a review of the methods used in shipbuilding in the Iberian Peninsula for the Modern Age. Different studies were undertaken by teams of historians and archaeologists, especially when related to ship wrecks along the coast of Portugal and Spain. These ones may tell us much about the methods used in the dockyards of these two countries. However, to define what is an Iberian ship still is not an easy task, and it may not be possible to find a straight answer (Barker: 1998; Castro: 2008). In this project perspective that uses a combination of maritime archaeology and dendrochronology, an Iberian ship may be: a ship built in the Iberian dockyards, a ship built with native trees, a ship built by Iberian carpenters, or a ship built under Iberian treatises. Maybe the definition could become overly attached to the team's own skills and interests, or to the research line that guides the ForSEAdiscovery Project. There is no absolute truth regarding a scientific project for humanities research. Although, "the combined textual and ethnographic evidence suggests, nevertheless, that Iberian ship design and construction was strongly influenced by imported Italian shipwrights, following a conceptual model that is believed to originate in Mediterranean galley construction, although archaeological proof of this is inconclusive. Arab influence may also have been important, although it is even more difficult to prove because there is an almost complete lack of evidence" (Castro: 2008, 63). But interpretation under the perspective of the wood sciences an Iberian ship is a vessel built with native trees from the Iberian Peninsula. So, to find a balance between these two main concepts was considered that independently of the shipbuilding tradition, a ship is always considered as a box that carries something and from one point to another by water. Which means that for the purpose of this research project, all known ships that belong to the two countries between the 16th to 18th centuries are potential candidates for the research.

3.1 Building a ship. Shaping the hull

Before any attempt to build a ship there is a need to draw in 2D the first lines where the hull shape was defined, and the theoretical perspective of where the master futtock, the bow and the stern meet each other. Those magic lines representing the three views (or plans) attend to materialize the idea that the shipwright had in his mind and, in fact they are more than just simple straight and curve lines. They represent centuries of knowledge achieved and passed from generation to generation. The basic lines gave to the carpenter the angles, the measurements and especially the shape that the hull must have.

There were three major shipbuilding methods used in Europe between 16th and 18th centuries – bottom first, shell first and skeleton first. Since the last mentioned in the Iberian dockyards is essential to understand how it is developed. The process started to be materialized when the first tree parts were place in the *Carreira* by joining the keel at one end to the bow, and at the other the stern, and the master futtock at mid-ship. When these main parts are in place, the skeleton is filled by all other similar parts with small variations between them. This gave the "box" the necessary shape, buoyancy, strength and stability to sail. The hull-form, even when associated to one specific shipbuilding tradition, may vary from place to place because it was continuously "affected by the extent of technical knowledge, available materials, intended routes, cargoes, economics, environment, social structure, political influences, and a host of other prevalent factors" (Steffy: 1994, 12).

3.2 Shipbuilding treatises

Besides the knowledge passed from master to apprentice, to increase safety at sea countries developed the need to standardize measures, shipbuilding methods and basic rules. This increased need came when the ships became bigger and heavier than ever. A launched ship at sea with the crew and cargo was too expensive to be lost. The first Portuguese treatises for shipbuilding were written by Fernando Oliveira (1580) *Livro da Fabrica das Naus,* and

by João Baptista Lavanha (1610) *Livro Primeiro da Architectura Naval*. These books tell us the basic rules, measures, and ships' main characteristics, but disregards the basic knowledge already achieved in the 16th century. However, "the combined textual and ethnographic evidence suggests, nevertheless, that Iberian ship design and construction was strongly influenced by imported Italian shipwrights, following a conceptual model that is believed to originate in Mediterranean galley construction, although archaeological proof of this is inconclusive. Arab influence may also have been important, although it is even more difficult to prove because there is an almost complete lack of evidence "(Castro: 2008, 63).

In Spain Juan Escalante de Mendoza (1575) *Itinerario de Navegación de los Mares y Tierras Occidentales*, Diego García de Palacio (1587) *Instrucción nautica para el buen uso de las naos, su traça, y gobierno conforme à la altura de México* and Tomé Cano's (1611) *Arte para Fabricar, Fortificar y Apareiar naos* contain the best descriptions of Spanish ships from late 16th to 17th centuries (Castro: 2008).

3.3 GLOSSARIES

Steffy (1994: 6) has said that "shipbuilders and sailors talked strangely. They spoke of futtocks and timbers and martingales and moonrakers". Considering that a ship is a world inside a world, every part of itself needed to have a name. Sailing on these vessels was a tremendous challenge, and the crew needed to understand instantly which part was meant, just by hearing to a name. For instance, when the ship was at sea sailing, there were no margins for bigger errors, so that every sailor on the masts needed to understand what was said by the masters of each mast, in order to perform the correct actions. Even today, the new cadets when aboard need to know the name of each part of the ship. However, the names changed from place to place and from time to time. The glossary is an essential tool to understand the treatises and to demystify the rules and measures, so that we may comprehend the shipbuilding techniques. The main challenges for building a glossary are the dating, the local terms and the shipbuilding tradition. Why cannot we "adopt one maritime dictionary as a standard?" (Steffy: 1994, 6). The answer for this question resides in the fact that we are studying ships that were built in several places, by different kinds of people and in such distant places. These three aspects are not established by a hierarchy between themes, but on the contrary they are strongly connected.

To develop the tasks undertaken in this research project, it is essential to have a glossary to help to establish in one way a link between the timbers as a part of the ship and, at the other to understand what kind of characteristics the timbers should have to be used in shipbuilding. This process is not linear and many referred names related to any other parts that do not involve the usage of wood, such as timber frames, planks or masts will be mainly disregarded especially because the main core of the project is to find answers related to the trees as a raw material.

Directly associated to glossaries is the data storage. Every excavation brings to light a huge amount of data related to an archaeological site, from which references are built and may tell us about shipbuilding traditions, artifacts and methodology. This data may be provided from several areas of expertise – multidisciplinary archaeological projects. In many cases, at the end each project the dissemination process takes place, and eventually the exhibitions of preserved artifacts. But, what will come after, all challenges, efforts and risks took by the team in order to achieve the aims to understand the construction principles and methods of a ship, that governed its conception and realization in a precise historical context (Pomey: 2011, 34). According to Steffy (1994: 189) "Piles of rotten timbers and broken artifacts constitute a wealth of information, yet much of that knowledge will remain unrecognized unless one develops a proper method of access to it. In case of shipwrecks, though, access is the mastery of a discipline … which is essentially the means of access the wealth of information stored in the remains of ships and boats and the orderly dissemination of the knowledge derived from them". Advances in technology such as computing, recording instrument and tools have impacted fieldwork development and how the data is presented and stored. Software "such as HPASS (Green and Souter 2002), Site Surveyor (Holt 2008), Photomodeler (Green, Mathews, and Turanli 2002) and Rhinoceros (Rhinoceros 2009) illustrates examples of applications used in nautical archaeology ranging from GPS and triangulation to CAD and 3D modeling" (Castro et al: 2011, 329). For the particular case of building glossaries, it may be considered relevant to combine sources from archaeological sites with the archives that may tell us the words and names of every ship part. Apparently this could be judged as common sense, but the joint between

archives and material culture may be present in several ways. One hypothesis is being developed under this research project by using collected data from archives, archaeological sites and previous studies and presenting it through a digital scheme. The selected timbers will be recorded using a digital 3D CAD with methods of precise accuracy, and displayed in layers in order to build a 3D glossary with multiple databases associated. The biggest risk of developing this glossary / database is the eventual need of having a powerful server to assist in any demands. However, to the end user all the information may be provided as a webpage and consequently available in any desktop, tablet or other device. The bigger advantage, is without any doubt the chance to have as much data as the server allows in real time. By using this process it is also expected to have enough data to understand some of the main key points for the Iberian shipbuilding tradition, its origins and evolution and outside influences.

4. IMPROVING THE TIMBER RECORDING METHODS IN MARITIME ARCHAEOLOGY

The recording methodology may be considered one of the most essential processes of excavation. This task usually involves a great part of the project's financial resources and team effort. Although, the record of timbers (and artifacts) is always an interpretation of the facts. By the assumption that every archaeologist uses their own skills, experience and knowledge, we will always have studies influenced by perspectives. Because of this perception, the biggest challenge may reside in what available technology we have today. As I am concerned, in the past 30 years of maritime archaeology, the record of underwater archaeological sites were done by using sophisticated techniques and software to achieve the objectives and purposes for the research. In comparison, the excavations in the early 80s (past century) for the excavation (coordinated by Alves) of the Admiral French ship *L`Ocean,* which sank nearby the fishing town of Salema, Lagos in Portugal, with the campaigns (coordinated by Alves and Castro) of the presumed *Nossa Senhora dos Martires* in late 90s (nearby Lisbon, Portugal), we may say that they were developed with a very thorough and professional methodology. But in fact, the times have changed and the pursuit for knowledge is remarkable. In the first decade of the 21st century the record of underwater archaeological site – ships became extremely advanced by using available technology in the purposes of archaeology. Image capturing devices adopted for underwater combined with specific software, such as Photoscan (Agisoft), new version of Rhinoceros (5.0), Autodesk (Maya) and others are being used to obtain more and accurate data. Also reduces storage physical space and is accessible in a faster and reliable frame.

Hocker (2006: 2) state: *"In the Philosophy of Shipbuilding we seek to create one of those departures point, a general theoretical statement on the process of shipbuilding, the most essential of maritime technologies. This is not meant to be definitive or final – in fact, the contrary. It should be noted that the authors do not always agree, and this divergence of view-point is an essential part of the book. It is meant to show both how far we have come and how far we have yet to go, what the major outlines are and where the gaps are. It is intended to provoke discussion, to encourage our colleagues to come up with better ideas. If we have done our jobs well, this volume may still have some use in a "history of archaeology" classroom in fifty years' time, but it should be rendered technically and theoretically obsolete long before then".*

The interpretation of Fred Hocker's words, leads us to constantly challenge the used methodologies for recording timbers. Most of the excavations that took place in Portugal and Spain adopted the 2D recording method by using a simple marker or a laser point. These drawings are remarkable and give to next generations enough information for data review. However, besides the existing rules and recommendations for the purpose the drawings are an interpretation of what the archaeologist saw in that moment. Years later may come the need to analyze those drawings and the perspective may already change and we will need to draw the timbers again (if they still exist). What is meant to say is that under a research project all the available tools should be used (reasonably and effectively). For instance to analyze the remains of the *Cais do Sodre* Ship (C14 – c. 1500) or the Corpo Santo Ship (C14 – c. 1400) or even the Ria de Aveiro A Ship (C14 – c. 1500) we will observe a very thorough and professional drawing displaying the timber shape, the nail holes, tree knots and scarves. But regarding the available data for this research project, as I am concerned it only give us a few details of the timber as a raw material and will not be enough to rebuild the trees. Which consequently will not provide sufficient data to

identify tree shapes, evidences of forest management or the pith location for tension (bend) analyses.

To develop a theoretical approach of the choices taken by carpenters regarding the usage of trees for shipbuilding, it may require in same cases to re-analyze all the timbers again. Obviously, this process may happen ever since a new technology became available for archaeology. Although, for maritime archaeology, especially when it refers to the interpretation of a shipbuilding tradition "the choice of trees to fell as a function of their species, the morphological characteristics of each individual tree, and the different structural element that it could provide, then the felling, transport, and storage, all set in motion a series of operations that reveal the organization system of the society that built the vessel" (Pomey: 2011, 31).

4.1 Previous studies: recording the past

Published in the 2000 in the Maritime Archaeology Newsletter from Roskilde Denmark nr. 14 the article 'New tools to archaeology' by Fred Hocker, states that "our [archaeologists] task is to develop better methods of collecting and managing the raw material of archaeology. "Better" means producing higher quality data that will allow archaeologists to answer current questions with more confidence, as well as new kinds of data to allow exploration of new avenues of research. "Better" also means finding ways to produce usable data more efficiently and to communicate the results of our research effectively. Finally, it means finding more effective ways of preserving the objects and sites we investigate, so that they can continue to generate new data for future archaeologists" (Hocker: 2000, 8).

The recording of ship timbers may be done in many ways, including the traditional 2D drawing, where the archaeologist represents the relevant data for his research. This process may be compared to the layers or sections on the excavation of archaeological sites inland. However, regarding shipwrecks, especially when the recording of timbers is taking place, there is an alternative methodology which is capable of representing those timbers not by layers, but by the three-dimensional thought of the shipwright when he was drawing the basic lines of the hull, and the carpenter when is choosing and shaping trees to convert them into timbers. This alternative recording method is also able to provide solutions based on the archives and remains of ships to rebuild the theoretical shape of the hull and ship. Using this specific methodology, that may be called reverse engineering, it will be possible to find answers for: What shape has the tree before been cut; how many timbers were used from the same tree in order to identify the converting used methods; and what methods were used to manage the forests? All these questions may vary from project to project, and in this research project it will be used for purposes mentioned in the introduction, but may be used in other investigations.

It may be considered that the excavation of the Newport Medieval Ship, which led to the usage of three-dimensional digitizer arms to record the ship's timbers, is most successful until the first quarter of this century. In fact, this procedure based on other previous studies generated a new way of looking through the timbers and collecting reliable data, under 3D CAD user friendly, easy to store, fully accessible by any person without special computing requirements, permitted the reconstruction the ship under a theoretical approach and, finally launched the challenge for the future of maritime archaeology.

4.2 The 3D CAD timber recording methodology: a different approach

The usage of three-dimensional digitizer arms to record ship timbers, as I am concerned, started under the development of a project undertaken by a team from the National Museum Denmark in co-operation with Klaus Stettrup Jensen of DKC (Hocker: 2000, 30). However, the increased usage of the 3D CAD recording occured during the excavation of the Newport Medieval Ship, discovered in 2002 where after the complete removal of timbers and artifacts, the Riverfront Theatre and Arts Centre in the city of Newport in South Wales was built. The team of archaeologists and conservators cleaned, recorded and initiated the conservation process of the timbers. The entire ship was disassembled and the timbers were displayed in tanks of fresh water for preliminary conservation. During this process, which included the analysis of the shipbuilding adopted methods, the artifacts and by the dendrochronological and historical research, the collected data indicated that the ship was built in the "middle of the 15th century possibly in South Western France" (Jones: 2008, 85). This process also included the recording of the complete set of timbers by using a FaroArm

three dimensional contact digitizers and Rhinoceros 4 digital modelling software, which allowed "to produce three dimensional physical and digital solid 1:10 scale ship model by converting three-dimensional draw into a by using using modelling software packages including Rhinoceros 4 and Solidworks" (Jones: 2008, 85). The timber shape was manufactured by a process of selective sintering, that consists in the usage of a laser beams to melt successive layer of finely ground nylon plastic dust. This allows the setting of the planks along the timber frames to achieve the hull shape and consequently the original hull form.

Another advantage of this process is the chance to generate the theoretical ship shape from the keel to the rigging and develop digital essays related to the hull performance in the water as well as for dissemination purposes.

CONCLUSIONS: CHALLENGES AND THOUGHTS

This specific research project will run for three years (started in 2014, 1 of September) and aims to develop a dendrochronological approach in maritime archaeology to understand how the carpenters choose and convert trees into timbers, as well as to contribute for the next step of the digital timber recording. This necessarily involves tree ring analysis, diving operations to collect samples from presumed Iberian shipwrecks, and improving skills in digitizer arms and computing.

The major challenges in this research are to keep looking at the remains of shipwrecks either at sea or in land and to see the trees through the timbers and hull shapes to identify possible shapes already visited by the carpenters, moments before they started to give them the needed angles in the dockyards.

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Tróia 1, a journey in time and sea. Shipbuilding and the shipwreck

Tróia 1, un viaje en el tiempo y el mar. La construcción naval y el naufragio

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Abstract: The 19th century is considered the epitome of shipbuilding techniques employed in Iberian dockyards. The increasing need to carry products over longer distances at higher speeds promoted the building of vessels and challenged the basic rules of buoyancy and maritime safety. In parallel with the need to produce more advanced vessels, shipyards also had to respond to new commercial interests that increasingly exploited existing maritime trade routes. The preliminary conclusions presented here describe multicultural and multifunctional ports where crews, passengers, dockers and sometimes shipowners interacted in such a small space. Based on this socio-economic, maritime and cultural context, this paper will focus especially on the shipwreck of Tróia 1 which sunk in the second half of the 19th century, near the city of Setubal, Portugal.

Key words: Maritime archaeology, shipbuilding, maritime routes, contemporary Age.

Resumen: el siglo XIX es considerado el epítome de las técnicas de construcción naval empleadas en los astilleros. La creciente necesidad de transportar más productos, a través de largas distancias a mayor velocidad, promovió la floreciente construcción de navíos que desafiaron las leyes elementales de la flotación y la seguridad marítima. En paralelo a la necesidad de producir navíos más avanzados, los astilleros también tuvieron que ajustar esta nueva realidad para poder corresponder a una interesada demanda comercial en el extranjero. En este siglo se asientan las rutas de comercio marítimas y los puertos representan una multicultural y multifuncional imagen, donde tripulaciones, pasajeros, estibadores, y a veces los propietarios de los barcos se cruzaban en un espacio tan reducido. Este artículo se centrará especialmente en el pecio de *Tróia 1* que se hundió presumiblemente en la segunda mitad del siglo XIX, cerca de la ciudad de Setúbal, Portugal.

Palabras clave: arqueología marítima, construcción naval, rutas marítimas, edad contemporánea.

Concepts and thoughts

Historians and archaeologists seek to reconstruct the past by reading and analyzing written sources and excavating structures and artifacts. Steffy is changing the way of looking at the past with his remarkable *Wooden Ship Building and the Interpretation of Shipwrecks* (Steffy, 1994). This teaches us that the act of reassembling the pieces of a long lost vessel, consists of much more than simply record their spoils. His concept allows us to think and go further than just the simple approach of trying to understand the remains of a vessel. A ship is born when the owner is moved by his desire to increase profit or the dream of exploring new worlds. The ship's writers and carpenters bring to life their thoughts and experience when the first basic lines started to be drawn and the first timbers started to gain the correct shapes. Their knowledge passed from generation to generation and demonstrates the complexity required to build a vessel capable of leaving a port, crossing an ocean and reaching its destination safely. With these ideas inspiring their actions, the shipwrights, carpenters and blacksmiths teach us today how they were able to convert hundreds of trees in the most diverse shapes and dimensions. Once built and launched on the water, the vessel becomes the residence of its captain and crew. These humans act as fishermen risking their lives in the North Sea or merchants who moved from port to port.

Analysis and interpretation of the wood structures and methods of shipbuilding

The remains of the Tróia 1 are completely scattered on an area of approximately 13000 square meters, where different wooden fragments of the hull may be seen.



Figure 1. Tróia 1 Archaeological site.

The wooden structure located in the central core is a fragment of the ship's hull where several planks are still attached to the timber frames. The wooden hull fragment close to the set of two anchors toward east-west (central core-spot «0») has a similar configuration to the first wooden fragment. At the west sector a fragment of a deck knee can be seen as well as the presence of beams. However, this section of the deck is displayed in an inverted position enabling the full visual observation of the deck planks. The keelson, and second keelson or buttress, were isolated from other hull structures after the collapse of the vessel and dragged through the bottom of the sea.

The anchor type «admiralty» located near the central core, presents a similar configuration to the other located at spot «0». Although it only remains a fragment and it's presumed wooden stock.

During the excavations the late finding of the bow proved to be critical for the interpretation of the shipbuilding method used in the manufacture of the ship. As a result of further analysis it was possible to identify and assess the possible dimensions of the vessel and to develop a theory as to the ship's size and function. Moreover, the positioning of the remains with respect to their geographical orientation provided useful information about the heading of the vessel. The bow was facing north which means that the ship's crew was trying to enter the Sado estuary bearing northeast. The winch also facing the same way, apparently fell on top of what would be the mooring storage and has not moved since the ship structure has collapsed. However, we still have not concluded where the ship was built or its provenance on its last journey. The timbers were analysed and we conclude that the hull is made from *Ulmus Minor* (elm) and *Abies Mill* (silver fir) (wood anatomy analysis developed by Claudio Monteiro (project curator)).

Another unanswered question that remains is related to the ship's propulsion. Given the presence of huge set pieces of rigging, the absence of any mechanism to add propulsion (such as boilers or any other kind engine), shaft, or bearings, and propellers. In order to address this question, it was necessary to analyse similar ships to understand the shipbuilding methodologies employed. The remains of the schooner *Novos Mares* displayed nearby the Maritime Museum of Ilhavo were analysed as well as the publications written by shipwriters and shipbuilders (Desmond, 1919; Castanheira, 1991; Silva, 1948). Table 1 shows the results of that analysis where the different measurements (schooner Novos Mares, Tróia 1 and the guidelines from the shipbuilder Silva Valente (1948: 33) are displayed.

Timber Typology		**Ships**		**Rules for shipbuilding from the shipbuilder Silva Valente**		
		Troia 1	Schooner Novos Mares	Basic measurements		
futtocks:				vessel configuration	length between perpendiculars	45.50 m
	futtock configuration	double	double		floating length	10.60 m
	thickness	16 cm	15 cm		deck length	10.60 m
	width	14.5 cm	15 cm		careens depth	4 m
	length	n/d	35 cm		aft draft	5.05 m
	spacing	17 cm	15 cm		fore draf	3.82 m
planks:				bottom-line of the hull and the perpendiculars fore and aft	bottom-line to the line	4 m
	outside	6 cm	10 cm / 8 cm		bottom-line to deck	7.75 m
	inside	4 cm	9 cm / 12 cm		bottom-line to the castle	10 m
					bottom-line to the bow top	10.80 m

Timber Typology		Ships		Rules for shipbuilding from the shipbuilder Silva Valente		
nails:	iron	n/d	1.5 cm	heights in the master frame	from bottom-line to deck	6.60 m
	copper	1.5 cm	n/d		bottom-line to top	6.60 m
kell:				height aft	bottom-line to fluctuation	4 m
					bottom-line to deck	6.25 m
	shape	n/d	composite		bottom-line to castle	8.50 m
	thickness	n/d	51 cm		bottom-line in the middle of the stern contour	5 m
	width	n/d	n/d	length of castles, depending of perpendiculars in overall length	sft castle	11 m
	length	n/d	n/d		Bow castle	15.50 m
					keel width	0.50 m
					keel thickness	0.50 m
keelson:	thickness	15	29 cm			
	width	35	32 cm			
length			43.68 m		53 m	
width			10.41 m			
depth			4.91 m		5.6 m	
Tonnage (bruta)			433.74 tons		between 110-1200 t	
tonnage (Liquida)			334.66 tons			

Table 1. Comparison Table between the dimensions of Tróia 1-Schooner the *Novos Mares* and Valente (1948, 36) and Desmond (1919, 22) tables.

Based on the foregoing table, it is possible to find answers to questions relating to the type, measurements and chronological period. For instance, there are some similarities in measurements between Tróia 1 and *Novos Mares*. Especially in timber thickness and width, the inside and outside keelson and lining as well as the thickness of the pins. The vessels therefore could have similarities in type or function. Moreover, according to the records the *Novos Mares* has strong similarities with the rules written by Valente, and in the applied scale we may achieve the Tróia 1 measurements by the rule (length × pontal *Novos Mares*) / length) = (43.68 * 5.6) / 53 = +/– 4.91). These measurements and analyses allow us to fit Tróia 1 into the typology of a schooner.

The last large wooden ships built in the country until the mid-twentieth century had bolts, rivets and iron nails (Silva, 1948). Although in some cases they could still be manufactured in brass materials to reinforce the assembly used in areas below the water line. However, neither

of these situations applies to Tróia 1, since in all wooden structures bolts, rivets and nails of bronze were used. This indicates that the Tróia 1 was first built between the beginning of the 19th and the first quarter of the 20th century.

According to the current stage of the site formation, its positioning, the scattering of remains found and the absence of structural parts of the hull, including the keel, may lead us to think that the reason that the vessel sank was a wrong approach to the deepest canal of the Sado (northeast). Where soil conditions promote significant variations on the water column that goes from depths below 20 m to 8 m and then to 4 m in relatively short distance. This may have influenced or originated a crash against the sand banks, causing massive and ongoing destruction of the hull along the entire length of the shoal.

Other issues arose during the research, such as: What was brought on board? We have not yet reached clear conclusions related to the cargo or structures and containers, but based on the existing archives (Torre do Tombo, Arquivo Distrital de Setubal), the port of Setúbal, was commonly used for trading fish and raw material such as salt. So we may conclude that the Tróia 1, *as* a schooner would have possessed a significant space for cargo and its main activity was likely related to the transport of salt, fish or other goods in bulk.

Historical background – the navigation and maritime routes

To make possible the interpretation of traces related to underwater cultural heritage in the Sado region, as well as the strategic importance of the delta of Sado, it is necessary to go back in time until the moment that people, having the need to transport more quickly, crossing a river or to navigate goods between islands, soon began to build small boats. Along with the evolution of the people and improving techniques of shipbuilding, work continued on a rolling process that has been recorded up to the present day. Tróia was located on the south bank of the River Sado during the Roman period (1st to 6th century of our era) and was an important center for the fish industry which benefitted from the significant abundance of salt and fish in the cool seawater. High levels of production and an expansion of the industrial compound also contributed to the increase maritime traffic. Not only with the intensification of fishing, but also with an increase in the number of vessels used to carry the fish products that mostly supplied Rome (Almeida: 2008, 12). However, the use of salt for the purposes of industry or trading was not only developed during the Roman occupation, but the beginning of it through centuries.

Since the early 1950s most of the archaeological artefacts recovered from the river Sado (especially in the Caldeira de Tróia) are mainly related to the Roman period. Although, the archives refer to a large number of shipwrecks in the Sado estuary especially at its mouth. There are just a few located shipwrecks though, and mainly from the second half of the 20th century, which made the finding of the Tróia 1 very significant for the area and its chronology.

For a better understanding of the importance of the sea and the estuary of the River Sado for the population of the surrounding towns, we can highlight two different usages of the water. The first one refers to a partnership with the sea, with populations in which its economy was based on the shipbuilding industry, stowage and transportation and fish commerce. For the second, the more restricted usage of the confined water of the estuary. Based on the nautical history perspective, we are in the presence of a population in which their livelihood is based unequivocally on activities related to the sea and the river. There are several factors that contribute to the success of this industry, such as the geomorphological setting of Sado region. Which is the first natural harbour for vessels sailing from south to north, which has ideal conditions for the safety of populations settled in nearby villages. This provided two things – easy access to the sea, essen-

tial to their livelihood; and a broad estuary capable of hosting an extensive and varied range of vessels regardless of their type, size or functionality. Strongly attached to *Sadino* culture, salt has over the centuries been of the utmost importance and reaches a greater significance in the mid-19th century, when the need to preserve food items was essential during long ship journeys. Thus it achieved the status of essential good, and became vital for countries producing goods with basic conservation needs, but were not salt producers themselves. For instance, countries in northern Europe, particularly Ireland with unsuitable atmospheric conditions for the production of salt, had a need to import in order to safeguard the production of artisanal butter (which was Europe's largest producer), and meat preservation for consumption across regions.

1. Bovine cattle, low metabolic productivity but very important as they were the typical *milch cows* of this landscape, are responsible for the production of milk and therefore the production of butter.
2. Swine cattle, which was considered highly productive but exclusively targeted for immediate consumption, since without salt for conservation, this could not be sent to British colonies.

During this process, operating in the prevailing commercial and maritime corridors between the two countries, the commercialization of salt saw it named locally as *white gold*. The salt, traded on a frequent basis but in small amounts, would eventually prove essential to the populations of Cork (Horta, 2005) whose livelihood was based almost exclusively on the production of handmade butter. However, Portugal later realized the importance of Cork, which proved to be decisive in establishing trade between the two countries, becoming one of the main destinations for the trade of domestic products (Horta, 2005).

The port of Cork, set in the south of Ireland and geographically aligned with the Atlantic Ocean currents, proved to be a strategic port for maritime trade between Portugal and the British Empire. The established shipping lanes and business relationships that came to develop, accelerated the trade in various goods such as salt, wine, cork and fruit (Horta, 2005). These products were transported almost exclusively by Portuguese vessels enhancing the economy of Portugal – particularly for shipbuilding and other labor associated with marine industries as well as all the necessary logistics for export (crews, ports, shipyards, etc). It became necessary to establish consular offices across borders in order to protect the rights of Portuguese navigators and sailors. Trade regulation was established including customs duties and aid to Portuguese vessels in case of wreck or accident. The importance of this export trade was so large that consuls and vice consuls were installed in many different areas such as Dublin, Limerick, Waterford, Belfast and Derry, embracing all Irish territory (Horta, 2005).

Salt production was carried out seasonally, which suited the slower and purely handmade production of butter in the country side cottages. In the return circuit, butter from Ireland was received in the port of Lisbon and then consumed in all regions of Portugal, which was the second largest consumer of butter immediately after England. This justifies the intense maritime traffic between the two countries, and highlights the fact that the port of Setúbal was the largest port of exports to Ireland, and Lisbon – the main destination of vessels from Ireland.

Considerations

The remains of Tróia 1, represent the first known underwater archaeological site near the mouth of the river Sado. But, as mentioned before, it likely represents just a small portion of the maritime heritage. The archives may tell us much about incidents related to ships, but under the perspective of an archaeologist it is far more interesting if we join the archives with material evidence. The Tróia 1 Project was developed during three (amazing) years where «us» archaeol-

ogists had the precious help of marine biologists, geologists, hydrographers, conservators, enthusiasts, and undergraduate and postgraduate students. This project was born from the will to know more about tremendously scattered ship remains. The dedication and enthusiasm of the team led to the development of the research project and it is expected that the answered questions constitute only the starting point for another three years of research. Every one that was involved in the diving operations soon became more and more interested to know about the site formation. The hull fragments, by the way they are displayed tell us so much, that sometimes we just stayed looking at it trying to figure out where to start. The Tróia 1 research project brought to light that a team with completely different backgrounds may work for the same purpose.

At the beginning no matter from which perspective we look, the wooden fragments remained a mystery. The devastation caused at the moment that the ship was sinking and successive winter seasons and storms, covered most part of the hull timbers. The first results only started to be achieved when the team learned when were the best tides to collect data during the dive operations. The site is predominantly plagued by strong tides and waves due to its 6 meters depth (in other places – such shallow remains are an advantage!). In this particular case there is an asymmetry between the northern and southern shore of the mouth of the river Sado. In the north where the navigation channel is established, the depth and tidal currents are stronger, but the bottom of the sea maintains its shape. However, in the southern channel, which today is only fit for the navigation of small boats, the depth changes from tide to tide. Day by day we may see a different sea landscape, which generates a permanent seabed mutation. This, the essential task of collecting data took us more time than expected. But yet, now we know with reasonable confidence that the Tróia 1 ship is very similar to a topsail schooner; the crew was trying to enter in the Sado estuary, possibly was bringing bulk products; the hull shape represents a shipbuilding methodology used between mid-19th century and the early 20th century; and, finally that the eventual cause that led to its sinking was a wrong approach to the entrance of the river, which was significantly violent to destroy the ship over a vast area.



Figure 2. General view of ship wooden remains.

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BELINHO 1: REGISTO E ANÁLISE PROVISÓRIA ÀS MADEIRAS DO NAVIO

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RESUMO

Durante as fortes tempestades ocorridas no Inverno de 2013/4, violentas marés arremessaram um conjunto extraordinário de madeiras de navios bem como centenas de outros artefactos ao longo da praia de Belinho no norte de Portugal. Uma equipa de investigação internacional, composta por arqueólogos do Concelho de Esposende, bem como de investigadores do projeto ForSEA-discovery, foi criada com o objetivo de estudar a coleção de madeiras e de artefactos arrojados, recorrendo a técnicas de registo digital e análise multidisciplinar. O projeto de investigação adotou uma metodologia que incluiu a representação tridimensional das madeiras em registo digital. A recolha de dados foi realizada com recurso ao digitalizador 3D *FARO-Arm* que potencializou a obtenção de dados com elevado nível de detalhe da superfície das madeiras da embarcação. Esta abordagem proporcionou a criação de um modelo integral digital de cada um dos espécimes, que foi posteriormente processado e analisado através do software *Rhinoceros 3D*. A informação recolhida permitiu aos investigadores envolvidos modelar e teorizar acerca das linhas originais do casco do navio, mas também sobre as árvores utilizadas na sua construção.O projeto ForSEAdiscovery tem como objetivo investigar a gestão das florestas dedicadas à construção naval ibérica entre os séculos XVI e XVIII. Neste âmbito a embarcação Belinho 1 representou um excelente candidato pelas suas características únicas. Por este motivo foi incluído como caso de estudo num projeto internacional e multidisciplinar, permitindo o desenvolvimento de metodologias de registo arqueológico e pela primeira vez em Portugal adotar-se o conceito de reconstrução do "navio" como uma floresta flutuante.

PALAVRAS-CHAVE: Arqueologia subaquática, dendrocronologia, registo 3D, construção naval, reconstrução digital de árvores.

INTRODUÇÃO AO CASO DE ESTUDO

As tempestades que ocorreram na costa portuguesa durante o inverno de 2013/4 foram excecionalmente ferozes. A linha de costa foi fustigada por ondas invulgarmente altas e ventos fortes que causaram danos significativos nos edifícios e instalações situadas nas zonas costeiras, causando erosão substancial à paisagem. As implicações calamitosas causadas pela erosão foram atenuadas pela descoberta das madeiras que o mar arremessou à Praia do Belinho, em Esposende, trazendo à luz um novo sítio arqueológico. Coube à Direção Geral do Património Cultural (DGPC), organismo do Estado português responsável pela tutela da herança cultural, designar como Belinho 1 este novo sitio arqueológico que compreende todos os achados encontrados até ao momento, bem como quaisquer achados futuros a si associados.

Descobertos de forma quase acidental pelo escultor João Sá durante uma caminhada pela praia de Belinho, que reconheceu nas madeiras que se aninhavam entre as rochas na maré baixa, formas criadas pelo homem. Inicialmente e por não reconhecer a importância do achado, João Sá transformou alguns dos pelouros encontrados em peças de arte. O seu interesse em relação a este sítio foi crescendo e com a ajuda do seu filho reuniu mais artefactos. Em pouco tempo, o que começou de forma casual, como um hobby, ganhou uma nova perspetiva e dimensão na sua vida. Pouco a pouco, o achador apercebeu-se que por exemplo, "as bolas de pedra" eram apenas parte de um vasto conjunto de artefactos. A ideia inicial de que as madeiras arrojadas à praia seriam troncos de árvores foi rapidamente abandonada pois cedo se apercebeu que estas nada tinham de vulgar, mas que seriam madeiras utilizadas na construção de navios. Com esta nova perspetiva em mente, João Sá contatou as autoridades para dar conta do que se passava na Praia do Belinho, encetando contatos com a Câmara de Espo-

sende e posteriormente com o Centro Nacional de Arqueologia Náutica e Subaquática (CNANS)/DGPC, num gesto que acabaria por se mostrar crucial para o salvamento dos achados. As duas entidades traçaram um plano que permitiu numa primeira fase avaliar a situação e posteriormente delinear uma estratégia que possibilitasse salvaguardar o máximo de artefactos. A fim de garantir a proteção desse património, as coordenadas foram mantidas em sigilo até que a extensão total dos destroços fosse conhecida.

Pela necessidade de caraterizar os achados, os arqueólogos começaram por investigar os artefactos arrojados, deparando-se com madeiras indiferenciadas, madeiras de navio, pratos em ligas de estanho e de cobre e cerâmicas. Nas marés baixas foram recolhidos os artefactos de maior porte, tendo sido utilizados para o efeito métodos improvisados no local, como o arraste ou o rolamento das peças de maior dimensão. Tornou-se evidente que mais de um naufrágio estaria representado neste novo sitio arqueológico, pois duas cronologias completamente díspares foram identificadas. O conjunto total dos artefactos corrobora esta ideia, constando no catálogo geral provisório centenas de fragmentos de cerâmicas com cronologia romana a par dos vestígios de um navio pós-medieval e sua carga.

Numa primeira abordagem os arqueólogos locais investigaram os artefactos, separando-os pelas suas cronologias. No caso dos artefactos pós-medievais o catálogo compreende mais de duas centenas de pratos em liga de estanho (com alto e baixo relevo), vários pelouros, artefactos pessoais e uma quantidade significativa de madeiras do navio.

Inicialmente, as cerca de 78 madeiras não aparentavam evidências de correlação entre si. No entanto, quando dispostas em laboratório a equipa de investigadores apercebeu-se que pelo menos alguns dos exemplares pertenceriam a uma estrutura comum. Com esta ideia em mente, a equipa de investigação foi reforçada por um especialista em construção naval em madeira. António Carmo, também conhecido por Samuel (o armador), integrou a equipa e começou a esboçar as madeiras. Cedo foi avançada a ideia que estes destroços eram parte integrante de um navio construído com técnicas tradicionais muito especificas. Paralelamente, as arqueológas Ana Almeida e Ivone Magalhães examinavam as mais de duas centenas de pratos fabricados em ligas de estanho e de cobre, a maioria destes últimos com imagens gravadas de santos e identificados com as marcas de fabricante.

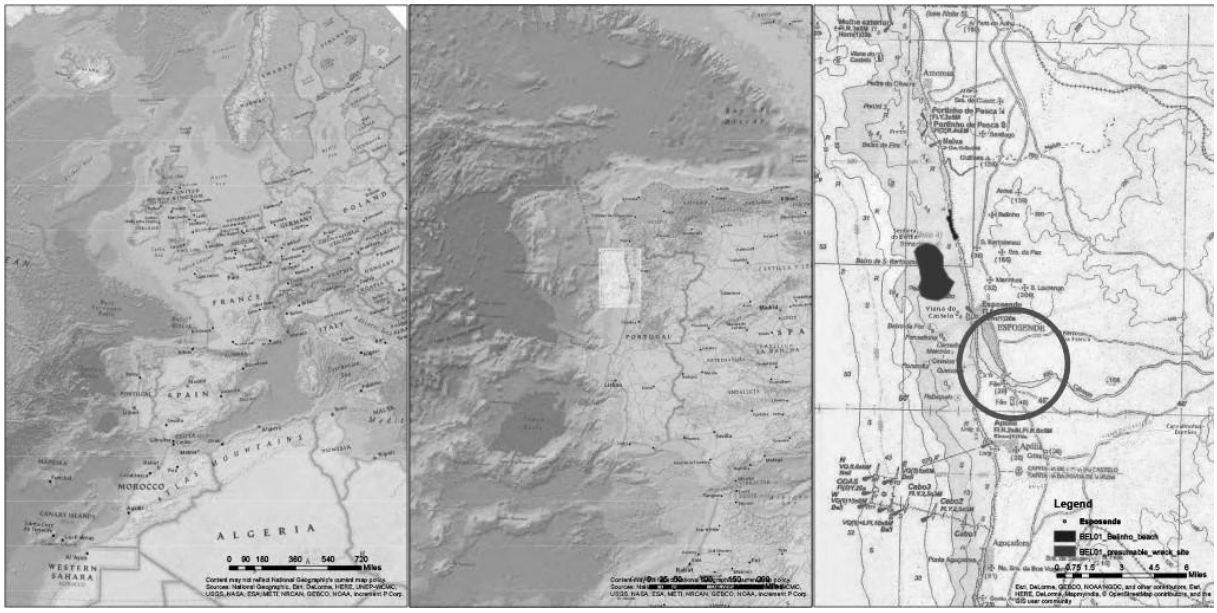


Figura 1. Mapas SIG indicando a região, localização e presumível posição do sítio do naufrágio do navio do Belinho 1 (Adolfo Martins).

Enquanto a investigação decorria, João Sá continuava a percorrer os areais do Belinho na expectativa de encontrar outros artefactos. Importa referir que àquela data (maio de 2014) o acervo era composto por 78 madeiras de navio, 280 pratos, travessas e uma caneca (?) em liga de estanho, 73 lingotes de cobre, fragmentos de três castiçais em liga de cobre, uma bala de espingarda em chumbo, 78 lingotes de chumbo, um conjunto de aros de barril, um parafuso de cobre, uma moeda de cobre, duas fivelas, um machado, partes de uma espada, 21 pedras de lastro e 24 pelouros de pedra.

INVESTIGAÇÕES ANTERIORES SOBRE OS DESTROÇOS DO BELINHO 1

Num estudo preliminar, um grupo de investigadores do Centro de Historia d`Aquém e d`Além-Mar (CHAM), coordenados por José Bettencourt, desenvolveram uma investigação que incluiu o estudo dos pratos e das madeiras (Bettencourt: 2014). Este estudo teve como objetivo identificar a possível tradição de construção naval do navio do Belinho e estabelecer a cronologia dos artefactos de madeira. No entanto, o trabalho desenvolvido consistiu na criação de um inventário detalhado das madeiras e na análise de alguns fragmentos selecionados para o efeito. A equipa de José Bettencourt optou pelo registo da quilha, do coral da popa e de uma das tábuas de forro, juntamente com nove madeiras consideradas como diagnósticas para a identificação das técnicas de construção naval utilizadas. Desta análise e das evidências recolhidas, a equipa do CHAM concluiu que as madeiras faziam parte de um navio construído no final do Séc. XVI (Bettencourt: 2014, 16). Desta primeira abordagem resultou a proposta de elevar a sítio arqueológico este achado, a ser devidamente inventariado e catalogado, bem como objeto de um plano de conservação, dada a sua relevância científica e patrimonial (Bettencourt: 2014, 10).

O trabalho da equipa do CHAM deu origem a um relatório provisório onde o autor conclui que (Bettencourt: 2014, 10):

- Dentro da coleção conhecida de madeiras foi identificada uma secção da quilha, um fragmento do cadaste e o coral da popa, várias cavernas, braços, tábuas de forro e a carlinga do mastro;
- De acordo com este mesmo relatório, Bettencourt concluiu que as madeiras analisadas foram presumivelmente moldadas seguindo métodos tradicionais utilizados na Península Ibérica entre séculos XVI e XVII. Estas conclusões foram baseadas nas evidências arqueológicas registadas, em particular, após o investigador encontrar escarvas tipo *rabo de minhoto* para a união entre as cavernas e os braços. A presença de um coral da popa para ligação da quilha ao cadaste e o uso de picas encaixadas neste, juntamente com uma sobrequilha que compreende a carlinga do mastro, eram também prova da mesma tradição de construção naval indicadas. O investigador reforça as suas conclusões com base na presença de uma folha de chumbo utilizada para proteger as obras vivas do casco do navio. De acordo com Bettencourt (2014, 16) este procedimento foi amplamente utilizado nos navios ibéricos (Atlântico) construídos durante os séculos XVI e XVII.

O relatório termina concluindo que as madeiras do navio que deram à costa na praia de Belinho, têm o seu lugar presumidamente num navio de tradição de construção naval Ibérica, que terá afundado nos séculos XVI ou XVII. o mesmo relatório afirma também que o navio encerra em si muito mais informação e valor (patrimonial e cultural) do que até àquela altura se pôde investigar (Bettencourt: 2014).

O estudo elaborado pela equipa do CHAM sobre o sítio arqueológico Belinho 1 constitui o primeiro relatório científico com especial incidência no estudo das madeiras. Esta foi efetivamente a primeira equipa de investigação convidada pela autarquia de Esposende para analisar o conjunto de madeiras do Belinho, tendo desenvolvido este trabalho preliminar em cinco dias. Muito mais informação existiria ainda por recolher e investigar. No entanto, foi essencial nesse momento interpretar os vestígios do navio, tentar perceber a sua proveniência e cronologia e identificar possíveis correlações entre o conjunto dos artefactos descobertos (Bettencourt: 2014, 15, 16).

O historiador Amândio Barros desenvolveu uma extensa pesquisa documental com especial atenção aos arquivos regionais da zona norte de Portugal. A sua investigação visou localizar referências a incidentes ocorridos com embarcações na zona de Esposende, mais propriamente na área da praia do Belinho. Amândio Barros localizou um registo referente a uma embarcação batizada como *Nossa Senhora da Rosa*, que no inverno de 1577 terá naufragado naquela área. O autor descreve esta embarcação como sendo uma nau com 70 a 80 toneladas, construída em Massarelos por Fernão D'Aires e António Eanes, ambos mestres carpinteiros, com árvores provenientes da área circundante de Porto (Barros: 2016,

7). O registo localizado e datado de 14 de Março desse ano é coincidente com a notícia de que os moradores da região terão descido à praia para recolher todos os bens provenientes de um navio naufragado. Não havendo mais registos de naufrágios na área, pressupõe-se que se trata do mesmo navio (Barros: 2016, 2). O historiador afirma que o navio português estaria na sua rota de regresso, com origem nas Ilhas Canárias, em direção a Vila do Conde, transportando vinho da Madeira e breu. De acordo com o autor esta rota Atlântica de transporte de cereais, vinho e plantas corantes era bem conhecida pelos marinheiros durante o século XVI.

METODOLOGIA PARA A RECONSTRUÇÃO DO NAVIO DO BELINHO 1 E AS ÁRVORES EMPREGUES NO SEU FABRICO

O projeto Belinho 1 foi elaborado de acordo com os pressupostos vertidos nas leis portuguesas em vigor e com normas inglesas – *MoRPHE Guidelines,* English Heritage 2006, Reissue date v1.2 01-04-2015 © Historic England[1] – e teve como objetivo principal caracterizar a natureza dos materiais arqueológicos recuperados desde o final de 2013, mas também servir como plataforma para desenvolver competências técnicas dos investigadores do Projeto ForSEAdiscovery. Dentro dessas aspirações foram determinados quatro objetivos:

- Caraterização do naufrágio Belinho 1 através do registo das madeiras do navio;
- Caraterização do naufrágio Belinho 1 através de estudos das madeiras, incluindo a anatomia microscópica da madeira, análise dendrocronológica e geoquímica;
- Demonstração da importância da avaliação das madeiras e amostragem no contexto das investigações arqueológicas marítimas;
- Criação de oportunidades de formação para os investigadores do Projeto ForSEAdiscovery, bem como estágio inicial a arqueólogos regionais e voluntários.

O projeto focou-se no registo e análise do conjunto conhecido das madeiras do navio. A metodologia adotada para registar as madeiras foi desenvolvida para ser o mais eficiente possível, devido às exigências da documentação, amostragem de artefactos e do estado de conservação em que os mesmos se encontravam. O processo consistiu na observação a *olho nu* da superfície visível da madeira, o que permitiu aos investigadores a divisão das mesmas em quatro grupos, de acordo com a sua função estrutural no navio: longitudinal, transversal, tabuado do forro e fragmentos não diagnósticos. Nesta fase, foi também possível produzir um catálogo simplificado (Castro *et al.*: 2015).[2] As madeiras de Belinho foram registadas individualmente nas *Timber Recording Sheets* (TRS) elaboradas para o efeito e subdivididas em função da sua relevância científica de cada peça, em termos de técnicas de construção naval e da investigação dendrocronológica. Este primeiro processo proporcionou igualmente a oportunidade para serem discutidos os aspetos mais prementes relativos à salvaguarda e conservação dos materiais arqueológicos.

O processo de limpeza das madeiras (superfície e orifícios) representou a fase seguinte no método de registo. As madeiras foram limpas com água doce para remover sedimentos que ocupavam as cavidades vazias, previamente preenchidas com cavilhas de madeira ou pregos de ferro. Este processo foi executado com extremo cuidado, para que quaisquer resíduos de breu ainda remanescente na superfície das madeiras pudessem ser analisados. Durante este processo alguns detalhes foram registados, tais como marcas intencionais de ferramentas, hipotéticas reparações, interrupção do fluxo natural dos veios da madeira e orifícios anormais.

O recurso à fotografia foi outra das metodologias adotadas, dado que permitiu registar as superfícies das madeiras de forma detalhada. O registo fotográfico foi realizado com recurso à técnica de fotogrametria pelo facto de possibilitar integrar as diversas faces de cada madeira num ficheiro único compatível com software 3D AutoCAD. Apesar da totalidade dos artefactos ser cientificamente relevante, as cavernas e picas da popa assumiram um maior destaque, pois são estas peças que possuem ângulos e proporções essenciais para a reconstrução do casco.

Paralelamente, uma segunda equipa de arqueólogos iniciou o registo de um segundo conjunto de madeiras recorrendo ao uso de técnicas de desenho tradicionais (técnicas semelhantes às utilizadas pelos investigadores do CHAM). Desenhos à escala 1:10 foram produzidos

[1] https://content.historicengland.org.uk/images-books/publications/morphe-project-managers-guide/HEAG024-MoRPHE-Managers-Guide.pdf/ (Junho 2016)

[2] https://tamu.academia.edu/FilipeCastro/Belinho-1-Shipwreck (Junho 2016)

sobre as madeiras que integraram o grupo composto essencialmente por tábuas de forro, fragmentos de cavernas, peças longitudinais e outras madeiras indefinidas. Primeiramente, os orifícios originados pelas cavilhas e pregos foram assinalados com varetas, de modo a permitir identificar o ângulo e a profundidade das cavidades. Posteriormente, uma folha de plástico translúcido foi disposta sobre cada uma das superfícies permitindo que os limites de cada madeira e os seus detalhes fossem visualizados e esboçados de forma a representarem o original. As tábuas de forro foram dispostas numa quadrícula (10 x 10 cm), permitindo desta forma a redução direta e representação de cada peça em papel milimétrico, à escala 1:10. Independentemente das técnicas acima descritas, os investigadores produziram desenhos à escala 1:1 ou 1:10 de acordo com o protocolo estabelecido para o registo das madeiras do *Newport Medieval Ship* encontrado em 2002 em Newport, País de Gales (Jones: 2014), que determina que apenas evidências claramente identificáveis, tais como os veios da madeira, a pregadura, orifícios, marcas de carpinteiro e entalhes ou escarvas devam ser registados. A adoção desta metodologia evita presunções sobre objetos ou más interpretações sugeridas por evidências parciais.

As madeiras estruturais de posicionamento transversal e longitudinal, que possuem maior relevância cientifica, foram selecionadas para um registo detalhado, recorrendo a técnicas digitais 3D,[3] usando um disposivo apropriado (FARO Arm). Para o efeito foram afixados em cada peça pontos de controlo, cruciais para a calibração do desenho tridimensional e da fotogrametria. Esta técnica foi utilizada, provavelmente pela primeira vez, em arqueologia para documentar a réplica do navio *Ladby* (Hocker: 2000, 27). Mais tarde, durante a investigação do "Newport Medieval Ship", os arqueólogos Nigel Nayling e Toby Jones (2014), registaram mais de 2000 madeiras do navio recorrendo à mesma tecnologia.

O uso desta técnica em Portugal para a produção de desenho arqueológico é inovador e por isso gerou um determinado número de dificuldades técnicas. O registo de artefactos arqueológicos recorrendo ao FARO Arm é inacessível em muitos projetos, pelo custo associado e pela relativa morosidade do processo, sobretudo quando se determine registar os veios da madeira e analisar a conversão das peças. O detalhe e precisão requeridos tornam este processo moroso e delicado, pois quando a sua utilização não é rigorosa, pode induzir em erros de interpretação e originar a perda de dados. A adoção de guias de procedimento é assim essencial para assegurar a análise crítica dos dados recolhidos, bem como para a obtenção de um registo detalhado e preciso de cada artefacto. Os objetivos da investigação estão dependentes dos recursos do projeto, e mais especificamente da experiência dos investigadores.

O registo digital das madeiras foi executado utilizando um digitalizador 3D equipado com tecnologia especificamente desenvolvida para a obtenção deste tipo particular de dados – a estrutura interna (veio) da madeira –com elevada precisão. O equipamento é geralmente usado com recurso ao software original, embora neste projeto tenha sido utilizado um *plug-in* do software *Rhinoceros* 3D. Esta técnica foi adotada por ter sido considerada a mais adequada ao objetivo proposto, que era na sua essência a reconstrução do casco do navio e das arvores empregues na sua construção.

Como atrás se referiu, as madeiras foram registadas com esta tecnologia de modo a obter o mais elevado nível de detalhe e exatidão sobre a superfície das peças do navio selecionadas para serem registadas por este método. Centímetro a centímetro todos os pormenores foram registados, incluindo os veios da madeira e seus anéis de crescimento. Algumas decisões foram forçosamente tomadas durante o trabalho de campo sobre como interpretar as madeiras no seu estado original. Devido ao elevado nível de erosão causado por anos no fundo do mar e posteriormente pelo arrojamento à praia em condições extraordinariamente adversas, algumas das características espectáveis, tais como escarvas e limites retilíneos entre superfícies foram irremediavelmente perdidas. Embora a erosão tenha afetado as madeiras como parte do navio, em relação à anatomia da árvore foi possível observar evidências claras de localização dos nós, anéis de crescimento, veios e fendas. Estes dados foram cruciais e depois de analisadas as fissuras longitudinais foi possível identificar a localização do cerne ao longo de cada peça analisada. Nos anéis de crescimento existentes na parte inferior e nos topos das picas foi possível identificar a posição onde o tronco se dividiu em dois ou mais ramos. Esta conclusão revelou-se essencial para obter uma melhor compreensão de como as árvores foram convertidas em madeiras de construção.

[3] O conjunto das madeiras registadas com esta técnica é composto por: BEL01-001W, BEL01-003W, BEL01-032W, BEL01-036W, BEL01-037W, BEL01-039W, BEL01-40W, BEL01-043W, BEL01-71W, BEL01-72W e BEL01-073W.

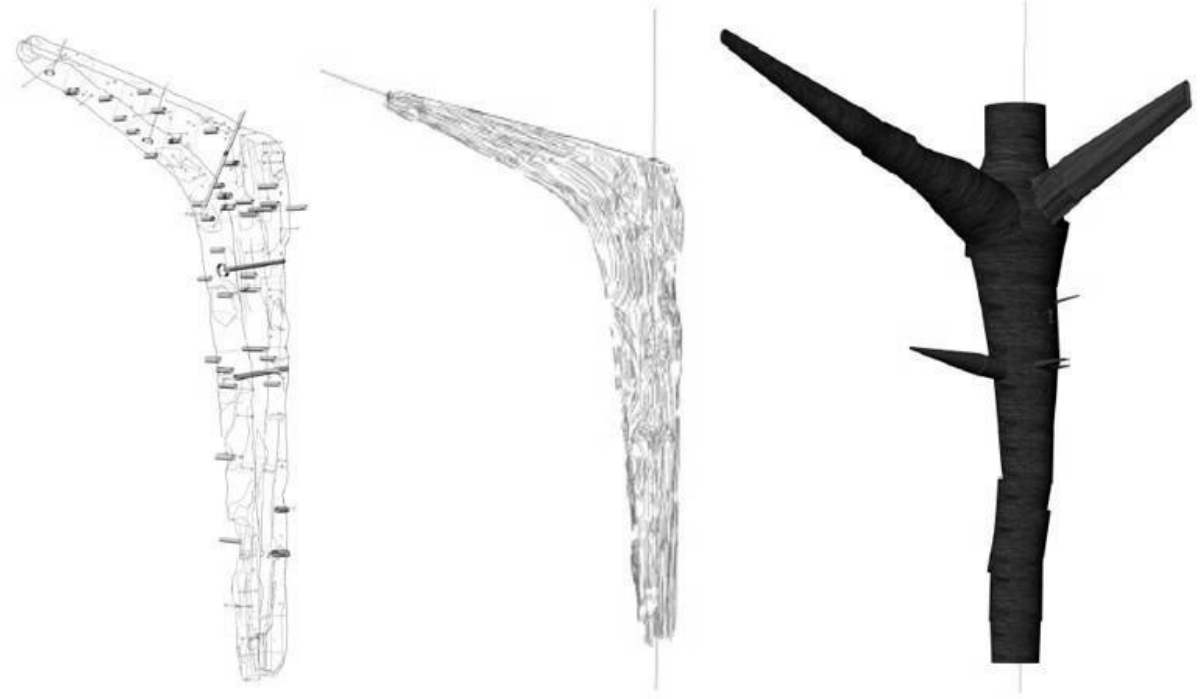


Figura 2. Exemplo de reconstrução de uma árvore baseada na morfologia do veio da madeira levantada com o FARO Arm (Adolfo Martins).

Os desenhos tridimensionais compreendem dois grupos interrelacionados de dados. O primeiro mais vocacionado para o estudo das técnicas utilizadas na construção naval ibérica Pós-Medieval e que compreende as características do casco, onde se incluem detalhes da pregadura, seus ângulos e formas, as escarvas e outros pormenores. Este grupo de camadas (*layers*) no programa *Rhinoceros* 3D permitiu reconstruir as principais características do casco do navio, através do posicionamento virtual de cada madeira na estrutura, e a reconstrução teórica da madeira como esta teria sido moldada pelo carpinteiro. Este método, desenvolvido já durante o pós-processamento de dados recolhidos e analisados pela equipa de investigação multidisciplinar, permitiu igualmente avaliar os efeitos da erosão e degradação causados pela exposição prolongada das madeiras aos fatores ambientais pós-naufrágio.

O segundo grupo de dados contém as características da madeira onde foram registadas as particularidades dos veios, nós, curvaturas naturais, limites exteriores do alburno – a parte exterior, menos resistente, dos troncos – e os ângulos do cerne – a parte interior, mais resistente.

A perda de informação referente a artefactos arqueológicos depositados no fundo do mar pode ocorrer por influência direta ou indireta da vida marinha, alterações climáticas, ação humana, ou de eventos geológicos. Estas ações promovem alterações na estrutura interna e externa das madeiras e variam de local para local. Exemplo disso é o elevado nível de sal (NaCl) no Oceano Atlântico, que contribui significativamente para uma rápida degradação dos artefactos arqueológicos orgânicos. Por outro lado, os níveis extraordinários de cloreto de sódio promovem a proliferação do molusco xilófago *Teredo navalis,* bem como de determinadas espécies de algas. Estes podem ser frequentemente observados a colonizar locais de naufrágio e na verdade tornam-se parte da formação do sitio arqueológico ao longo dos anos. Outro agente ou variável é o fluxo de água, acelerado pelas correntes marítimas e tempestades no oceano, o qual promove a erosão devido ao desassoreamento do fundo do mar. A preservação destes artefactos arqueológicos orgânicos *in situ* depende da redução dos níveis de oxigénio (O2). Sítios arqueológicos situados em ambientes anaeróbicos revelam uma melhor preservação devido à reduzida existência ou mesmo inexistência de vida.

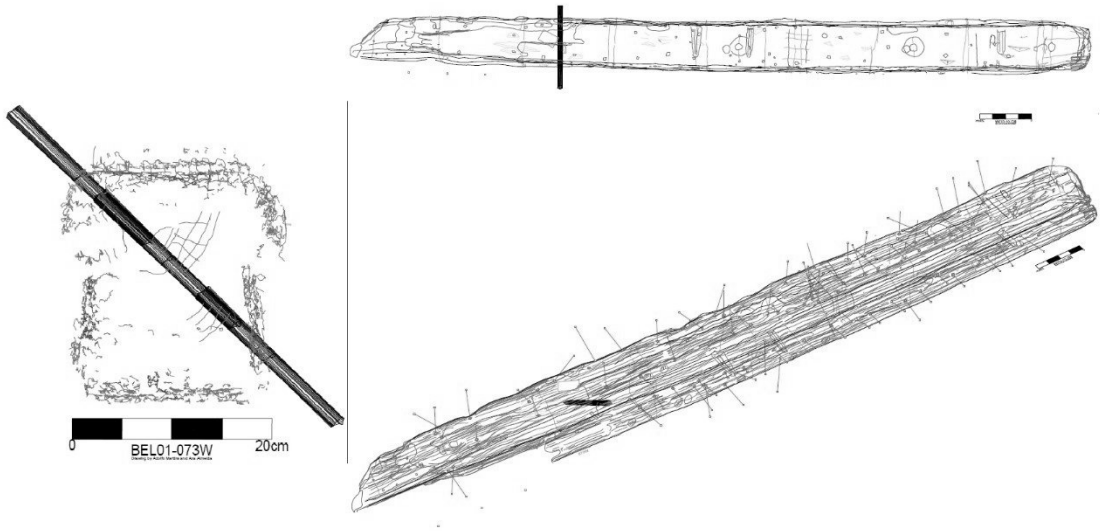


Figura 3. Representação tridimensional da peça BEL01-073W 3D mostrando a posição da amostra retirada para análise dendrocronológica (Adolfo Martins).

Em arqueologia, erosão pode representar uma reação em cadeia dupla, por um lado, proporcionando a revelação de materiais ou contextos, como no caso do Belinho 1, ou em oposição expondo e induzindo a degradação acelerada, ou mesmo a destruição do sitio arqueológico. As madeiras do navio do Belinho são sinónimo da combinação destes agentes externos, em que se torna possível observar evidências significativas de erosão e degradação promovidas por uma exposição provavelmente recente no fundo do mar.

Para registar as madeiras de um navio com elevados níveis de erosão, foi necessário aos investigadores ajustar técnicas conhecidas e contornar problemas diários. Identificar as formas naturais da madeira e os formatos provocados pela mão humana revelou-se uma tarefa com elevado grau de dificuldade durante o processo de registo, uma vez que que os artefactos foram provavelmente arrastados no fundo, antes de serem arrojados à praia por fortes ondas, numa paisagem rochosa. No entanto, as madeiras conhecidas foram catalogadas e registadas (Castro *et al.*: 2015), processo este que contemplou varias semanas de trabalho e meses de pós-processamento em laboratório.

Na investigação do navio do Belinho 1 foram reunidos os especialistas e os recursos necessários para desenvolver um estudo interdisciplinar. Os dados coletados foram partilhados entre os participantes, com o objetivo de maximizar as conclusões alcançadas em cada campo da investigação.

No âmbito das ciências florestais, após seleção das madeiras[4] e conclusão do processo de registo, foram colhidas amostras de 14 exemplares – cinco tabuas de forro, cinco fragmentos de cavernas, do cadaste, de uma pica e de duas curvas – com vista à realização de diversas análises, nomeadamente para datação e identificação de espécie, bem como avaliação das propriedades químicas. A amostragem, que seguiu as regras estabelecidas nas normas *Historic England Waterlogged Wood Guidelines* e *Historic England Dendrochronology Guidelines*[5] foi realizada através de duas técnicas – extração e corte – de modo a ser o menos intrusivo possível. A técnica de extração foi utilizada nos casos em que o ponto com maior potencial de sucesso (maior quantidade de anéis de crescimento) se encontrava em local impeditivo para corte, evitando deste modo a destruição do artefacto.

[4] O conjunto de madeiras com maior potencial para a realização de análises no âmbito das ciências florestais compreende BEL01-009W, BEL01-013W, BEL01-023W, BEL01-024W, BEL01-032W, BEL01-035W, BEL01-038W, BEL01-047W, BEL01-048W, BEL01-054, BEL01-061W, BEL01-069W, BEL01-070W, BEL01-073W e BEL01-075W.

[5] https://content.historicengland.org.uk/images-books/publications/waterlogged-wood/waterlogged-wood.pdf/ e https://content.historicengland.org.uk/images-books/publications/dendrochronology-guidelines/dendrochronology.pdf/ (Junho 2016)

A primeira técnica (extração) foi adotada para extrair amostras dos exemplares BEL01-032W, BEL01-023W e BEL01-032W. Relativamente aos restantes exemplares a opção recaiu sobre a técnica de corte, pois as amostras foram recolhidas das extremidades das madeiras mitigando deste modo o impacto sofrido, pois não afetou a integridade do artefacto.

A análise realizada em laboratório às amostras colhidas, revelou que (Domínguez-Delmas *et. al* : 2015, 2):

- BEL01-009W-01S (tábua de forro) tem 50 anéis - *Quercus* subg.;
- BEL01-013W-01S (tábua de forro) tem 134 anéis - *Quercus* subg.;
- BEL01-023W-01S (fragmento) tem 92 anéis - *Quercus* subg.;
- BEL01-024W-01S (fragmento de tábua de forro) tem 128 anéis - *Quercus* subg.;
- BEL01-032W-01S / BEL01-032W-02S (pica) tem anéis 54m - *Quercus* subg.;
- BEL01-035W-01S / BEL01-035W-02S (fragmento de caverna) tem 82 anéis - *Quercus* subg.;
- BEL01-038W-01S (curva) tem 4 anéis - de madeira de coníferas, não identificado (considerado não adequado para análise dendrocronológica);
- BEL01-047W-01S (curva?) tem 43 anéis - de madeira de coníferas, não identificado;
- BEL01-048W-01S (fragmento) tem 19 anéis - *Quercus* subg., (Considerado não adequado para análise dendrocronológica);
- BEL01-054W-01S (tábua de forro) tem 100 anéis - *Quercus*. subg.;
- BEL01-061W-01S (tábua de forro) tem 55 anéis - *Quercus* subg.;
- BEL01-069W-01S (fragmento de caverna) tem 68 anéis - *Quercus* subg.;
- BEL01-070W-01S (fragmento) tem anéis (?) - espécie tropical não identificada (considerado não adequado para análise dendrocronológica);
- BEL01-073W-01S (fragmento de cadaste) tem 56 anéis - *Quercus* subg.;
- BEL01-075W-01S (fragmento de tábua de forro) tem 47 anéis - *Quercus* subg.

No decorrer da análise dendrocronológica a equipa de investigação da USC – Universidade de Santiago de Compostela identificou uma correspondência nas assinaturas climáticas nas amostras BEL01-013W-01S e BEL01-024W-01S. Este resultado pode significar que ambas as madeiras são originárias da mesma árvore ou no limite, de árvores que cresceram nas mesmas condições/área (Domínguez-Delmas *et. al* : 2015, 2). No entanto, ainda não foi possível encontrar quaisquer *Cross Matches* relacionados com séries dendrocronológicas conhecidas, oque significa que não é (ainda) possível datar as madeiras Belinho01 através de uma abordagem dendrocronológica.

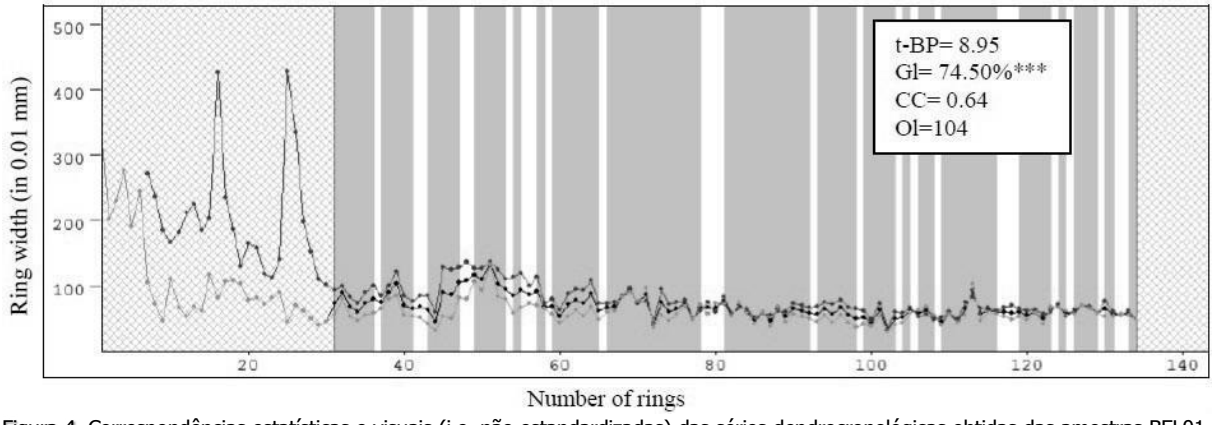


Figura 4. Correspondências estatísticas e visuais (i.e, não estandardizadas) das séries dendrocronológicas obtidas das amostras BEL01-002W-01S (laranja; dendro-code BEL00020) e BEL01-004W-01S (encarnado; dendro-code BEL00040). A curva média das duas séries (BEL2_4MM) está representada a negro. A porção inicial das séries BEL01-004W-01S é assíncrona e foi ignorada. Legenda: t-BP: distrubuição Student's t adaptada de acordo com Baillie and Pilcher (1973); asteriscos representam o nível de significância de GL (***, p<0.001); Gl: percentagem de variação paralela, definida por Eckstein and Bauch (1969), e indicada a sombreado; CC: coeficiente de correlação; Ol: sobreposição das séries (=104 anos) (Domínguez-Delmas *et. al*: 2015, 3).

CONCLUSÕES REFERENTES À CARACTERIZAÇÃO DO NAVIO E DAS ARVORES UTILIZADAS PARA A SUA RECONSTRUÇÃO

Embora com uma forte componente de registo digital a metodologia adotada não invalidou a utilização de técnicas tradicionais. Nesta primeira fase do projeto concluímos que para coletar, analisar e auferir conclusões baseadas na eficiência, viabilidade e sustentabilidade de recursos, arqueólogos tais como os restantes cientistas estão continuamente obrigados a procurar novas ideias e soluções. A reconstrução de um navio naufragado foi desde sempre considerada uma tarefa exigente e tende a ser controversa, pois está repleta de divergências de opinião no que diz respeito à forma do casco e ao número de cobertas. Na sua generalidade deverá ser sempre baseada na interpretação das madeiras, em comparação com estudos anteriores e assente na experiência da equipa envolvida no projeto em curso. Os investigadores devem possuir conhecimento sobre as técnicas de construção naval e das leis da física, tais como a flutuabilidade, gravidade e estabilidade. Só o entendimento destas áreas permite a construção de modelos de navios em que as suas características se aproximem da realidade.

A criação de modelos virtuais garante a possibilidade de testar as características do navio em termos de comportamento hidrodinâmico e a análise crítica dos dados. A utilização desta metodologia permite colocar à prova as considerações iniciais, pois é nesta fase do processo que são testadas e avaliadas.

Tendo em mente que os navios pós-medievais foram produzidos inteiramente por mão humana, todas as peças que compõem esse puzzle são únicas, encerrando em si a experiencia dos carpinteiros e anos de evolução técnica, ambas diferindo de região para região, em função dos desafios que o mar oferece, do acesso a matérias-primas, de factores económicos e sociais, estruturais ou conjunturais, e do gosto e competência da rede complexa de intervinientes envolvidos na conceção e construção de um navio.

Sobre o navio em estudo apenas se conhecem 78 madeiras, onde se incluem cavernas, tábuas de forro e outros fragmentos da estrutura. O registo tridimensional das madeiras do Belinho 1 deve ser encarado como uma vantagem por permitir identificar o posicionamento das picas e do cadaste em função dos ângulos e pregadura do coral de popa, bem como da sobrequilha e das cavernas, em função das particularidades da quilha. Embora nesta fase do projeto não tenham sido consultados os tratados de construção naval portugueses ou espanhóis, a próxima fase da investigação incluirá um estudo comparativo de cada peça de madeira com os paralelos conhecidos. A representação virtual das madeiras foi movida nos eixos X, Y e Z, na tentativa de identificar a sua posição original sem que a escala fosse alterada. Deste modo foi possível identificar a posição do cadaste em função da pregadura do coral e das picas, pelo angulo e pregadura existente no mesmo.

Como já havia sido sugerido no estudo do CHAM, o navio Belinho 1 parece pertencer à tradição Ibero-Atlântica de construção naval definida por Thomas Oertling (2001, 234). Por esta razão, após conclusão do processo de análise preliminar, os desenhos tridimensionais foram comparados com os planos geométricos de dois navios do mesmo período cronológico. O primeiro ensaio teve como base os planos desenvolvidos para construção da replica da caravela *Boa Esperança*, desenhos por peritos em construção naval da Academia de Marinha Portuguesa, mas contendo elementos anacrónicos, como o caimento da quilha para a popa, e o segundo as linhas conjeturais do casco da presumível nau *Nossa Senhora dos Mártires*, reconstruídas com base em marcas de carpinteiro conservadas nas madeiras daquela nau e no tratado de construção naval *O livro da fábrica das naos*, datado de cerca de 1580 e da autoria do padre Fernando Oliveira, que como se sabe, não era construtor naval (Castro: 2005). O modelo tridimensional, desenvolvido no programa Rhinocerous, é da autoria do Professor Engenheiro Tomás Vacas (Vacas *et al.*: 2010).

Embora a inclusão destas madeiras na tradição construtiva ibérica seja preliminar e baseada numa série de características construtivas observadas em vários restos de navios portuguese e espanhóis dos séculos XV a XVII, e descritas em tratados de construção naval coevos, algumas destas características aparecem em navios do norte da Europa (e.g. os navios de Rye A, Cattewater, B&W7, ou Princess Channel) e uma origem não peninsular destes restos não possa ser excluída, as medidas que se apresentam abaixo são baseadas nas medidas típicas dos navios Ibéricos deste período (Castro: 2006; Thomsen: 2010).

Neste exercício teórico e preliminar, considerámos a distância entre côvados, designada por plão e que estimamos em cerca de 2.5 m e estimámos a boca em 7.5 m

(tradicionalmente duas a três vezes o plão, dependendo do tipo de navio), a quilha em 15 (duas vezes a boca) e o comprimento do navio em cerca de 23 metros (ume vez e meia o comprimento da quilha). Nesta fase do projeto estimámos a boca em cerca de três vezes o plão porque as dimensões das madeiras indicam um navio de médio porte. As medidas estimadas aqui estão próximas dos valores típicos para este período e permitem estimar a tonelagem, sem qualquer garantia de rigor, em cerca de 80 toneladas, considerando um *block coefficient* de 0.5, valor médio para navios de carga deste período. O *block coefficient* é o quociente entre o volume deslocado e o paralelipípedo que contem esse volume, que se calcula multiplicanto o comprimento da linha de água medido ao londo do eixo central do navio (18 m), pela boca na linha de água (7.5 m) e o calado (2.5 m). Com base nos valores indicados acima, estimámos o volume deslocado em cerca de 170 m^3 (18 x 7.5 x 2.5 x 0.5) e a tonelagem em metade daquele valor (85 t). O modelo tridimensional da nau *Nossa Senhora dos Mártires*, cujas proporções, como se referiu acima, se baseiam no tratado de Fernando Oliveira, sugerem que as proporções do navio do Belinho 1 não se afastam muito dos valores estimados:

- Comprimento da quilha: cerca de 15 m;
- Boca 7,5 m;
- Pontal 7 m;
- Altura mínima do casco (três cobertas) 7 m;
- Calado máximo 4,5 m;
- Calado mínimo 3 m;
- Ângulo do cadaste 74º;
- Mastreação composta por três mastros e gurupés.

A desconstrução do navio virtual possibilitou também aos investigadores o estudo das madeiras no que concerne à sua anatomia e das árvores utilizadas. Pois, é na desconstrução que os investigadores têm a possibilidade de isoladamente analisar cada uma das madeiras, a sua relação com o conjunto, dimensões, formas, ângulos e curvaturas, mas acima de tudo refletir que tipo de caraterísticas as árvores deveriam possuir para sua utilização na construção naval na Península Ibérica entre os séculos XVI e XVIII.

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RECONSTRUCTING TREES FROM SHIP TIMBERS: DATA ANALYSIS AND SCHEMATICS

Adolfo Miguel Martins*

RESUMO

O presente artigo pretende demonstrar através de engenharia reversa em que medida a madeira como matéria-prima influenciou a carpintaria e a tecnologia na construção naval. O exercício conceptual e filosófico de reconstrução de um navio baseado em evidências arqueológicas, bem como a investigação documental contribuíram significativamente para o conhecimento científico do período dos Descobrimentos. Durante os Descobrimentos o impacto causado pelo incremento do uso da madeira desencadeado pela construção naval teve implicações sem precedentes. Gerações de carpinteiros trabalharam no desenvolvimento de tecnologia que permitiu construir embarcações magníficas capazes de atravessar oceanos, o que implicou o fornecimento de madeiras "nobres" tais como carvalho e pinho provenientes das mais variadas regiões. Cada árvore é única, mas partilham simultaneamente algumas características. Interrogar os achados arqueológicos para entender os navios, as técnicas de carpintaria e a tecnologia usada na construção naval, obriga a uma abordagem multidisciplinar que compreenda estudos de reconstrução de árvores, registo arqueológico, reconstrução tridimensional e dendro-arqueologia.

INTRODUCTION

During the Iberian Age of Discoveries (15th to the 17th-centuries) wood resources were one of the most valuable assets. The demands on wood increased exponentially, as timber was being widely consumed as a raw material in many industries. As a result of the demands on productivity, industrial compounds were entering a competition among each other to expand their areas and flawless routes for timber supply.

Economical interest and the expansionist policy placed the shipbuilding industry on the higher ranking of priorities for the Iberian crowns (Devy-Vareta: 1986, 7). After the administrative reorganisation of the forests, the exploitation of woodlands progressively started to have royal intervention over privateers.

Across the Iberian Peninsula, this industry assumed such relevance that soon became a key element for the crown. In the northeast of Iberia, during the 14th-century the interest on maritime trading routes and commercial fishing increased pressure on the shipbuilding industry and consequentially on wood supply. After this region have been united to Castile, royal decrees "the fueros" reinstate an older practice of reserving forests for shipbuilding (Loewen and Delhaye: 1986, 100). Meaning that to encourage shipbuilding and ensure local timber supply, oak forests within a radius of 11 km from the coastline would be entitled to crown's subsidies for planting new oak trees. At the same time in Portugal, the King also took measures to ensure that timber supplies would not be interrupted either by the creation of forests specifically dedicated to shipbuilding, but also by the creation of laws and regulations to protect them (Devy-Vareta: 1986, 7).

In the 15th-century broad-leaf trees considered essential for shipbuilding and at the same time for the reforestation of the woodlands. Oak trees were the "noble" raw material for shipbuilding requirements, in particular, to build oceangoing ships enlisted on trading and exploration routes. By royal decree, carpenters could cut trees "onde mais lhes apraz"[1] (Devy-Vareta: 1986, 10). However, the paradox has changed in the early 16th-century when the lack of wood to supply the shipyards had become a concern. The woodlands could not provide suitable trees for this industry in such haste. The solution found by the Portuguese crown was to import timber from other regions and by 1566, shipyards were already importing timber from Galiza, Asturias, Biscay, Britain, Ireland and Flanders (Moreira: 1984, 104).

Previous studies (Oertling: 2001; Castro: 2008; 2010) concluded that during the Age of Discoveries, vessels were built in accordance with the Iberian shipbuilding treatises such as the *Livro Primeiro da Carpintaria* Naval (Lavanha: 1616), *Livro da Fabrica das Naus* (Oliveira: 1580) and the *Ordenanzas* from 1607, 1613 and 1618 (Hormaechea, Rivera and Derqui: 2012). The

[1] English translation: "where it pleases the most".

suggested geometric plans on these documents comprehended the required technology to build the ships, but also the necessary shapes and dimensions of the main timbers. Shipyard carpenters following the suggestions present in the treatises and own experience shaped the logs in a way to fit in the predesignated positioning. Although the existent architectural signature observed on ship`s remains, might be recognised, but only by performing complementary studies would be possible to identify which tree species, shapes and growth patterns were employed in distinct parts of a vessel's structure. These timbers were selected by carpenters by particular reasons which included the usage of trees having specific curvatures, width, length and density.

Within this historical context, the Iberian shipbuilding industry was no longer being supplied by local forests, but with trees felled elsewhere. As a consequence, ships began to be built from oak and pine tree sub-species planted in dissimilar landscape geomorphology and climate signatures. In addition to this constraint, timber logs were being felled in distant forests and assumedly also according to different shipbuilding tradition/technology. The interaction between the local shipyard carpenters and the local forests dedicated for shipbuilding suffered an abrupt interruption since the timber logs started to be supplied from distant regions.

The present paper aims to identify particularities and patterns on trees employed in the Iberian shipbuilding industry. According to the archaeological evidence suggested that trees were not randomly chosen. To present this investigation, the following section will be focusing on the legacy of previous studies in which ship timbers assumed the major relevance. The subsequent section aims to present three case studies of successful tree reconstruction based on the existent archaeological evidence. Finally, the last section will present the provisional conclusions on tree reconstruction techniques and which data can be extracted by employing this method of analysis.

TIMBER RECORDING AND ITS LEGACY STUDIES

Timber recording can be performed using a variety of techniques, but it is the end product that influences what details to look for. Archaeologists undertake investigation focusing on timber expecting that these artefacts provide enough information to accomplish research questions. It seems clear that some techniques are being adopted from previous studies and slightly adjusted according to the particularities of each archaeological site. The following case studies represent potentially triggered points in which a new path began and new techniques/methods of performing timber recording and conducting data analysis were remarkably achieved.

THE GRAVENEY BOAT LEGACY

The Graveney boat found in 1970 was jointly excavated by the National Maritime Museum and the British Museum (Fenwick and Morley: 1978; Greenhill and Morrison: 1995, 180). Dendrochronology dating placed the construction of this vessel around 930 AD sustaining the previous Radiocarbon 14 dating (Fletcher *et. al.*: 1978, 123). The remains of the vessel had approx. 10 m in length and 3.5 m wide. The construction method employed iron rivets and treenails to secure the clinker-built planking boat (Fenwick and Morley: 1978).

The timber recording process involved two stages:

- During the excavation of the vessel, the waterlogged timber was kept moist to avoid wood decay, while archaeologists undertook recording techniques such as tracings, hand notes and photographs (Oddy and Geersdaele: 1972, 32);

- During laboratory analysis, timbers were kept in fresh water tanks and one by one were carefully unwrapped in order to be cleaned from incrustations, mud and other irrelevant materials that would interfere with the tracing. The next step was to record individual timber features and shapes by hand notes, tracing, measurements and photographs (Mckee: 1978, 37). In order to record direct measurements, timbers were placed on a 10 cm square grid board to set up the datum lines (Mckee: 1978, 39). Direct measurements (length, width, thickness and cross-sections[2]) were recorded on individual timber sheets with the catalogue number and date. After completing the direct measurements record, archaeologists used the same grid as before for the tracings. Catalogue number and tracings were then recorded with felt-tip pens[3] on mylar sheets (Mckee: 1978, 41). Three distinct colours were used to highlight characteristics and created a clear view of the group of

[2] Sections were taken using straight edges and set squares with metric graduations (McKee: 1978, 39).

[3] Felt-tip pens were trimmed with a razor to give a line no more than 2 mm broad.

features reproduced on the drawings: Black to draw edges, fastening holes and tool marks, blue to record signs of wear and damages and red for the positioning of the recorded cross-sections. Once each drawing was rechecked and considered complete, archaeologists stored it on cardboard tubes.

The team of archaeologists adopted an approach in which the recording had to meet the high scientific standards, but also to allow development of multitasking recording within an emergency archaeological operation. The concerns about having a thorough record of the site and individual timbers were sustained by the fact that, the ship remains would be reassembled for display (exhibition) and educational purposes.

The investigation held on the Graveney Boat timbers also comprised wood morphology analysis and some of the first known attempts to reconstruct the trees based exclusively on the archaeological evidence (Fletcher and Trapper: 1984, 121). In completion of the study performed by the researchers, the trees used to build this vessel "had to come from trees left to grow to good lengths in woods, forests or hedges often coppiced to encourage straight and prolific growth" (Hinton *et.al.*: 2011, 424).

THE SKULDELEV BARRIER AND CRUMLIN-PEDERSEN`S LEGACY

In the late-1950s archaeologists initiated the investigation of five Viking ships which were deliberately sunk to build a barrier to obstruct a channel at the Roskilde Fjord in Denmark (Steffy: 1994, 108). These wrecks were subject to an intensive scientific program aiming for their conservation and reconstruction as remarkable examples of Viking Age shipbuilding tradition (Steffy: 1994, 108). The archaeological site was different in many aspects to most terrestrial excavation sites. In some cases, waterlogged timber presented significant levels of decay which led archaeologists to investigate the imprints of the already vanished timbers. On the other hand, the timber assemblage of most wrecks was softened by an extended period exposed to the marine environment but sufficiently preserved to be recognised and interpret (Crumlin-Pedersen: 2002, 50).

In 1962, "optimal" techniques of excavation and recording were adopted with a "view towards" avoiding further damage to the wood from the weight of the stones and from the "excavation tools" (Crumlin-Pedersen: 2002, 50). The complexity of this site required the implementation of specific methods which included the building of a cofferdam to lower the water and uncover the remains of the vessels. Archaeologists considered this method the most efficient because of the nature of the site "a pile of ships and stones in an exposed on a channel with strong currents" (Crumlin-Pedersen: 2002, 51). To reduce work time and maximise the efficiency of recording the scattered and greatly fragmented timbers had to be recorded *in situ*. The artefacts were photographed from different angles during each photogrammetrical surveys (Crumlin-Pedersen: 2002, 51). The method involved capturing at least three predefined markers in order to plot the measurements into the general plan. The post-process analysis revealed that the usage of this technique equals to "traditional methods of documentation" in terms of time consumed and efficiency (Crumlin-Pedersen: 2002, 51). However, the most significant disadvantage when using this technique (at that time) refers to the long period taken during the plotting process and inability to check if the sections had enough overlap between each other. In addition, the wood analysis was performed on individual ship timbers. The further microscopic analysis was carried out on a total of 254 samples which gave detailed data about the trees used to build the Skuldelev Ships: ash, alder, lime, beech, birch, hazel and willow. The identification of the tree species revealed to be essential to categorise the building location "as well as repairs and modifications" (Crumlin-Pedersen: 2002, 56). Wood anatomy analysis has shown that boatbuilders carefully selected the trees for the construction of the vessels. The building methods are not uniform across the ships, but it seems to be the best option for the intention, according to the "right species, sizes, shapes and quality" (Crumlin-Pedersen: 2002, 56).

The dendrochronological analysis concluded that annual rings have considerable variations. The average rings on the oak planks vary from 3.20 mm to 0.71 mm and on the pine samples from 2.73 mm to 0.41 mm. In general, the oak planks were radially-orientated in the log. This, suggest the method of radial splitting "of the parent tree" to produce "clone boards from which planks were cut" and then refined with the usage of axes (Crumlin-Pedersen: 2002, 56). A few planks from the wreck 3 were made of a log with a different orientation (Heide: 2014, 97). All pine planks were tangentially orientated in relation to the annual rings. The logs were "evidently"

made by splitting it into two halves and "cutting these to plank shapes" (Crumlin-Pedersen: 2002, 56). Individual elements were cut in a way to avoid cutting across the grain. Archaeological evidence from the Skuldelev ships shows that boatbuilders had an exceptional knowledge, care and effort to build the vessels. Some of the timbers are "strongly curved" and cut very slender which required specific acquaintance about trees. Ole Crumlin-Pedersen also attempts to reconstruct trees based on the archaeological evidence. This approach was taken in order to identify the construction process of individual timbers:

- The Skuldelev 1 planking was built of pine of high-quality parent trees (having just a few knots) (Crumlin-Pedersen: 2002, 129);
- Dendrochronological analysis of 14 samples gave the youngest tree-ring between 921AD and 1025 AD and a high correlation" value against the mean curve for samples from Kaupanger and Urnes stave churches in western Norway" (Crumlin-Pedersen: 2002, 129). From these 14 dendro samples was possible to identify the orientation of the tree stem and most likely that only two planks were processed from the same tree stem;
- Some of the planks have a curved shape, in particular, the" hooding ends" which were cut from planks of straight growth "as indicated in the cracks in the planks" (Crumlin-Pedersen: 2002, 129). According to the studies performed on the preserved planking and the analysis made on the ship reconstruction model, was possible to identify the maximum length of the pine planks needed to build the vessel;
- Based on the analysis and the assumption that only two planks could be extracted from a parent tree, to build the Skuldelev 1 boatbuilders would need:
  - Three largest trees having a stem with the minimum of 10.5 to 12.5 m and the width after removing the bark of 45 to 55 cm (minimum);
  - The hood ends would be needed six smaller trunks in length having from 2.5 to 4 m;
  - For the bottom, planking boatbuilders would need curved tree trunks having between 6.5 to 9 m and a minimum diameter of 35 cm;
  - For the hood ends and the smallest amidships planking straight tree trunks with a minimum length of 2 to 6 m, and a diameter between 25 to 35 cm would be needed;
  - For the 18-35 cm wide planks of the lower eight strakes, a total length of *ca.* 165 m was needed on each side" (Crumlin-Pedersen: 2002, 129):
- Evidence showed that the majority of the planking integrated the vessel´s hull having the pith location inwards orientated from strake 5. However, from bottom to strake 5 had the opposite orientation (exception for the hood ends) (Crumlin-Pedersen: 2002, 130);
- Regarding the framing timbers, it was possible to observe in particular on the Skuldelev 2, that:
  - Five frame timbers were cut from oak trees at the junction from the trunk width a thick brunch and one frame timber was built from a curved tree (Crumlin-Pedersen: 2002, 156);
  - This means that the framing system was built within a lack of tree shape consistency.

3D SHIP RECONSTRUCTION AND RICHARD STEFFY'S LEGACY

Excavations undertaken during the 1960s and 1970s in Eastern Mediterranean Sea focusing on the wrecks of the Cape Gelidonya, Yassiada, Serçe Limani and Kyrenia Ship have triggered a profound transformation in the discipline of maritime archaeology.

- The investigations held on the Cape Gelidonya wreck, turned out to be essential for the development of nautical archaeology as an independent discipline. In particular, by its innovative approach in which diving archaeologists coordinated and executed an excavation employing full scientific methods commonly used on inland excavation techniques (Throckmorton: 1962; 1964).
- This investigation undertaken on the Yassiada wreck demonstrated to be essential to improve the excavation techniques employed during the investigation of the Gelidonya wreck (Throckmorton: 1996, 86). This excavation under the coordination of George Bass and Frederick van Doorninck, witness the use of underwater techniques at its full potential for the time. To achieve the greatest understanding of the site a multidisciplinary approach was adopted. This way, the contribution of fourteen experts from different areas demonstrates a concern by the archaeologists in reaching the highest level of knowledge about the wreck (e.g. Doorninck and Steffy – ship´s hull reconstruction, Throckmorton and Finch – ship archaeology; Marean - rigging).
- The excavation, dismantling, conservation and reassembling of the Kyrenia Ship allowed archaeologists to

investigate how the ship was in fact built and not as theorists thought how it should be. This vessel was also subject to a pioneer study on three-dimensional ship reconstruction led by Richard Steffy (Steffy: 1985) based on archaeological evidence.

- The diorama built at a scale 1:10 from the Serçe Limani excavation records was at the first stage developed for ship reconstruction analysis and studies but sooner, became useful for teaching purposes. Other advantages were found after building this 3D model such as the correlation between the artefacts and hull remains but also the study of aspects related to site formation, its patterns or particularities. This, innovative post-excavation method of analysis achieved such significance that started to be used around the world as a patterning method in underwater archaeology (Steffy: 1982, 15).

Richard Steffy concluded that building three-dimensional models of an underwater archaeological site provide a comprehensive understanding of the evidence. This also pushes archaeologists to a deeper analysis of the construction techniques employed to build the vessels, since the diorama is built from multiple parts representing individual timbers.

Building the diorama involved a systematic recording of the archaeological site and looking at hundreds of photographs taken underwater. Notes gathered from field daily reports, sketches and catalogue detail of the wooden structure and the remained objects. Particularly, the timbers were subject to an intense record procedure including where seams were located, frame limits, planking, nail locations, pressure marks, wood discolorations and other features (Steffy: 1982, 15).

According to Steffy, the development of a diorama has advantages in comparison with a (2D) flat drawing. Three-dimensional diorama can be produced in such detail that "even to those who excavated the wreck in sections" can have a full clear view of the entire hull. 3D laboratory models can also be updated whenever significant progress have been achieved (Steffy: 1982, 15). Each model should be built to higher standards and realism to reproduce in detail the bathymetry, artefacts, concretions and unexcavated perimeters.

Richard Steffy proposed a method that enable researchers to investigate the remains of a vessel in a controlled environment 365 days per year without the constraints imposed by fieldwork and the implied resources. It also, allows other specialists within a multidisciplinary environment to investigate the evidence during the post-excavation process.

Richard Steffy was not seeking the details of ship construction, but the mental process of "conceptualizing a ship and the challenge of extracting it from the physical remains" (Bass and Hocker: 2014, 168). He was indeed on the genesis of the cognitive archaeology.

THE CAVALIER-SUR-MER TIMBERS AND FOREST PRACTICE IN THE NORTHERN IBERIAN WOODLANDS

The Cavalier-sur-Mer vessel has aroused great interest for the study of the Ibero-Atlantic shipbuilding, timber supply and wood provenance in the 15th and 16th centuries (Loewen and Delhaye: 2006, 99). Long-distance shipping was encouraged in the Basque Country from the 13th-century. Given the importance of this industry, oak trees plantation was at that time subsidised by the crown, retrieving of an older practice to dedicate "oak forests within 11 km of the sea for shipbuilding" (Loewen and Delhaye: 2006, 100). Maritime trade across the British Channel assumed a strategic relevance. At that moment, ships sailed to the North carrying wool and wine across returned with wheat, linseed and forest products. Simultaneously, commercial fishing was increasing which led Basque crews to sail longer distances (e.g. Iceland and Newfoundland).

The investigation held by Loewen and Delhaye based on the Cavalier-sur-Mer remains aimed to identify construction features and to evaluate the correlation between its timbers and their parent trees: "Three comparisons were made: the tree`s curvature versus that of the timber: the tree`s branch-free length versus timber length; the tree`s diameter versus the timber`s squared dimensions" (Loewen and Delhaye: 2006, 102). In order to compare the curvature of the tree against the ship timber Loewen and Delhaye concluded that:

- The centre of the growth pattern was traced on both fore and aft faces of the timber. To assume that this pattern has a "good" match, the centre of the grain needed to correspond with the centre of the timber. Having done this exercise, archaeologists found that trees did not have a smooth "arc" as they show a high degree of correspondence with the timber. Although, tree shapes were slightly straighter than timbers at the ends of the inboard face and at the centre of the outboard face. – Within the analysed timbers, there was a

consistency between the timbers` curvature and the parent trees;

- Existent waney[4] edges simplified the comparison between the timbers` square dimensions and the tree`s diameter. – The analysis concluded that the trees were not split into two futtocks;
- After comparing branch-free length against the produced timbers was found that finished timbers, in particular, first and second futtocks were all found to be free from major branches. – The investigation undertaken on this matter reached a conclusion that trees were pruned to produce a better quality of naval timber;
- The authors of this research also concluded that the selection of the parent trees was only interrelated with the predesigned geometrical hull.

This result implied that the Cavalier-sur-Mer was built from trees obtained on an abundant forest dedicated to shipbuilding. Oak trees were carefully pruned and selected to construct the vessel. Based on tree-ring counting[5] technique was possible to determine in which extent parent trees were managed. Despite the known limits of this process, ring counting by "naked eye", became clear that the trees employed for this vessel, were felled at the age of around 65 years old (+/- 5) (Loewen and Delhaye: 2006, 102-103). Furthermore, close inspection on the first and second futtock suggested that the parent trees were cultivated and harvested as a single crop. It seems that floor timbers reflect a more "opportunistic" selection of the parent trees:

"These findings would be compatible with the practice of pollarding, in which old trees are cut at a height about two meters and four to six new shoots springing from the stamp are left to grow into branches. (…) These young branches of uniform age could be 'trained' to the desired curvature by spreading them apart forcibly with props, while allowing the heads to return naturally to vertical position (Albion: 1926, frontispiece; Marzari: 1991, 63; Marzari: 1994; Ballu: 2000, 76, 77)" (Loewen and Delhaye: 2006, 103).

Cavalier-sur-Mer wreck offers a distinct study about Iberian forest management and timber supply. Based on the evidence collected on the vessel remains, Brad Loewen and Marion Delhaye conducted their studies orientated to obtain data and knowledge about Iberian shipbuilding, but also to identify evidence of trees used for that industry.

NEWPORT MEDIEVAL SHIP AND THE ADVANCES ON DIGITAL TIMBER RECORDING

During the construction of the new Theatre and Arts Centre in Newport (Wales) in 2002, a remarkable clinker-built hull was discovered. Archaeological remains were initially exposed by builders during the process of sediment removal from the cofferdam built to accommodate the foundations of the Arts Centre.

At the end of 2004, the post-excavation investigation included "detailed examination, cleaning and digital recording of individual timbers" (Jones: 2009, 38). Several advanced recording techniques were tested before starting the 3D recording of the timber assemblage. Those techniques included laser scanning and the usage of an "articulated digitizer arm[6]" (Jones; 2009, 38). This last technique was considered as the ideal, in terms of cost effect offering a high standard end product[7].

After completing the recording of the ship´s timber assemblage, individual timbers were assessed to identify potential for dating by dendrochronology (Nayling and Susperregi: 2014, 280). Following a standard sampling protocol, several timbers were selected[8] for their potential for dating and dendro-provenance. Dendrology analysis allowed archaeologists to conclude that:

- Planks were "radially split with carefully hewn scarves and lands" (Jones: 2009, 37);

[4] Definition of waney: not of uniform size throughout; - said especially of sawed boards or timber when tapering or uneven, from being cut too near the outside of the log. http://www.thefreedictionary.com/Wany,2017, 20th of January.

[5] The team of archaeologists opted to perform visual ring counting cross-checked to avoid significant errors.

[6] The team of archaeologists developed trial compared test within several recording techniques. Hand drawings revealed to be slow in execution on the other hand, laser scan was the fastest method but the point cloud would require a long post processing. The articulated digitizer arm was considered as the most suitable technique. A compromise between the desirable end product and the decision making by the operator would be reached using this method.

[7] The three-dimensional drawings produced using a 3D digitizer arm in conjunction with Rhino 3D software (Jones: 2009, 39) had an accuracy of 0.25 mm.

[8] The criteria for selection of these timber was based on the assessment of previous ring counts and presence/absence of sapwood "(Nayling and Susperregi: 2014, 280).

- Initial dendrochronological samples collected from the oak timbers had more than 50 rings;
- Further samples collected from timbers displayed on the top of the vessel´s structure was dated "against British reference chronologies providing felling dates in the winter of AD 1467/8 and winter 1465/6" (Nayling and Susperregi: 2014,279). This date was corroborated also by the Newport Medieval Ship associated artefacts[9];
- The keel was built from beech tree having 97-year dendro-sequence. Although, it could not be possible to date by matching its dendrochronological series against other timbers on site, neither against historical data for medieval beech in Britain (Nayling and Susperregi: 2014, 281);
- For the planking, ring-width analysis proved that individual timbers were obtained from same parent trees which also helped to analyse and identify possible construction sequence;
- Dendrochronological analysis on one of the struts presents a date of 1468/9 as well as some of the timber repairs also from the mid-15th-century. Moreover, other artefacts were found in situ including stone shots, an archer's wrist guard and several Portuguese coins dating to the mid-15th-century;
- There was an attempt to correlate strakes on both sides of the hull and along it to identify possible if were shaped from the same parent tree.

This investigation significantly boosted and improved timber recording techniques. The usage of the 3D digitizer in a larger scale following a specific protocol demonstrated that it is possible to rely on digital techniques to acquire precise archaeological data.

NEW PATHS FOR THE ANALYSIS OF SHIP TIMBERS

Fieldwork recording techniques and methods of analysis developed by Gordon Childe (Trigger: 1980) are nowadays still in practice. Archaeologists seek to understand aspects of the human interaction with the environment. As seen in the previous section, archaeologists developed their studies focus on specific questions and used high standard methodologies. The approach determines the initial questions and the methodologies but at the same limits, the achieved conclusions. As mentioned before, the excavation of the Graveney Boat only started after the designing of a plan in which it was essential that every task would be performed within higher standards. The process included the detailed recording of the timbers and the interpretation of the construction techniques. The methodology included the recording of individual timbers and their positioning in relation to the structure. Each timber was investigated in such detail that archaeologists developed specific techniques to ensure the best possible record. At that time, the aim was also to preserve and reassemble the boat`s hull for exhibition and educational purposes. Their legacy can be observed in several maritime archaeology investigations in particular, regarding the techniques of acquiring dimensions by direct measurements, tracing by layers and the usage of extensive photographic recording.

Crumlin-Pedersen also significantly contributed to a shift in the archaeologists` perspective by reinforcing a multidisciplinary approach. Engineering, dendrology and technology were present from the first year of fieldwork held at Skuldelev and furthered the maturation of the discipline. Maritime archaeology and technology are deeply associated as mentioned before Crumlin-Pedersen used photogrammetry which is a technique that almost became a fashion nowadays. Photogrammetry is more than a "pretty picture" (Yamafune: 2015) and can be used for a variety of purposes. The usage of three-dimensional modelling engineering software level up the standards when carefully used. The post-excavation process held on Skuldelev proved that it is possible to conduct an investigation into higher standards using this technique/technology. However, it also demands suitable hardware and software which needs to be fast enough to deliver results within each project time frame limits.

The following case studies will demonstrate the investigations performed on tree reconstructions on the *Batavia* ship, Bremen Ship and Belinho timber assemblage based on the wood morphology and archaeological evidence. These studies aim to gain a better understanding of forest practice, wood provenance, wood morphology conditioned and influenced shipbuilding technology and how this, in turn, is reflected in the evidence found on the archaeological remains.

[9] Post-excavation analysis of the keel revealed a recess into which a French silver coin from July AD 1447 which according to archaeologists implies that the ship could be built before May AD 1447.

THE *BATAVIA* CASE STUDY

This section of the present paper does not intend to discuss the archaeological evidence either archival information about the *Batavia* ship. The aim of this section is to present the studies performed on the vessel`s planking in order to characterise aspects of the wood morphology and tree reconstruction.

The *Batavia* was built in Amsterdam in 1628 for the Dutch East India Company and sunk one year later off the western coast of Australia. The remains of the 650 tonnes ship (56 meters in length and 10 m wide with a crew of 341 including the passengers) are in displayed at the Shipwreck Museum at Fremantle, Australia. The section in display on the Batavia Gallery includes the aft part of the vessel on its port side.

The recording, investigation and rescue of the surviving timbers were performed by Jeremy Green and his team during the 1970s (Baker and Green: 1976). The conservation of the timbers took place over several years by full saturation with polyethene glycol (PEG). Once the predefined levels of saturation were achieved the most representative hull timbers were reassembled and put on display on a permanent exhibition (Duivenvoorde: 2009, 61).

At the present stage, the vessel`s timber surface show a significant level of impregnation by PEG giving a waxy appearance as a reflex of the adopted conservation procedures. On the other hand, this waxy surface inhibits the chance to visualise the wood growth pattern (grain-lines), knots and other aspects of the tree morphology, but provides extra protection to the timbers in the display.

The first stage of the wood morphology and tree reconstruction performed on the Batavia remains, initiated by carefully selecting the timbers which would provide more information about their features. After performing a close inspection to the planking it was determined that the first three planks of the first three strakes due their curvature and torsion were the more suitable candidates. These planks compose a significant part of the aft. The timber gives shape to the hull from the transom (stern post) along the port side of the vessel.

The next step was to undertake a digital record by photographing the select timbers which included detailed photos of timber morphology and a sequence of photographs to produce a computer vision photogrammetry (Yamafune: 2015). Over 200 hundred photographs were taken from the planking in the display. The 3D digital model produced from the photographs was then calibrated to a 1:1 scale using the control points and hand notes (having an error on the axis of 0.3 cm). From the main model, selected planks were then turned into three individual timbers. Using the CAD program Rhino 3D several attempts were performed in order to identify potential cross-match (growth-patterns, natural curvature) between planks. This process revealed to be ineffective due to the waxy surface of the timbers which inhibit all the wood features essential for the present study.

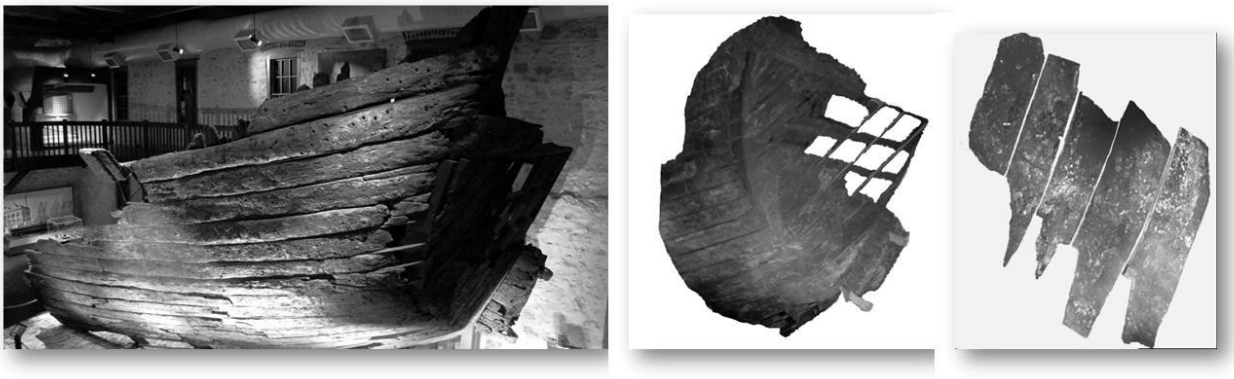


Figure 1. (From left to right) photograph of the remains of the Batavia in dispay on the Shipwreck Museum in Fremantle, Australia; sample of the photogrammetry produced from the photographs taken from the remains; representation of the individual timber (planking) (photographs and 3D models by Adolfo Miguel Martins).

Another method was employed to extract wood features from the selected timbers. This time, using an image processing software photographs were processed and rendered by layers to extract the grainlines, knots and other wood features. Once again, the waxy surface produced a series of lines which do not correspond to the grain lines or any other wood feature.

In completion of the studies performed on the Batavia`s planking in the display, the employed techniques and technology revealed to be ineffective to extract and characterise the wood morphology.

THE BREMEN SHIP TREE SHAPES

The Bremen cog (ship) was found in 1962 during dredging operations in the Weser river in Germany (Lahn: 1992). The vessel built of oak timbers was dated by dendrochronology to 1380 (Daly: 2009; Haneca and Daly: 2013). The cog is 24m in length, 8m wide and an estimated 130 tonnes of load capacity. The cog was built using a mixture of carvel and clinker built technology (Crumlin-Pedersen: 2000, 231). The surviving timbers consist of the almost complete part of the starboard and approximately a third of the port side. The timber assemblage was preserved by saturation of polyethene glycol which took almost 18 years to attain the required impregnation level of the timbers (Crumlin-Pedersen: 2000, 230). All parts were then reassembled and put on display at the German Maritime Museum in Bremerhaven since 2000. At the German Maritime Museum, the vessel has a dedicated hall which provides the required controlled environment where the surviving reassembled timbers are being sustained by scaffolding. This offers a combined function in which conservators ensure the preservation of the remains and at the same time allows visiting that heritage.

In accordance with the wood analysis and dendrochronological studies, D. Aoife Daly has been undertaking a sampling campaign on the Bremen ship to date the surviving timbers and wood provenance studies (Daly: 2009). The Bremen ship planking came to my attention, in particular, the strakes no. 7 to no. 10, in order to undertake studies, focus on wood morphology and tree reconstruction. These strakes are composed by an aft plank, the centre plank and the forward plank. On most of the planking from the port side of the vessel, it is possible to identify their morphology (growth-pattern, knots and the pith location).

Despite the obstruction caused by the scaffolding, the centre plank from strake no. 8 presented the most relevant features to perform tree reconstruction. This timber has 751 cm in length and 57.1 cm sided and 4.29 cm moulded. It has a scarf on each end to accommodate the forward and aft plank. On the upper part overlaps on the outboard face to the strake no. 9 and on the lower part of the inboard face with the strake no. 7. This also constitutes an obstacle for the digital recording due to the hidden parts (an area that overlaps with the upper and lower strakes). Strake no. 8 also accommodates some of the deck beams in which the scaffolding sustains the deck beams hiding part of the plank no. 8.

The present circumstances in which the Bremen ship is in display increased the difficulty for the recording of the centre plank from strake no. 8. To conduct computer vision photogrammetry (Yamafune: 2016) and to acquire precise measurements using a 3D digitiser arm it was necessary to readjust the recording protocol and the techniques (Jones: 2015). The photogrammetry was built from over 200 photographs having an overlap of more than 60% between each other. The first set of photographs capture the entire starboard and was used to acquire the shape of the hull on its full length. Then strake no. 7 to 9 was photographed in detailed having between each photograph an overlap of more than 70% from the previous. This ensures the required capture of the wood morphology and enough overlap to allow an accurate match between each photograph. The next stage was to use a 3D digitizer arm in conjunction with Rhino 3D to record in detail the selected plank. The 3D drawings were produced into three parts due to the obstruction caused by the scaffolding. Equally, on these drawings the area where the plank overlaps with the strake no. 9 the tracing was disrupted which generated a blank part. This allowed capturing the precise location of the grain-lines, knots, cracks and other relevant wood features.

The information collected from centre plank on the strake no. 8 was then analysed and files produced from the photogrammetry software "psz" file exported to Rhino 3D as "obj" file. This allowed analysing possible incorrections/inaccurate measurements produced on the dense point cloud. Once the photogrammetric model merged onto the 3D drawing produced with the 3D digitizer it was possible to have the timber on its full length and detail.

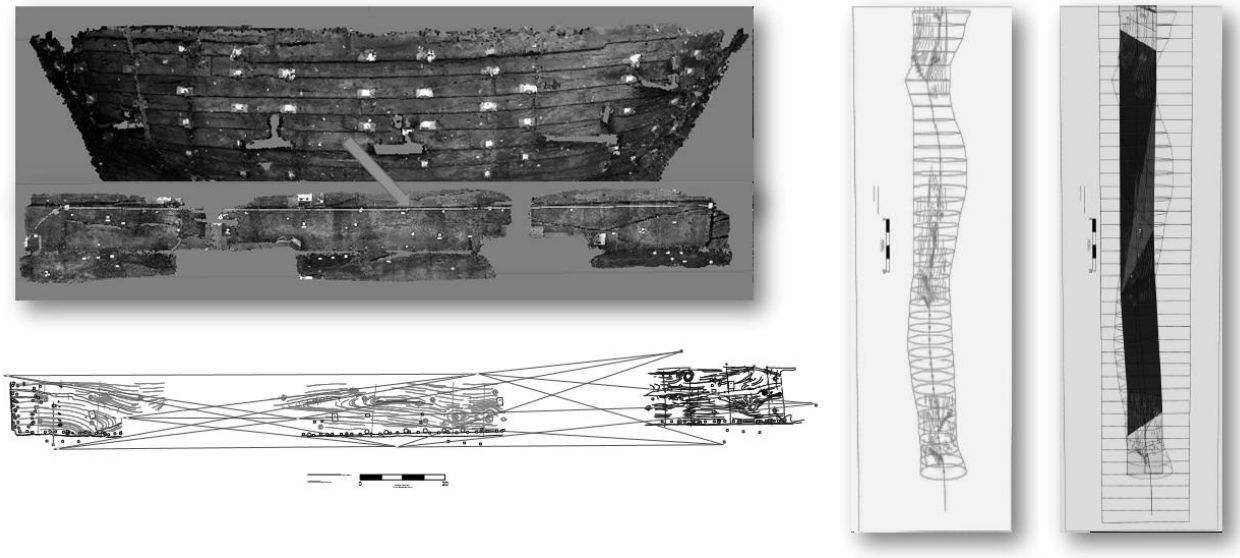


Figure 2. Tree reconstruction studies based on data recorded from timber 8.2 (photogrammetry, 3D drawings and tree reconstruction y Adolfo Miguel Martins).

The produced 3D model 1:1 scale, hand notes and direct measurements became at this moment essential to reconstruct the parent tree from timber no. 8.2 (amidships port side plank). The location of the pith it is the most important data in which relay the reconstruction sequence. Once identified the positioning of the first annual ring, was then possible to determine the maximum extent (edge) of the surviving timber. The next stage was to determine the growth direction (canopy as opposed to the roots). The location of the knots determines the side branches and provides information about the type of forest (dense forest as opposed to isolated trees). The maximum length of the timber only ensures that the parent tree had at least the minimum of 751cm in length. On the other hand, not having traces of surviving sapwood on timber no. 8.2 it was not possible to establish the full width of the parent tree.

In completion of the studies performed on the wood morphology and tree reconstruction focus on the Bremen ship plank no. 8.2 was possible to conclude that:

- The plank was built from a tree having a straight stem with the minimum of 751 cm;
- The tree stem was highly populated by side branches (10 in total) of several dimensions;
- The sapwood was removed to shape the timber, but the heartwood seems to preserve its maximum extent;
- The tangential cut of the plank show evidence of the pith along its extent, but its location alternates from the outboard face (forward of the vessel) to the inboard face;
- It seems that the solution found by carpenters to fill the holes made by the knots was the application of wood patches;
- Some cracks present evidence of stitches possible to avoid the timber to split in two or more pieces.

THE BELINHO 1 CASE STUDY AND SHIP RECONSTRUCTION

A remarkable timber assemblage washed ashore at the beach of Belinho in the north of Portugal continuously since the winter of 2103/2014. At the present stage, the catalogue consists of 75 surviving timbers associated with a vessel[10] (Castro *et al.*: 2015; Martins *et. al.:* 2015). A selection of these timbers was recorded using advanced digital techniques due to their potential for wood morphology studies and tree reconstruction. The recording techniques included computer vision photogrammetry (Yamafune: 2016) and 3D digital tracing with a digitizer arm in conjunction with Rhino 3D (Jones: 2015). The

[10] However, the list of surviving artefacts is increasing and the catalogue will be updated in the near future.

selection of timbers encompassed the Y-frames, floor timber, the sternpost, stern knee, portion of the keel and the keelson (mast step).

The recording protocol was designed under the experience gained from studies undertaken on the ship remains found at Newport, Wales (Nigel and Jones: 2014). This enabled identification of the exact angle of curvature and potentially the diameter of the parent tree in comparison with the shape and size of the selected individual timbers. Evidence of knots, cracks and growth patterns were used to identify the pith location along the full length of each timber. The tree rings visible at end of the Y-frames clearly indicated the points where the tree stem split into two or more branches. The grain lines and the inclination of the knots are essential to identify the direction of the tree (roots as opposed to the canopy). However, the lack of sapwood exception made for the BEL01-001W (Y-frame) prompted the complexity to identify the maximum diameter of each timber.

In completion of the studies performed on the surviving timbers, evidence has shown that to build the Belinho 1 ship carpenters needed at least four types of trees:

- Y-frames – straight stemmed oak trees ending with at least two branches in the canopy forming symmetrical angles from vertical;
- Floor timber and futtocks – long stem or branches having a smooth curvature;
- Stern knee – large stem and branches with an angle closer to 105º;
- Keel – long straight stem having the minimum of 900cm in length.

The following timbers represent examples of the performed tree reconstruction studies focus on structural elements of the Belinho 1 hull allowing to conclude that:

BEL01-001W (Y-frame):

- The 74 cm minimum diameter of the port side branch 18cm angle stem to branch 15º minimum diameter of the starboard side branch 21.4 cm angle stem to branch 156º maximum length of the stem with the absence of knots 149 cm;
- The absence of knots along the main stem;
- Specific V-shape of the canopy;
- The width of the stem is consistent with other timbers in the ship's stern;

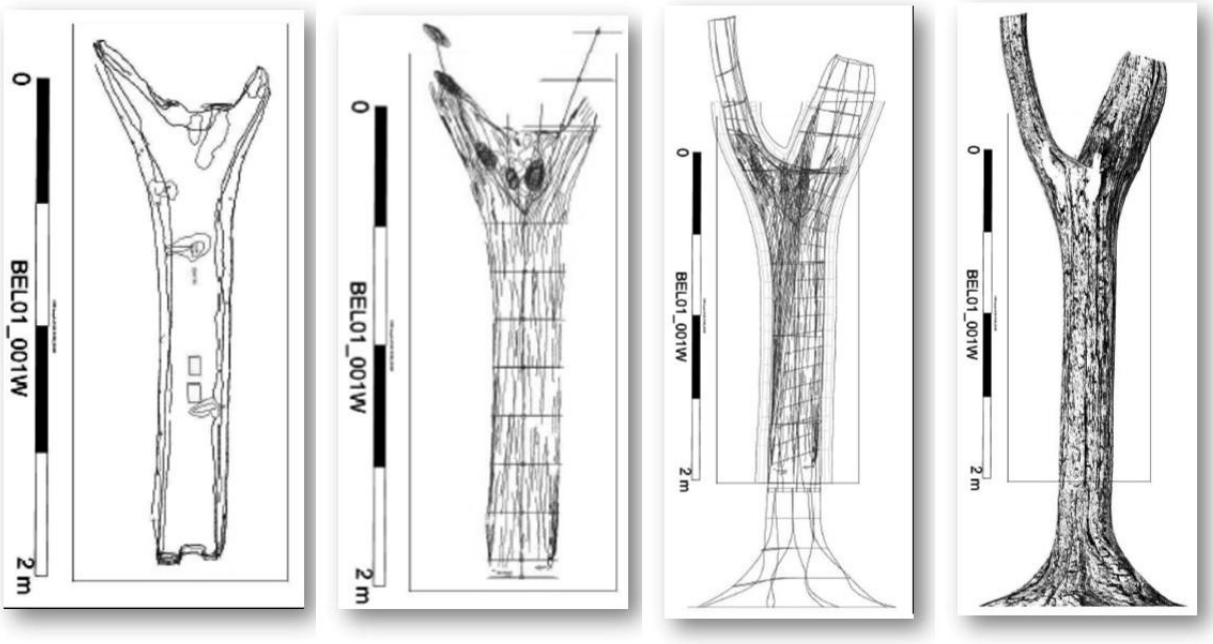


Figure 3. Reconstruction of a tree based on wood morphology evidence recorded on the BEL01-001W (Y-frame).

- The pith, growth pattern and the split of the stem into two branches provided the shape required for the ship construction;
- The growth rate (i.e., average ring width) is consistent with higher levels of moisture (precipitation/groundwater levels);
- The sapwood was removed to shape the timber, but the heartwood seems to preserve its maximum extent (some traces of sapwood).

BEL01-003W (floor timber):

- Clear growth orientation of the timber (crown/stem);
- The abundance of knots at one end;
- The curvature of the timber is consistent with the natural curvature of the tree;
- Fast-growing timber suggests a landscape abundant in water and minerals;
- The grain at the lower end of the timber suggests the existent of forest practice to encourage the growth of multiple branches (pruning/pollarding);
- At the bottom of the timber, the growth pattern is consistent with forest management techniques.

CONCLUSIONS

The process of tree reconstruction involves complex data analysis in which every wood feature needs to be carefully inspected. It is required that archaeologists would need to have experience in shipbuilding characterization and dendrology. The recording process should be efficient in the way that aspects related to shipbuilding and wood anatomy are recorded as seen and avoiding assumptions. Errors when recording the growth pattern (grain), knots or annual rings might determine the lack of information available for tree reconstruction. Moreover, the misinterpretation of the evidence can culminate in the wrong/inaccurate reconstruction of the tree. The recording protocol should always be carried out within the higher standards. The 3D digitizer arm, when connected to Rhino 3D, can be a powerful tool to record evidence on timbers. Although, to maximise the efficiency and reduce time-consuming the operator would need to strictly follow the adopted protocol. On the other hand, fieldwork time constraints can dictate which timber would be the subject of 3D digital recording (as in the case of the projects mentioned above).

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J. Richard Steffy Ship Reconstruction Laboratory

ShipLAB

TEXAS A&M UNIVERSITY

Recording Early Modern Hull Remains

Report 35

Draft 1 - April 2018

CMAC

Center for Maritime Archaeology & Conservation

Filipe Castro, Charles Bendig, Marijo Bérubé, Ricardo Borrero, Nick Budsberg, Chris Dostal, Miguel Martins, Rodrigo Torres, Kotaro Yamafune

Foreword

This little report is intended for young nautical archaeologists and follows a number of other reports and presentations made by the ShipLAB team for the UNITWIN network.

We strongly believe that archaeologists should adopt a common methodology to record ship's hull remains, so that they can be easily compared and shared among the growing community of nautical archaeologists.

It is available online at https://tamu.academia.edu/FilipeCastro/UNITWIN, together with a glossary in six languages, and we expect to improve the graphics and the contents of these collective projects.

Basic proceedings for recording and publishing shipwreck hull remains

1. Introduction

We have an impressively small sample of ship remains from the period than spans from the Bronze Age to the Renaissance.

As J. Richard Steffy put it, some were built to transport goods across bodies of water, some were built to fish, some for commerce, and some for war. They were a part of everyday life of the societies that built and operated them, sometimes inconspicuous and sometimes admirable. They were a product of the culture, the territory, and the ecological conditions that determined their shape, structure and construction sequence. They were imbued with meaning and existed in an ideological frame.

None of these important factors can be grasped, however, if we don't understand how they were conceived and built, how their shape was controlled, how they were repaired and controlled, and what building materials were used, or why they were chosen.

The first step to study the history and significance of ships and boats is to excavate, record, and publish their hull remains in a clear and concise way, and to make available for reinterpretation the primary data that allowed their concise and clear publication (Castro et al. 2017).

Publications should always contain a location map, a short description, plans, sections, and images, and a scantlings list.

Below we propose a standard approach to shipwreck publication. It is understood that the level of detail in a report depends on the money, time, site conditions, and means available to the team.

This report is indicative and proposes a standard structure for the publication of shipwrecks, and follows the steps adopted by J. Richard Steffy in the 1970s. We believe that, having been around for half a century, the present structure has endured the methodological and technological changes of two generations of nautical archaeologists and stands as a solid frame for the description of a shipwreck.

And we hope that more archaeologists adopt this standard, so that comparative studies become easier and quicker, as data sharing and peer review of surveys and excavations.

We hope that sharing primary data becomes the norm in our research field, and that the younger generations of nautical archaeologists will use the internet to share their primary data and replace the 19th century paradigm, which preferred the publication of final reports after decades of secret studies, to the hard sciences way, in which knowledge increases constantly by small increments.

2. Description of the site

The first step in describing a shipwreck is an introduction containing:

1. The location of the site, including the depth, elements preserved, and the probable site formation process;
2. A short history of the site, detailing how it was found, whether there is indication that it was salvaged or looted since the shipwreck, and dates and bibliography pertaining to its surveys and previous interventions;
3. A description of the remains: rough dimension of the ballast pile, number and size of anchors, number and size of guns, the nature of the cargo, personal artifacts, the rough dimension of the hull remains, and description of its main components;
4. A short description of the most relevant artifacts apparent;
5. A location map;
6. A site map of the site as found on the seabed;
7. Cross-sections of the site in orthogonal directions;
8. A tentative identification of the site with a description of the most probable chronological range (*terminus post quem* and *terminus ante quem*);
9. An account of the basic construction features apparent, specifically related to known architectural signatures.
10. A first impression of the wood characteristics (e.g. hard or soft), tree ring-width average, conversion technique (e.g. tangential cut, split) and growth pattern (e.g. knots, grain flow orientation, roots or canopy).

Example of a location map:

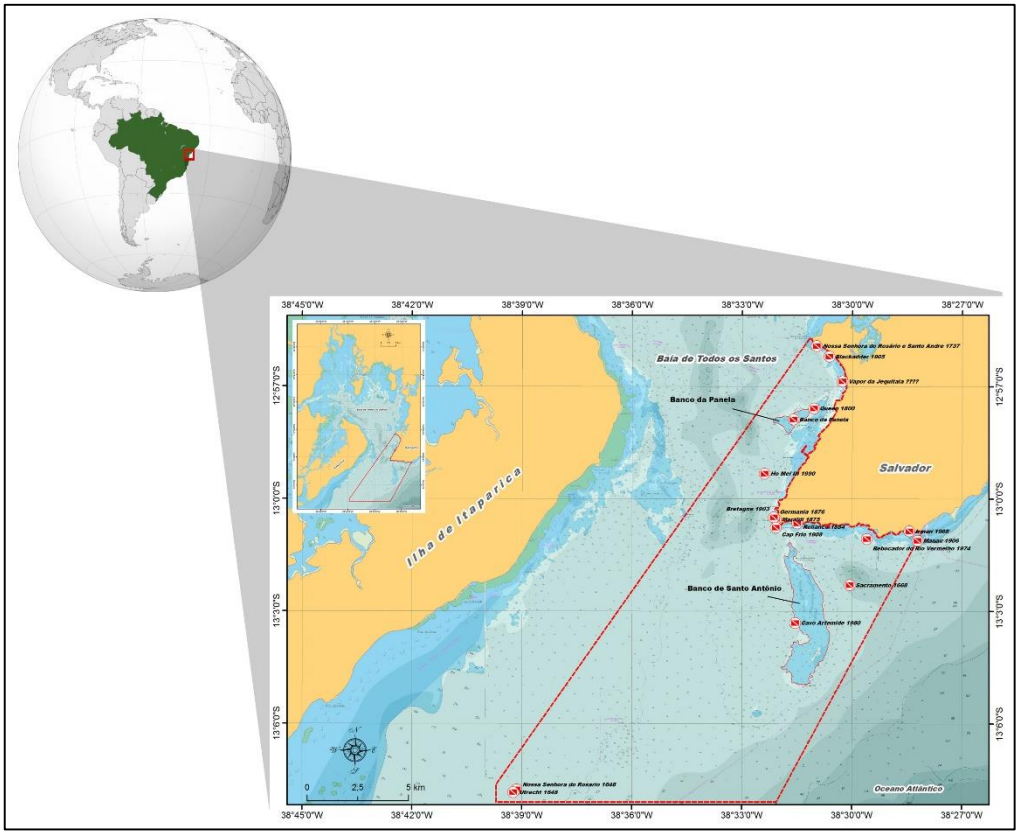


Figure 1 – Location map of the Project Observabaía (Torres 2016).

The recording of a site must tell the story of the archaeological intervention. It is normal and common for archaeologists to make mistakes, and a continued recording can mitigate or even resolve this problem. The first step of every intervention is the definition of a sufficient number of fixed datum points. Sites should be recorded before any cleaning or intrusive action is taken.

Once the basic site plan is developed and scaled – if there is enough visibility photogrammetry is the cheapest, quickest, and most precise way to record a pre-disturbed site as a mesh or a point cloud – cleaning and tagging all apparent elements is the second step.

Unless the structural remains are completely exposed and can be clearly interpreted, it is good practice to number all hull components sequentially, as the timbers are exposed or recorded, regardless of their function or position.

If photogrammetry is a viable option, periodical tridimensional meshes of the surfaces exposed can be saved, published in real time on the internet, and compounded later, as the earliest ones will have better detail of the surfaces exposed (timber surfaces erode quickly during the excavation).

Ideally ships should be disassembled and each timber recorded in detail. This practice is expensive and time consuming, and it is often impossible to do more than to select a small number of diagnostic components, and record them in detail.

Examples of site maps:

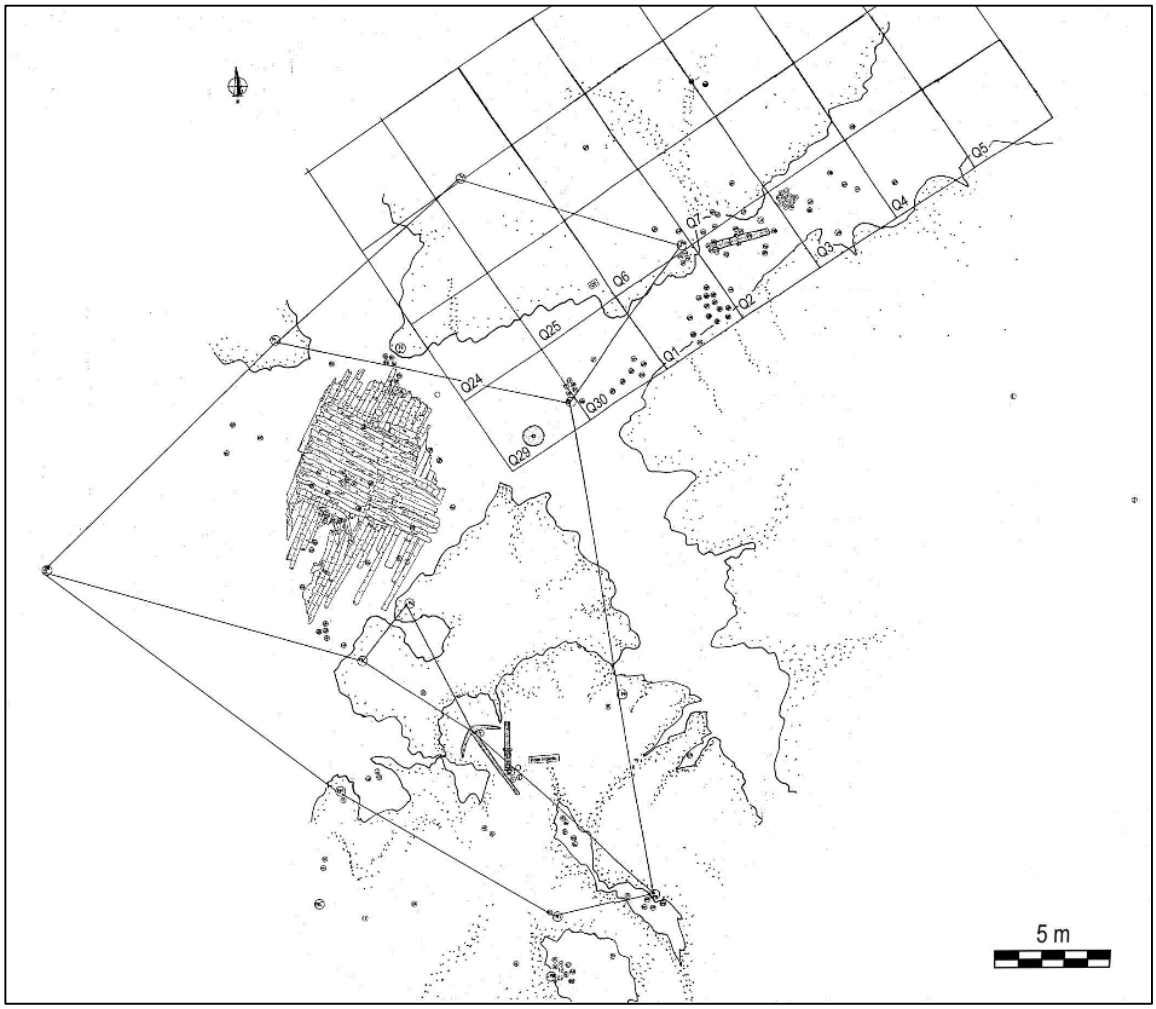


Figure 2 – Pepper Wreck (Castro 2003).

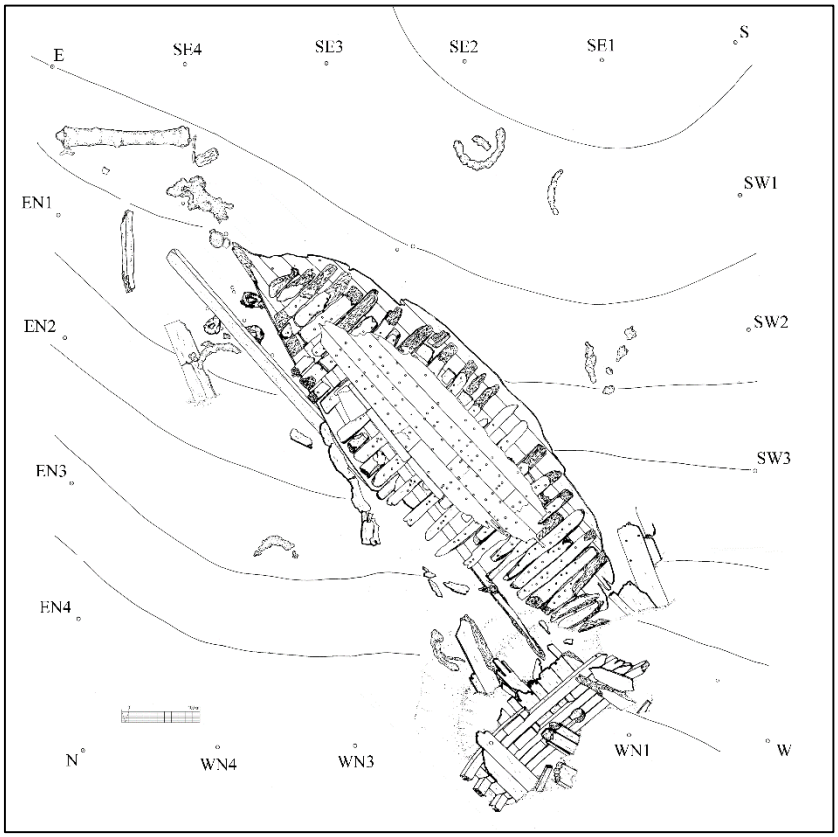


Figure 3 – Arade 1 (Castro 2005).

The characterization of a site should include:

1) The size of the hull remains preserved;
2) The estimated reconstructed size of the ship (keel length, length overall, beam, depth in hold, etc.);
3) A tentative characterization of the ship, including the number of decks, masts, rigging type, function, etc.;
4) A short description of the timbers preserved, preferably presented in a table with two columns, indicating the designation and description of the hull components preserved;
5) A summary table with the list of the most important scantlings;

Once a site is described and the hull remains characterized, it is paramount to describe each timber analyzed.

Mapping a site requires some training and can be facilitated by the use of computers. Trigonometry programs such as *Site Recorder 4* can produce good maps from direct measurements between datum points and particular points in the structure to be mapped. If there is enough visibility, computer vision can make the tasks of mapping a site extremely easy (Drap and Long 2001; Drap et al. 2003; Drap et al. 2013; Drap et al. 2015; Yamafune et al. 2017).

Using the principals of photogrammetry, computer vision can produce point clouds or meshes with the shape and color of the surface recorded down to centimetric precision. These clouds can be sliced to produce sections and combined to reveal the changes occurred during the excavation process.

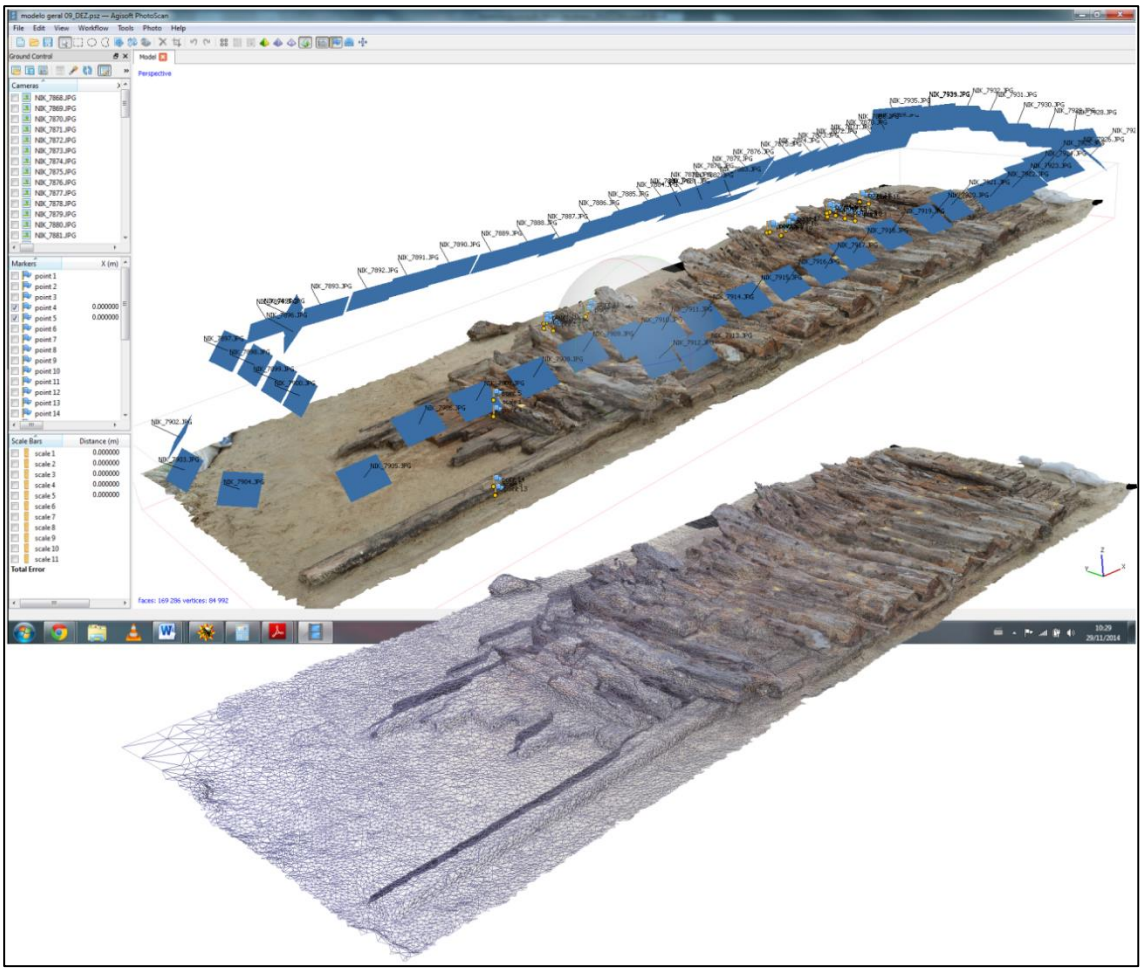


Figure 4 – Lagoa do Peixe site (Torres 2015).

Meshes can also be used to produce scaled orthophotos, which can be worked in GIS to produce layered maps with different construction features (Torres 2015).

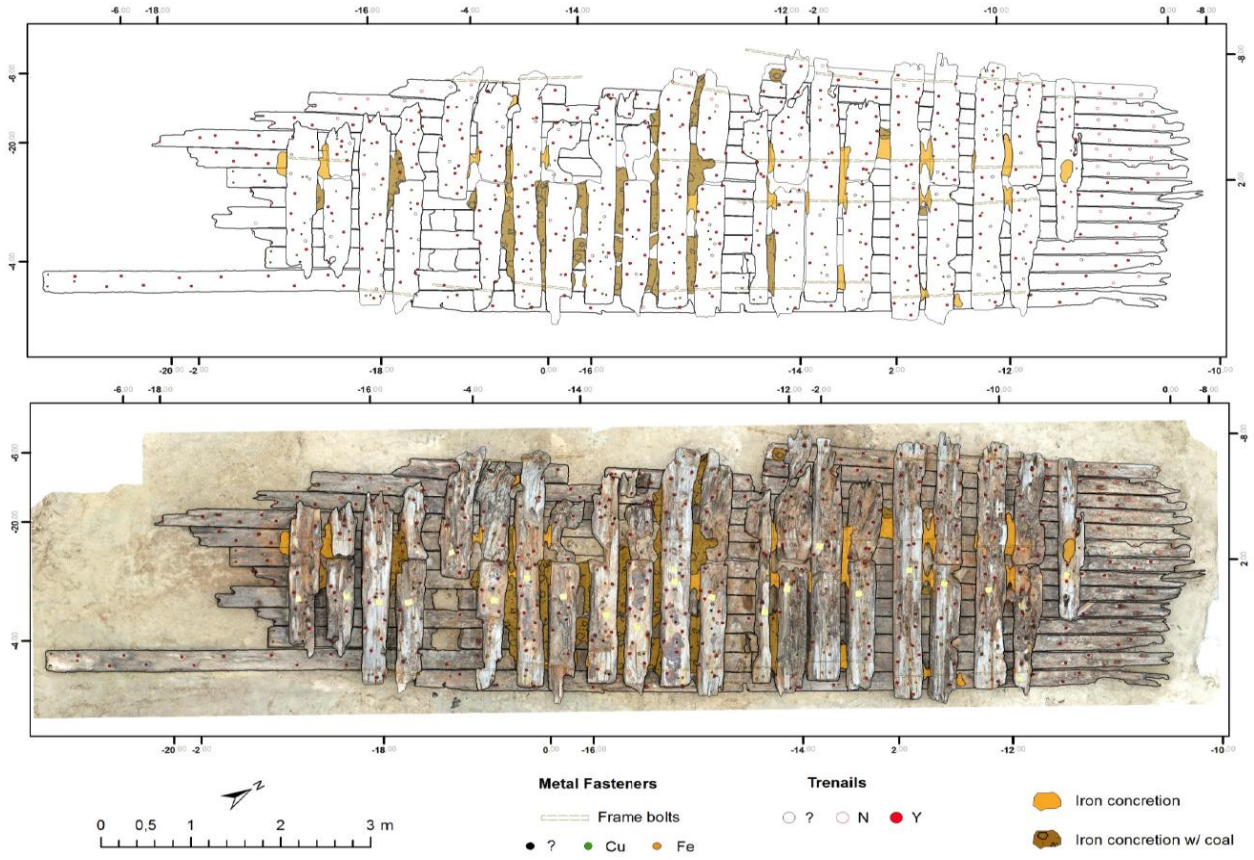


Figure 5 – Lagoa do Peixe site scaled orthophoto (Torres 2015).

3. Timber Catalogue

The second section in a shipwreck hull report should be a catalogue of the timbers preserved, which should be organized in the following way:

1. A scaled site plan with the upper layer of timbers tagged, which generally should include:
    a. Keelson and maststep;
    b. Aprons and filling timbers at the bow;
    c. Deadwood and filling timbers at the stern;
    d. Stringers and breast hooks;
    e. Ceiling planking;
    f. Pumps and pump sumps.

2. A scaled site plan of the keel and framing structure with all floor timbers and futtocks tagged;

3. A scaled plan of the lower layer of the hull structure with all timbers tagged, which should include:
    a. Keel and posts;
    b. Hull planking;
    c. Wales.

4. A table with each timber referred by its tag number, and characterized by the following measurements:
    a. Additional location information, e.g. square, layer, or depth (if necessary).
    b. Length preserved;
    c. Length reconstructed (when possible);
    d. Sided dimension;
    e. Molded dimension;

Examples of site plans with two and three structural layers preserved:

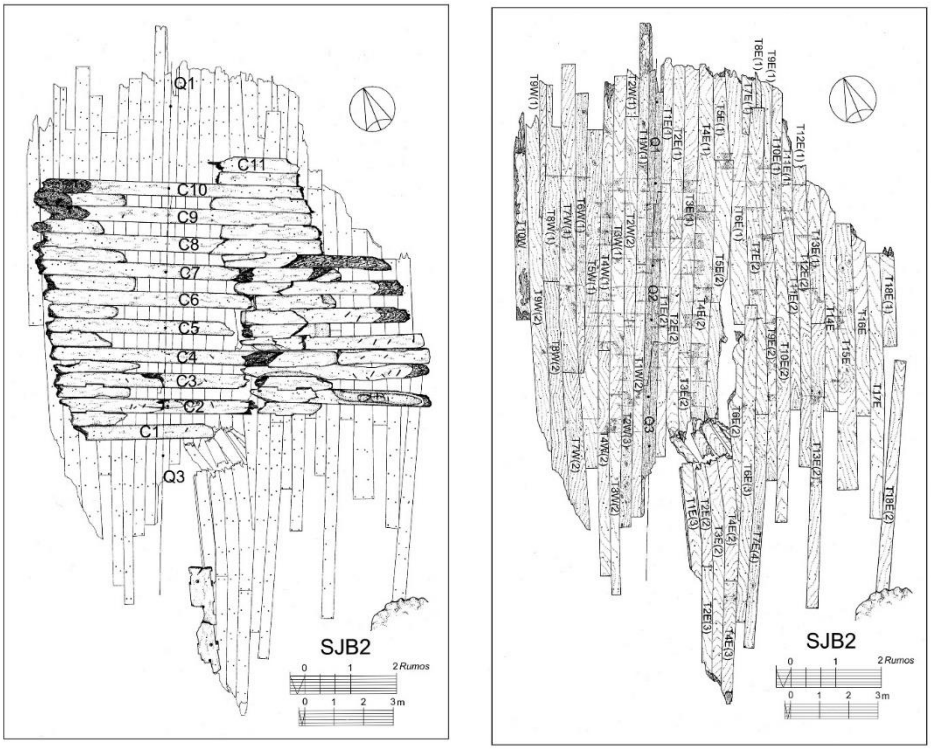


Figure 6 – Pepper Wreck (Castro 2003).

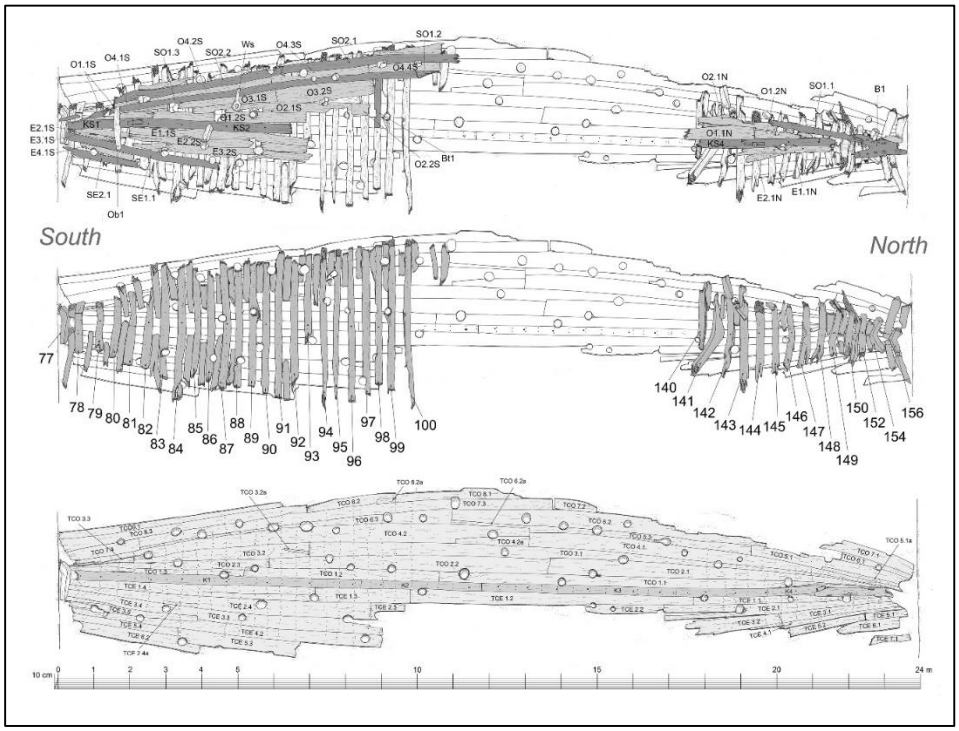


Figure 7 – Cais do Sodré Wreck (Castro et al. 2011).

Example of a table with the timber inventory:

Ref.	Location	Length pres.	Length rec.	Sided [cm]	Molded [cm]

5. A fiche per timber with the following basic information:
    a. Reference (tag);
    b. Additional location information, e.g. square, layer, or depth (if necessary).
    c. Date recorded and signature;
    d. Sketch;
    e. Length preserved;
    f. Length reconstructed (when possible);
    g. Sided dimension;
    h. Molded dimension;
    i. Carpenter (construction) marks;
    j. Scarves;
    k. Fasteners (type, dimensions, timbers connected);
    l. Tool marks;
    m. Wood species;
    n. Timber conversion, including ring-width average and growth pattern;
    o. Samples;
    p. Additional comments.

This information can be entered directly in a computer, or recorded on paper, in a fiche like the one presented below, and can be completed with additional drawings and sketches.

Timber Recording Sheet

Date: _____

Author: _____

Reference (tag no.): _____ Position: _____

Sketch:

Length preserved: _____m
Length reconstructed: _____m

Sided dimension: _____cm
Molded dimension: _____cm

Wood species: _____
Samples (no.): _____

Section / Conversion:

Scarves:

Fasteners:

Carpenter (construction) marks:

Coatings/paints/sheathing:

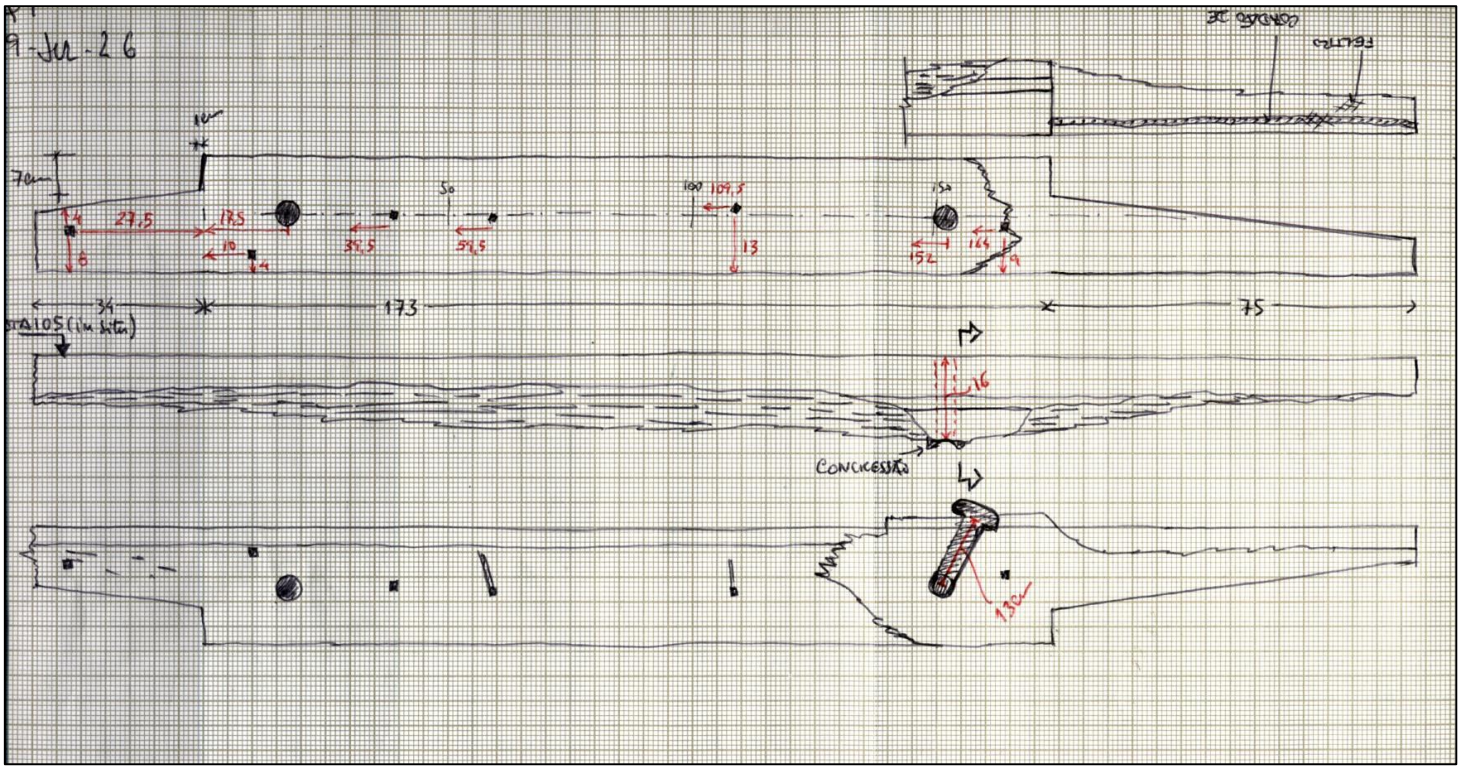
Bevels:

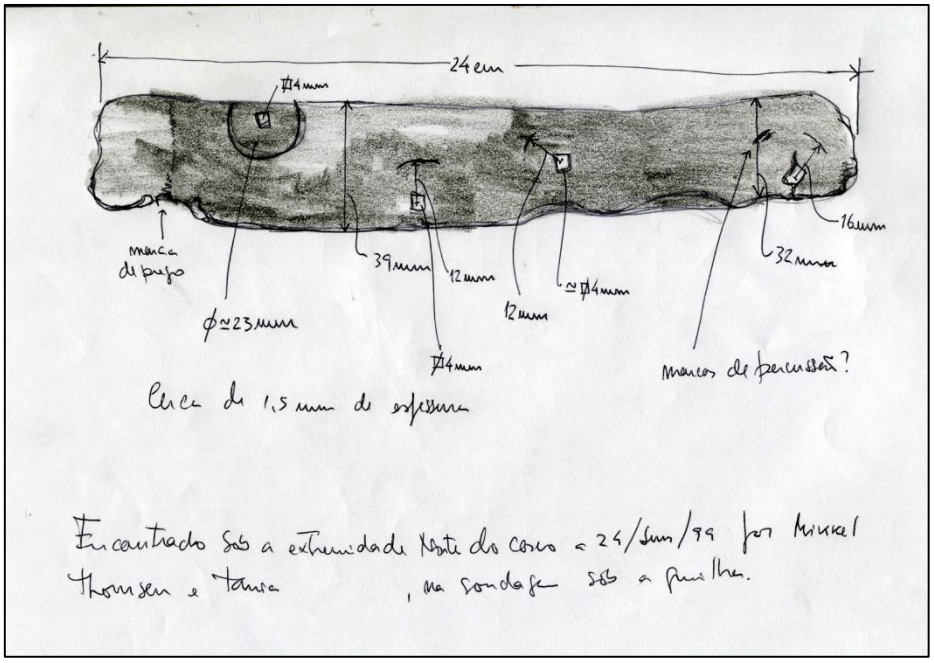
Additional Comments:

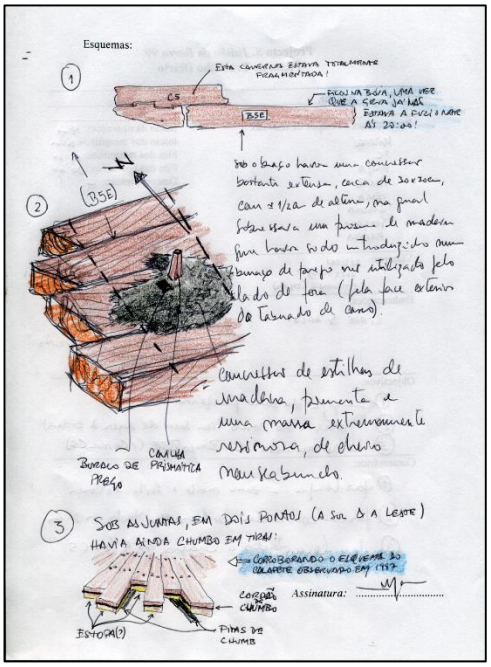
Additional Sketches

Date: _____

Author: _____







All additional drawings and sketches should be scanned and filed.

6. A drawing of the timber containing:

   a. Four views and at least one section;
   b. Shape;
   c. Comments.

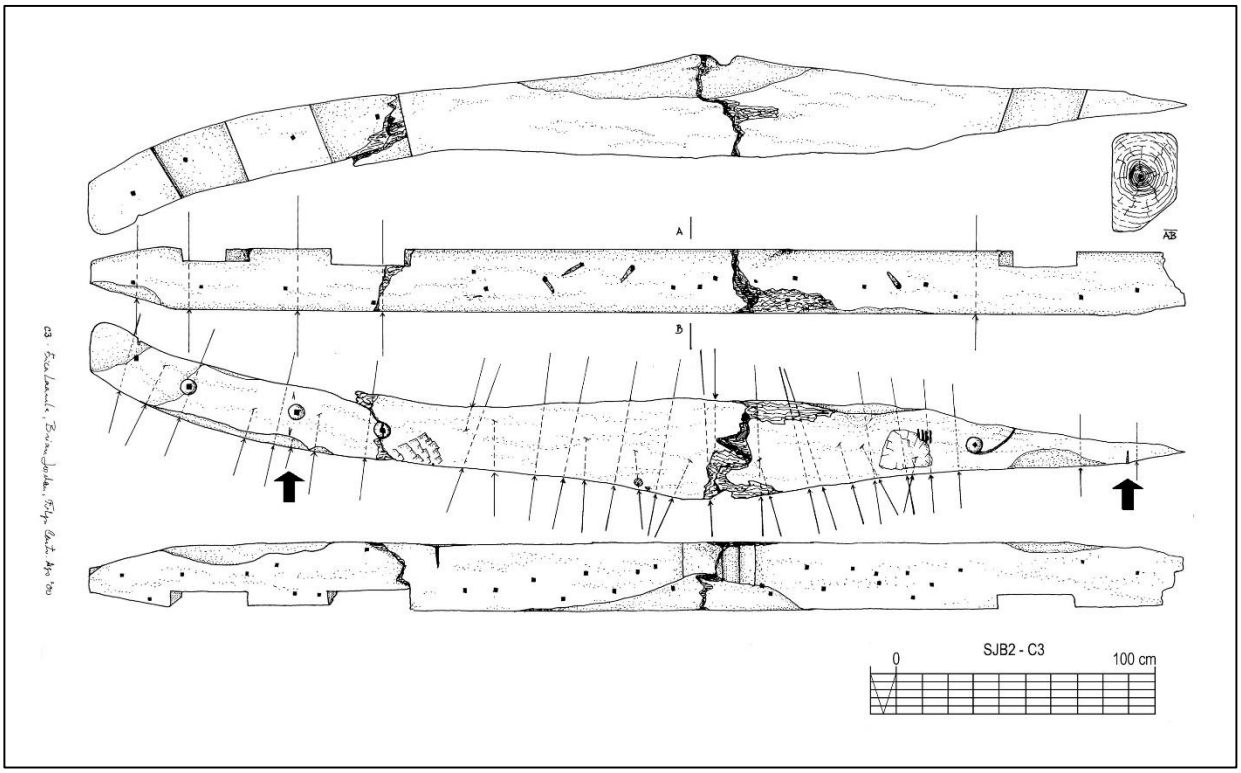


Figure 8 – Pepper Wreck (Castro 2002).

7. A folder with images and scanned measurements and sketches.

8. The main hull components to be considered in the elaboration of the timber catalogue are indicated below:

   a. Keel;
   b. False keel;
   c. Stem;
   d. Stem heel;
   e. Apron;
   f. Sternpost;
   g. Stern heel;
   h. Stern knee;
   i. Floor timbers;
   j. Half frames;
   k. Futtocks;
   l. Keelson;
   m. Maststep;
   n. Garboards;
   o. Planking

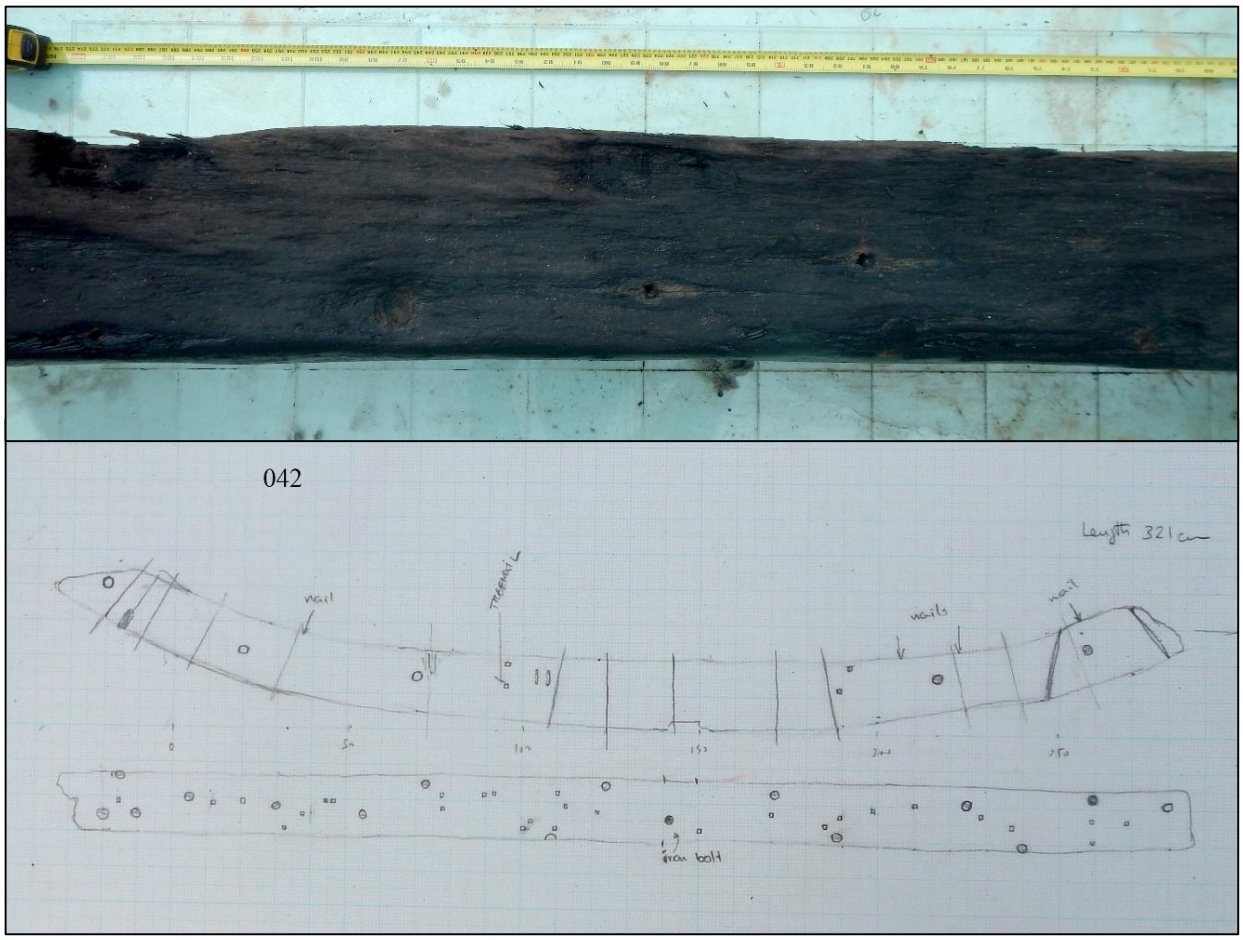
p. Stringers;
q. Ceiling;
r. Riders;
s. Wales;
t. Clamps
u. Knees;
v. Waterways;
w. Beams, carlings, and ledges;
x. Deck planking;
y. Hatch coamings;
z. Stanchions, bitts, pumps and sumps, rigging, and other features

9. If raised, individual timbers can be recorded in many different ways, ranging from the traditional 1:1 hand drawings in transparent film (Figure 9) to direct scaling, by placing the timber over a grid (Figures 10 and 11). Again, computers are simplifying the recording process and timbers can be recorded using photogrammetry (Figure 12), or scanned with laser technology (Figures 21 and 23).

It is fundamental to take scaled pictures of every surface and every detail.



Figure 9 – Recording the Arade 1 timbers on a horizontal plane, using a laser and transparent film (Photo: Filipe Castro).



Figures 10 and 11 – Recording the Belinho 1 timbers on a horizontal plane, using a 10 x 10 cm grid underneath and recording it directly on millimetric paper, at a 1:10 scale (Drawing and photo: Filipe Castro).

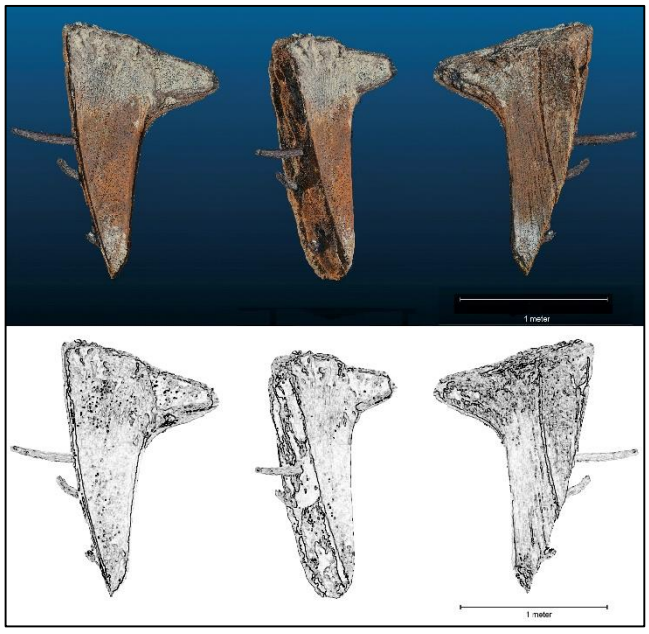


Figure 12 – Tridimensional model obtained with photogrammetry (PhotoScan). There are a few basic rules to simplify and streamline this process, namely controlling the light and setting the timbers on a surface that can be easily edited out of the pictures (Torres et al. 2017).

When timbers are recorded in situ the traditional way is to make sketches and take measurements by hand. Curvature is very important and there are several simple ways to record it, the most common being:

1. Manual goniometer: as shown in Figures 13, 14 and 15, this method consists of measuring the distance between two points, which make the third side of an isosceles triangle. The archaeologist places one of the sides along the curve to be recorded, moves the second side to the horizontal position, with the help of a level, and measures the third side of the triangle. This method requires that you know the position of the goniometer along the curve that you are recording.

2. Digital goniometer: this method is similar to the previous one but simpler, because electronic goniometers record the angle to the horizontal (Figures 16, 17, 18, and 19).

3. Offsets: this method is simple and easy for short curves and consists of a horizontal bar set over vertical poles, with a tape measure glued to it, representing the 'x' axis. The vertical 'y' measurements are taken with a tape measure with a plumb on the bottom (Figure 20).

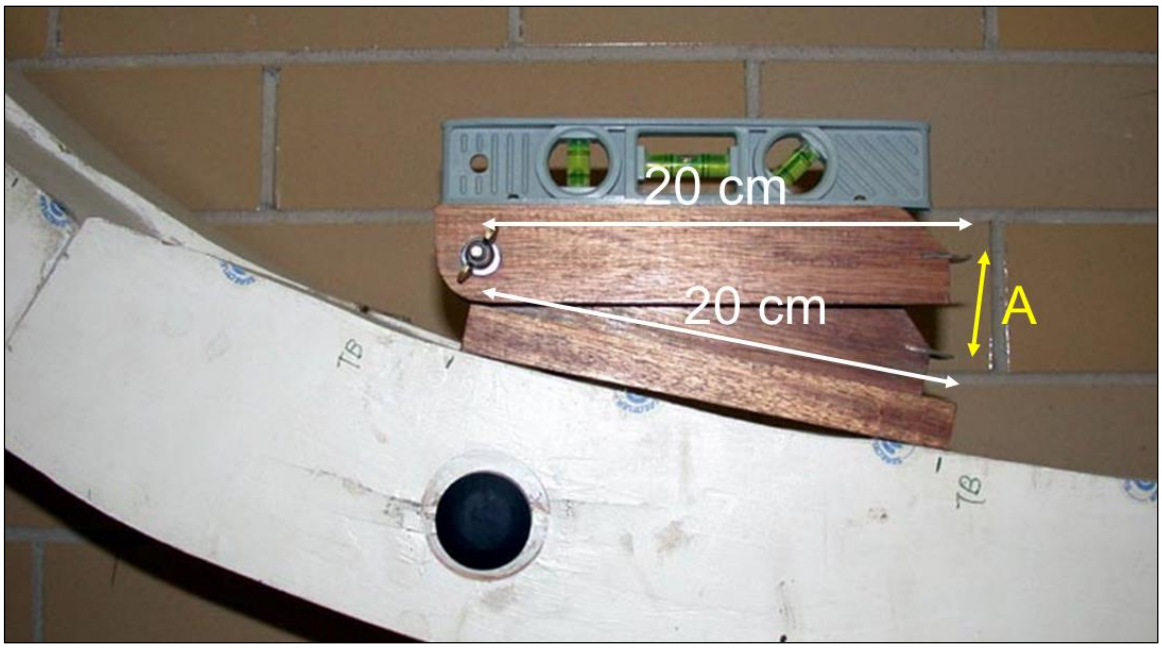


Figure 13 – Manual goniometers are a quick and accurate way to retrieve slopes and capture curves (Photo: Filipe Castro).

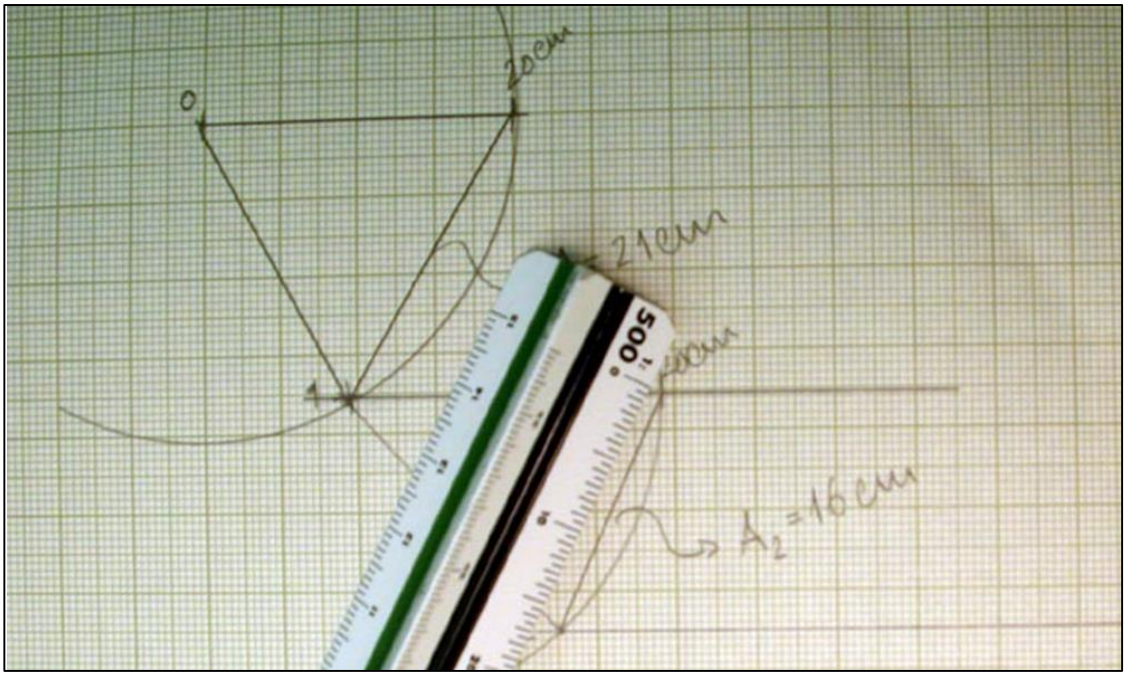


Figure 14 – Points 0, 1, 2, etc., are spaced 20 cm (the length of the goniometer) and define the curve recorded (Photo: Filipe Castro).

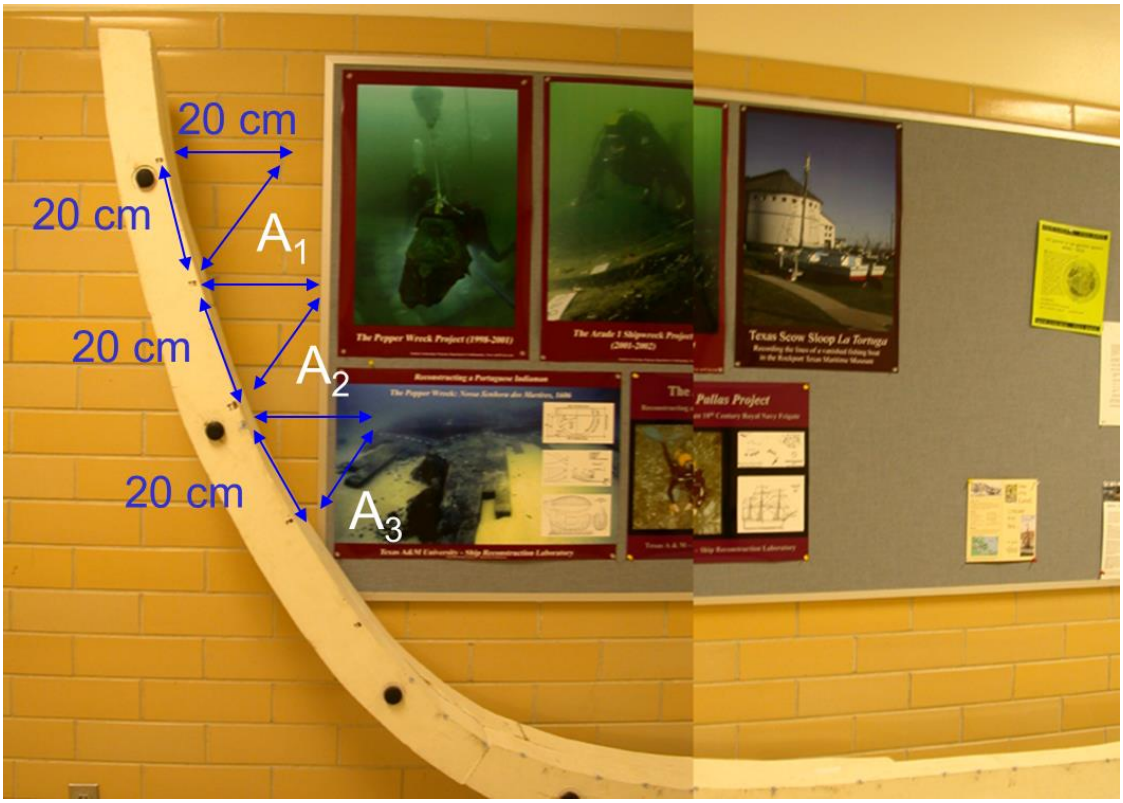


Figure 15 – Taking the curve of a replica of a frame from the 1686 French shipwreck *Belle* (Photo: Filipe Castro).



Figure 16 – Digital goniometer (Photo: Filipe Castro).



Figure 17 – Dry case for a digital goniometer (Photo: Filipe Castro).

The digital goniometer must be mounted on a base with a known distance, so that the angles can be accurately plotted on each incremental distance.

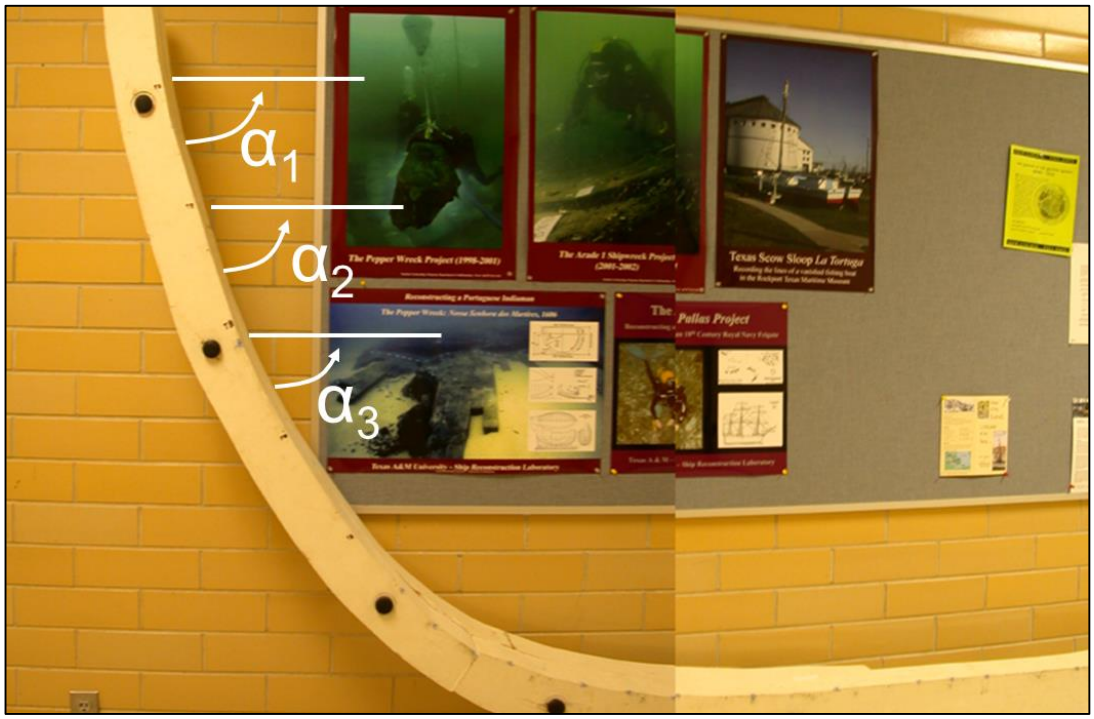


Figure 18 – Taking the curve of a replica of a frame from the 1686 French shipwreck *Belle* with an electronic goniometer (Photo: Filipe Castro).

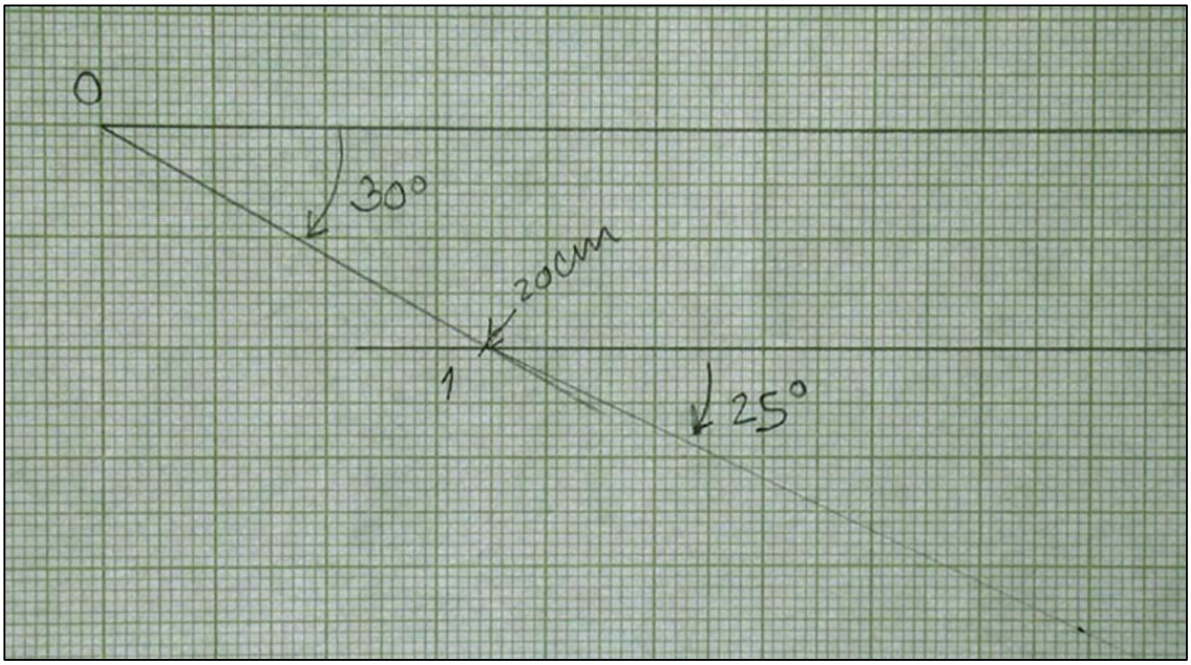


Figure 19 – Points 0, 1, etc., are spaced the distance of the base on which the digital goniometer is mounted define the curve recorded (Photo: Filipe Castro).

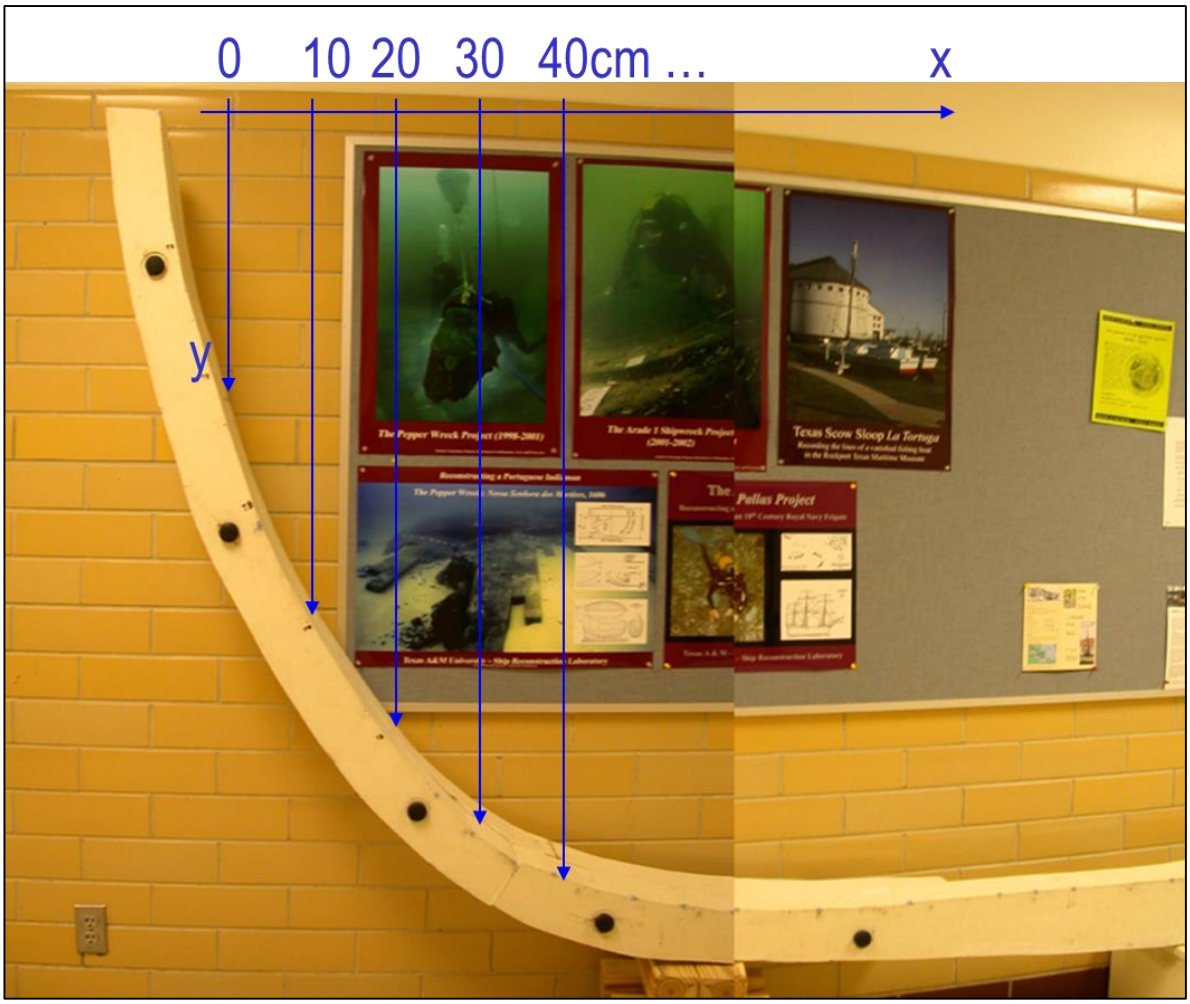


Figure 20 – Taking the curve of a replica of a frame from the 1686 French shipwreck *Belle* with offsets from an horizontal line (Photo: Filipe Castro).

10. When documenting disarticulated ship timbers via laser scanning, the resolution of the laser scanner will determine the additional information needed for adequate documentation of the timbers. Assuming sufficient resolution, some of the details normally recorded by hand are easily discernible, such as wood grain patterns and direction, treenail locations, and markings. At the Conservation Research Laboratory (CRL), laser scanned models of timbers are incorporated into the documentation of the vessel in three ways.

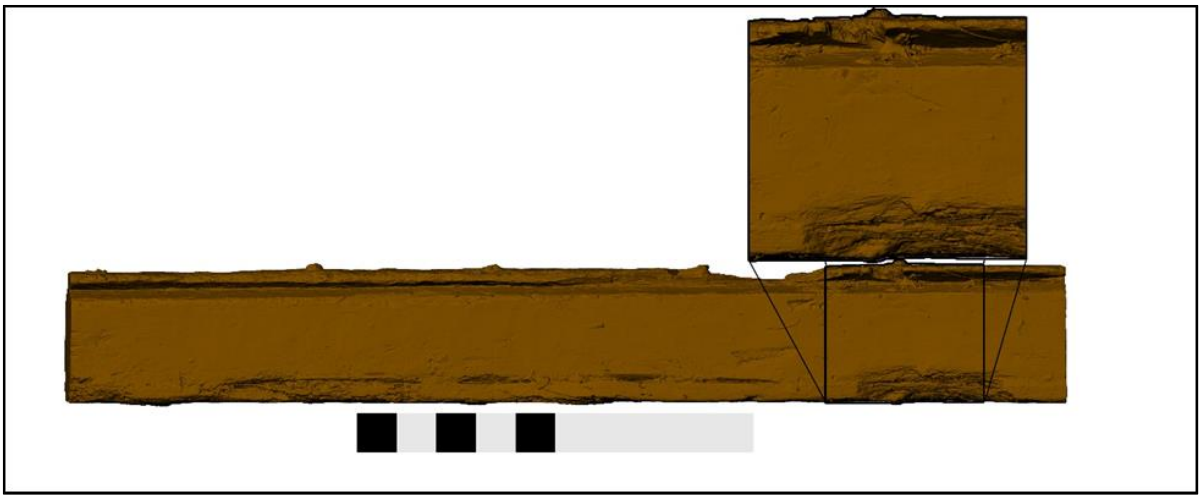


Figure 21: Laser scan section of the keel from the 18-century ship from Alexandria, VA. The resolution of the scan is high enough to pick out the grain pattern, erosion, and fasteners in the wood (Image: Chris Dostal).

First, the models themselves are always included. Ideally, online hosting with open access and the ability to download the models is utilized to facilitate complimentary research and critiques. At a minimum, a non-proprietary version of the models should be available upon request.

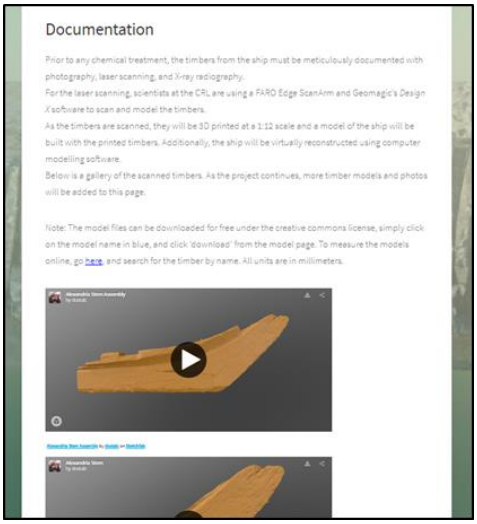


Figure 22: Downloadable 3D files for the 18th-Century Alexandria Ship Project hosted on the CRL website. The models can be manipulated directly in a browser, allowing for easy access to researchers (Image: Chris Dostal).

A researcher having the ability to manipulate the 3D model of each individual timber greatly increases the reliability of the data by reducing several of the layers of interpretation necessary for traditionally recorded timbers. When recording the sided and molded dimensions of a particular futtock for example, the person doing the recording has to determine where one face ends and the next starts; this is obvious when dealing with a very squared timber, but for timbers with rounded sides, a semi-arbitrary demarcation point is necessary. With a manipulatable 3D model of a timber, no such arbitrary demarcation point needs to be established.

The second way to incorporate a laser scanned 3D model of a timber is to use the model to develop a timber drawing with the 4-5 faces traditionally included for timber drawings. If the manipulatable 3D model is not part of the documentation for the project, cross section views are needed to show the shape of the timber. If the model is included, the shape can be more precisely seen by rotating the model. Color and lighting settings in the software are crucial to the success of this process. The color should be chosen to roughly approximate reality but off enough that it is clear to the reader that it is not original to the wood. The lighting must be consistent for each of the faces and should be adequate to not obscure details.

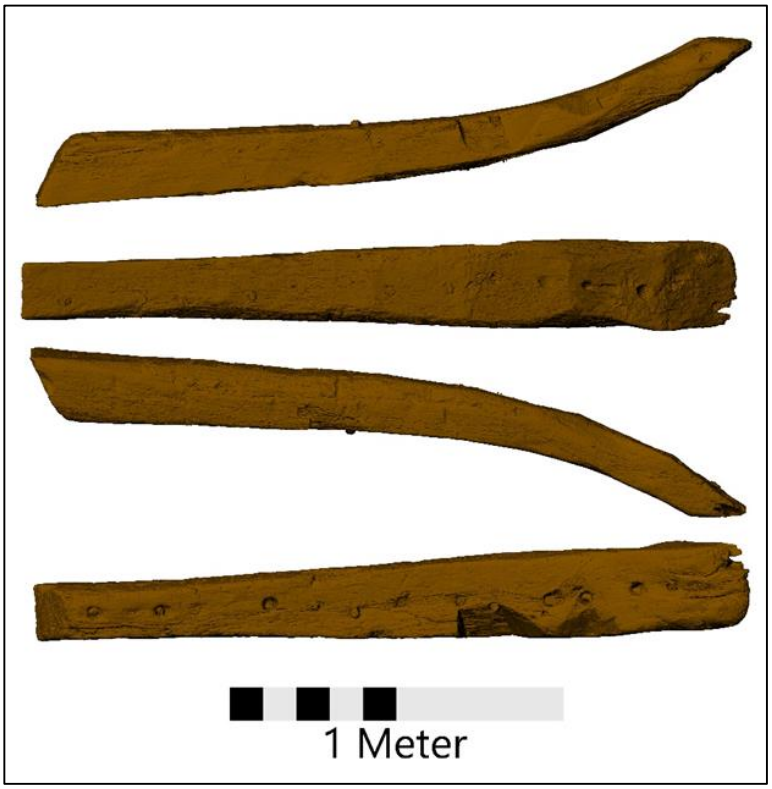


Figure 23: Orthogonal views of a laser scanned timber (Image: Chris Dostal).

The third way to incorporate laser scanned models is to use the model as a starting point for a more traditional style drawing. We do this to create simplified drawings that can focus attention on specific details, like fasteners, cracks, dubbing marks, tool marks, concretions, etc. To accomplish this, the outline of the model at each face is created, and then that outline is used as the boundary for the drawing. The faces of the model as seen in Figure 23 are then printed out and drawn over while inspecting the physical timber and drawn in atop the image. Everything noted is then traced in using CAD software.

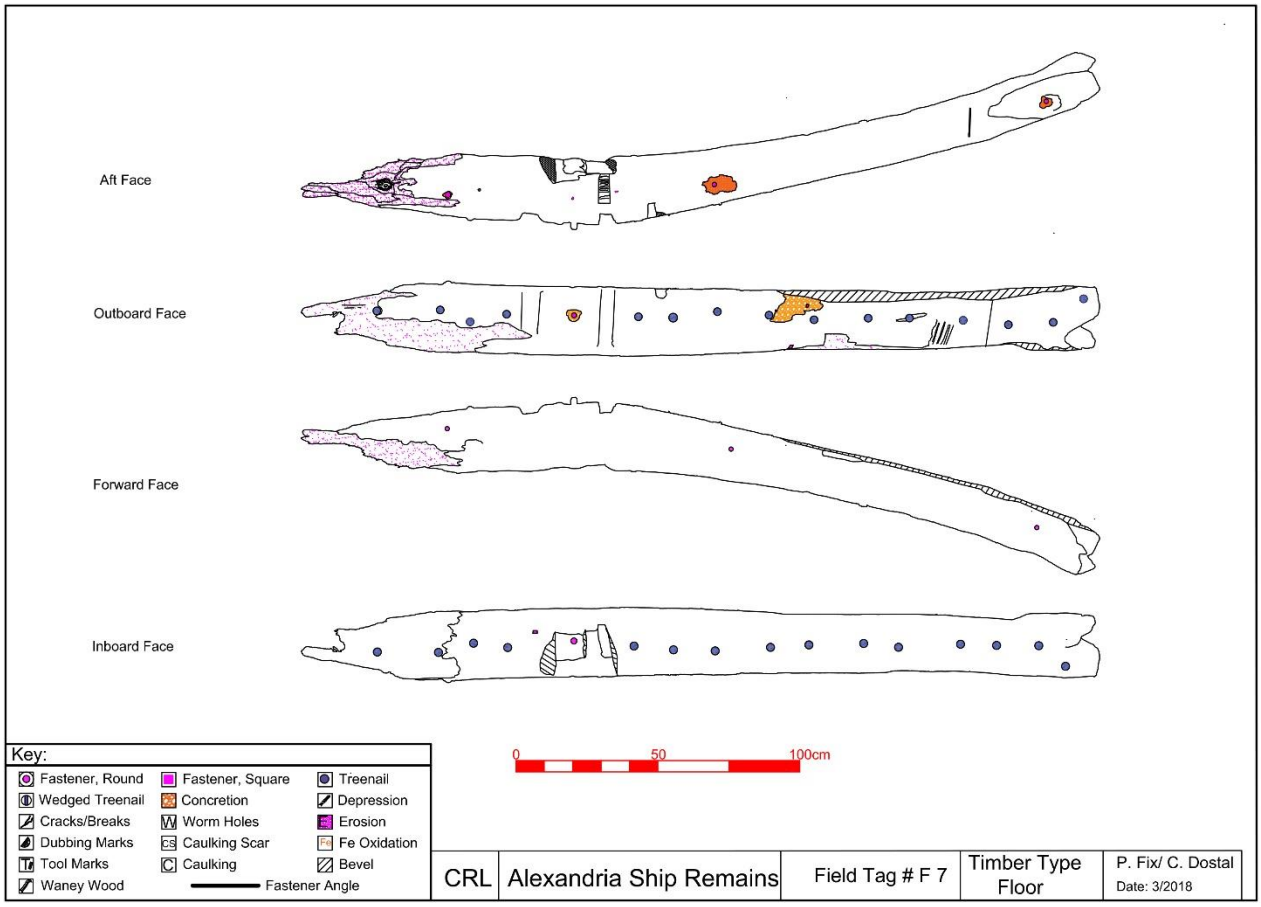


Figure 24: Timber from the Alexandria Ship (Image Peter Fix and Chris Dostal, CMAC/TAMU).

11. The parameters to be recorded in each timber indicated above is detailed below, in the following pages:

a. Keel

1. Length preserved;
2. Length reconstructed;
3. Shape;
4. Number of components;
5. Scarves;
6. False keels or rising timbers;
7. Section geometry;
8. Rabbets;
9. Sided and molded dimensions at bow, amidships and stern, as applicable;
10. Fasteners: between components, Keel/Stem or Stem knee, Keel/Apron, Keel/Sternpost or Stern knee, Keel/Stern Heel, Keel/keelson;
11. Calking in the scarf tables;
12. Wood type;
13. Conversion;
14. Construction marks;
15. Tool marks;
16. Coatings;
17. Additional comments.

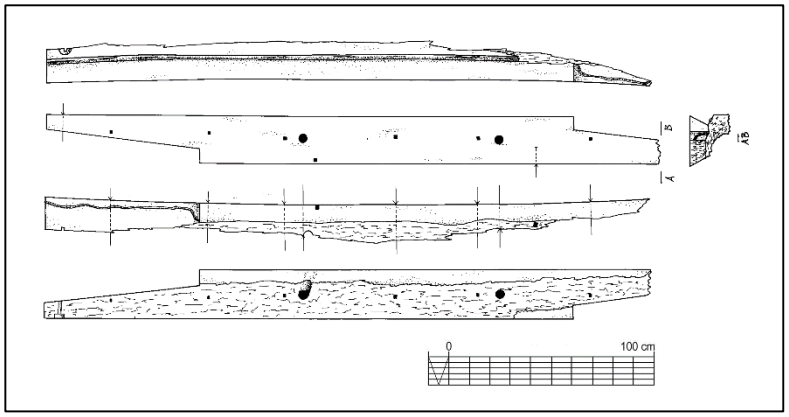


Figure 25 – Fragment of a keel section from the Pepper Wreck (Castro 2002).

b. False keel

1. Length preserved;
2. Length reconstructed;
3. Shape;
4. Number of components;
5. Scarves;
6. Section geometry;
7. Sided and molded dimensions at bow, amidships and stern, as applicable;
8. Fasteners;
9. Wood type;
10. Conversion;
11. Construction marks;
12. Tool marks;
13. Coatings;
14. Additional comments.

c. Stem

1. Length preserved;
2. Length reconstructed;
3. Shape;
4. Number of components;
5. Scarves;
6. False Stems and other associated timbers;
7. Section geometry;
8. Rabbets;
9. Sided and molded dimensions at heel and head, as applicable;
10. Fasteners;
11. Wood type;
12. Conversion;
13. Construction marks;
14. Tool marks;
15. Coatings;
16. Additional comments.

d. Stem heel

1. Length preserved;
2. Length reconstructed;
3. Shape;
4. Scarves;
5. Aprons and associated timbers;
6. Section geometry;
7. Rabbets;
8. Sided and molded dimensions at heel and head, as applicable;
9. Fasteners;
10. Wood type;
11. Conversion;
12. Construction marks;
13. Tool marks;
14. Coatings;
15. Additional comments.

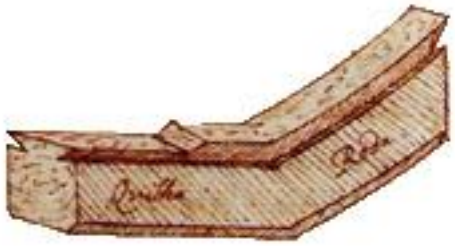


Figure 26 – Stem heel (Lavanha c. 1600).

e. Apron

1. Length preserved;
2. Length reconstructed;
3. Shape;
4. Scarves;
5. Associated timbers;
6. Section geometry;
7. Sided and molded dimensions at heel and head, as applicable;
8. Fasteners;
9. Wood type;
10. Conversion;
11. Construction marks;
12. Tool marks;
13. Coatings;
14. Additional comments.

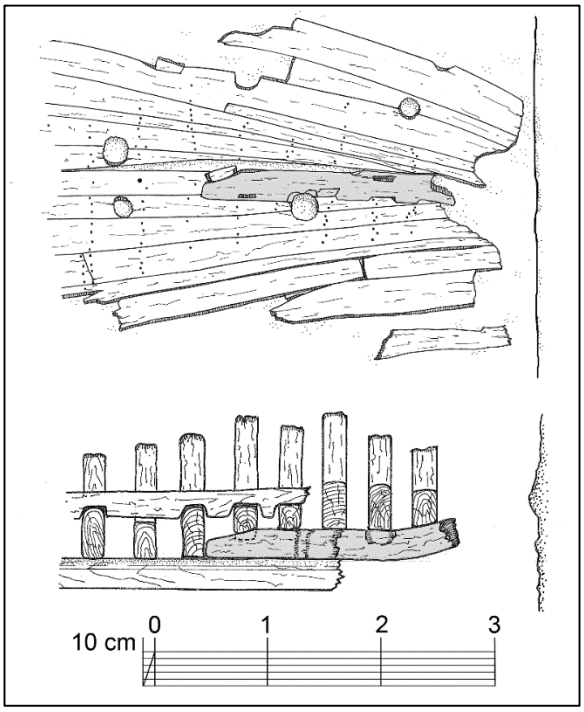


Figure 27 – Cais do Sodré Wreck (Castro et al. 2011).

f. Sternpost

1. Length preserved;
2. Length reconstructed;
3. Shape;
4. Number of components;
5. Scarves;
6. False Sternposts, fashion timbers and other associated timbers;
7. Section geometry;
8. Rabbets;
9. Sided and molded dimensions at heel and head, as applicable;
10. Fasteners;
11. Wood type;
12. Conversion;
13. Construction marks;
14. Tool marks;
15. Coatings;
16. Additional comments.

g. Stern heel

1. Length preserved;
2. Length reconstructed;
3. Shape;
4. Scarves;
5. Associated timbers;
6. Section geometry;
7. Rabbets;
8. Sided and molded dimensions at heel and head, as applicable;
9. Fasteners;
10. Wood type;
11. Conversion;
12. Construction marks;
13. Tool marks;
14. Coatings;
15. Additional comments.



Figure 28 – Stern heel (Lavanha c. 1600).

h. Stern knee

1. Length preserved;
2. Length reconstructed;
3. Shape;
4. Scarves;
5. Associated timbers;
6. Section geometry;
7. Sided and molded dimensions at heel and head, as applicable;
8. Fasteners;
9. Wood type;
10. Conversion;
11. Construction marks;
12. Tool marks;
13. Coatings;
14. Additional comments.

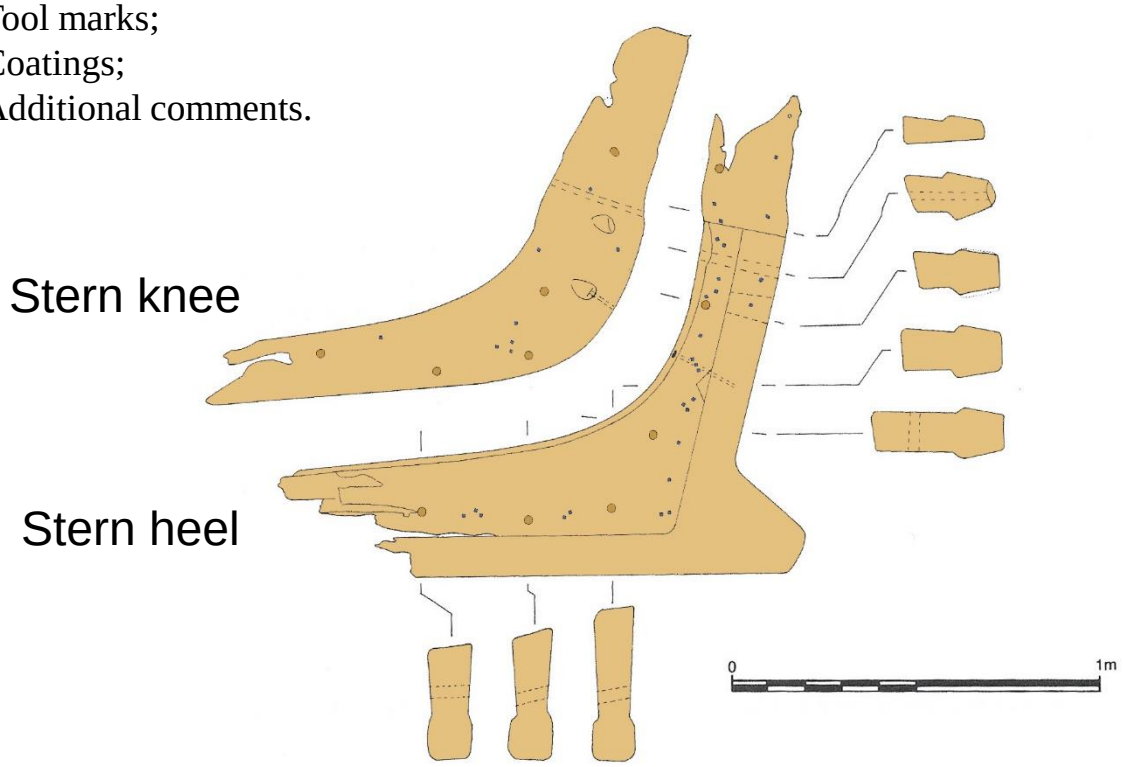


Figure 29 – Corpo Santo (Drawing: Miguel Aleluia).

i. Floor timbers **j. Half frames** **k. Futtocks**

1. Framing plan;
2. Section geometry;
3. Locations and dimensions of limber holes;
4. Sided and molded dimensions (max., min, av.) at keel and intermediate dimensions, as applicable;
5. Room and space, the distance between frame centers (max., min, av.);
6. Scarves and chocks;
7. Fasteners: floors/Keel, floors/futtocks;
8. Wood type;
9. Conversion;
10. Shape;
11. Bevels;
12. Construction marks;
13. Tool marks;
14. Coatings;
15. Additional comments (e.g. inclination, square or canted, etc.).

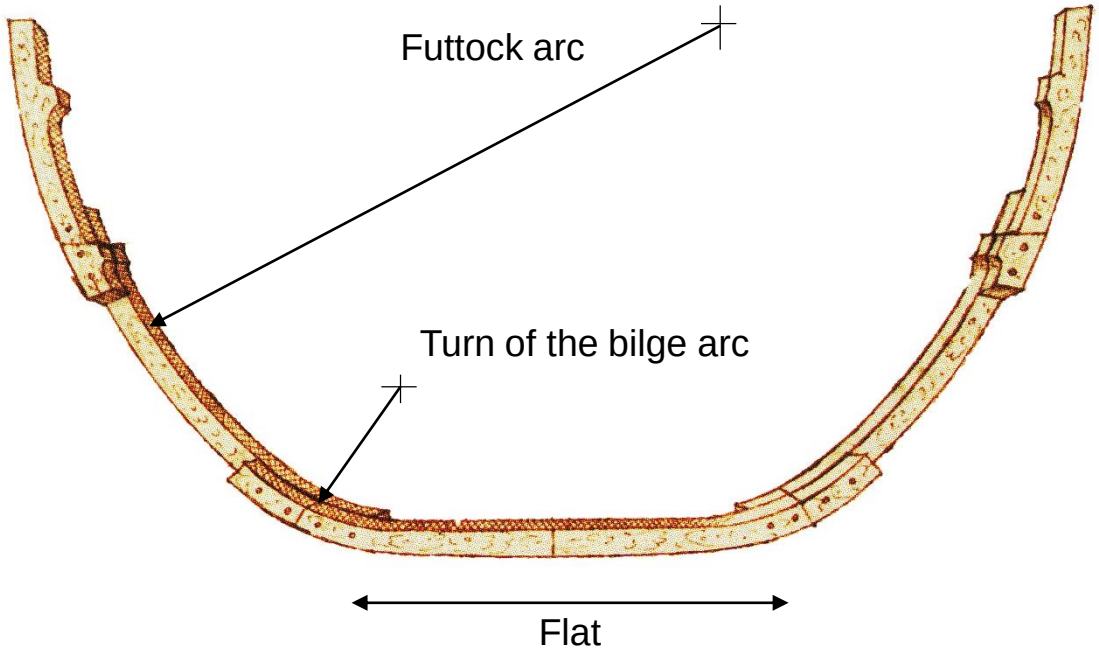


Figure 30 – Stern heel (Lavanha c. 1600).

i. Floor timbers **j. Half frames** **k. Futtocks**



Figure 31 – Frame (Lavanha c. 1600).

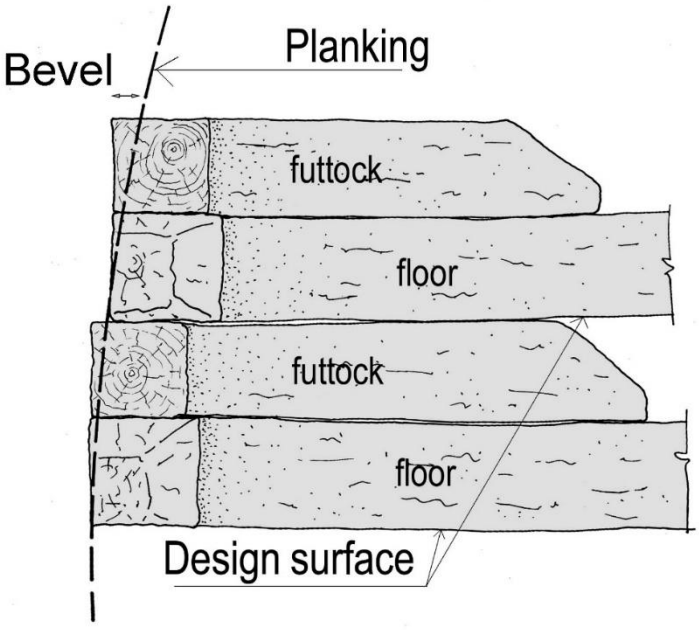


Figure 32 – Pepper Wreck (Drawing: Filipe Castro).

11. Bevels: all frames are beveled to receive the planking, and if properly measured, the bevels can be used to check the shape of the diagonals and water lines in the reconstruction phase.

l. Keelson

1. Length preserved;
2. Length reconstructed;
3. Shape;
4. Scarves;
5. Notched over floor timbers;
6. Mortises;
7. Sided and molded dimensions at bow, amidships and stern, as applicable;
8. Fasteners;
9. Wood type;
10. Conversion;
11. Construction marks;
12. Tool marks;
13. Coatings;
14. Additional comments.

m. Maststeps and butresses

1. Length preserved;
2. Length reconstructed;
3. Shape;
4. Number of components;
5. Scarves;
6. Notched over floor timbers;
7. Mortises for masts, stanchions and other cuttings;
8. Section geometry;
9. Sided and molded dimensions at bow, amidships and stern, as applicable;
10. Fasteners;
11. Wood type;
12. Conversion;
13. Construction marks;
14. Tool marks;
15. Coatings;
16. Additional comments.

n. Garboards

1. Length preserved;
2. Length reconstructed;
3. Shape;
4. Number of components;
5. Scarves;
6. Section geometry;
7. Sided and molded dimensions, as applicable;
8. Fasteners;
9. Wood type;
10. Conversion;
11. Construction marks;
12. Tool marks;
13. Coatings;
14. Additional comments.

o. Planking

1. Planking plan, number of strakes;
2. Length preserved;
3. Length reconstructed;
4. Shape, hoods, and scarves;
5. Sided dimensions and thickness, as applicable;
6. Fasteners;
7. Wood type;
8. Conversion;
9. Construction marks;
10. Tool marks;
11. Caulking;
12. Coatings;
13. Sheathing: thickness and sheets' shapes and position, tucking around posts and keel;
14. Additional comments.

p. Stringers and breast hooks

1. Length preserved;
2. Length reconstructed;
3. Shape;
4. Number of components;
5. Scarves;
6. Section geometry;
7. Sided and molded dimensions, as applicable;
8. Fasteners;
9. Wood type;
10. Conversion;
11. Construction marks;
12. Tool marks;
13. Coatings;
14. Additional comments.

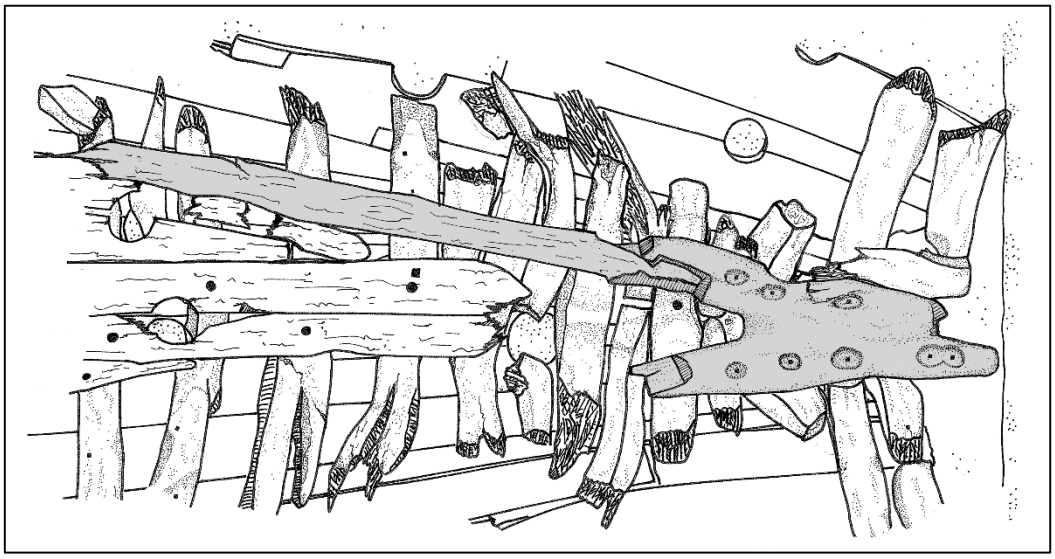


Figure 33 – Cais do Sodré Wreck (Castro et al. 2011).

q. Ceiling

1. Length preserved;
2. Length reconstructed;
3. Shape;
4. Sided dimensions and thickness, as applicable;
5. Fasteners;
6. Wood type;
7. Conversion;
8. Construction marks;
9. Tool marks;
10. Coatings;
11. Limber boards:
12. Additional comments.

r. Riders

1. Framing plan;
2. Section geometry;
3. Locations and dimensions of limber holes;
4. Sided and molded dimensions (max., min, av.) at keel and intermediate dimensions, as applicable;
5. Room and space (max., min, av.);
6. Scarves and chocks;
7. Fasteners: floors/Keel, floors/futtocks;
8. Wood type;
9. Conversion;
10. Shape;
11. Bevels;
12. Construction marks;
13. Tool marks;
14. Coatings;
15. Additional comments (e.g. inclination, square or canted, etc.).

s. Wales

1. Length preserved;
2. Length reconstructed;
3. Shape;
4. Number of components;
5. Scarves;
6. Section geometry;
7. Sided and molded dimensions, as applicable;
8. Fasteners;
9. Wood type;
10. Conversion;
11. Construction marks;
12. Tool marks;
13. Coatings;
14. Additional comments.

t. Clamps

1. Length preserved;
2. Length reconstructed;
3. Shape;
4. Number of components;
5. Scarves;
6. Section geometry;
7. Sided and molded dimensions, as applicable;
8. Fasteners;
9. Wood type;
10. Conversion;
11. Construction marks;
12. Tool marks;
13. Coatings;
14. Additional comments.

u. Knees

1. Length preserved;
2. Length reconstructed;
3. Shape;
4. Scarves;
5. Section geometry;
6. Sided and molded dimensions, as applicable;
7. Fasteners;
8. Wood type;
9. Conversion;
10. Construction marks;
11. Tool marks;
12. Coatings;
13. Additional comments.

v. Beams, carlings, and ledges

1. Length preserved;
2. Length reconstructed;
3. Shape;
4. Scarves;
5. Section geometry;
6. Sided and molded dimensions, as applicable;
7. Fasteners;
8. Wood type;
9. Conversion;
10. Construction marks;
11. Tool marks;
12. Coatings;
13. Additional comments.

w. Waterways

1. Length preserved;
2. Length reconstructed;
3. Shape;
4. Scarves;
5. Section geometry;
6. Sided and molded dimensions, as applicable;
7. Fasteners;
8. Wood type;
9. Conversion;
10. Construction marks;
11. Tool marks;
12. Coatings;
13. Additional comments.

x. Deck planking

1. Length preserved;
2. Length reconstructed;
3. Shape;
4. Sided dimensions and thickness, as applicable;
5. Fasteners;
6. Wood type;
7. Conversion;
8. Construction marks;
9. Tool marks;
10. Coatings;
11. Limber boards:
12. Additional comments.

y. Hatch coamings

1. Length preserved;
2. Length reconstructed;
3. Shape;
4. Section geometry;
5. Sided dimensions and thickness, as applicable;
6. Fasteners;
7. Wood type;
8. Conversion;
9. Construction marks;
10. Tool marks;
11. Coatings;
12. Limber boards:
13. Additional comments.

z. Stanchions, bitts, pumps and sumps, rigging, and other features

1. Length preserved;
2. Length reconstructed;
3. Shape;
4. Section geometry;
5. Sided dimensions and thickness, as applicable;
6. Fasteners;
7. Wood type;
8. Conversion;
9. Construction marks;
10. Tool marks;
11. Coatings;
12. Limber boards:
13. Additional comments.

aa. Summary of the fasteners

Even though this is a redundant section, it is useful to include a section on the fasteners, mentioning the fastening types, patterns and sizes:

Timbers	Fasteners	Patterns
Keel sections		
Keel / Posts		
Floor timbers / keel		
Keel / Keelson		
Floor timbers / futtocks		
Planking / floor timbers		
Etc.		

Fastener types:

Type	Section	Dimensions	Comments
Treenails			
Bolts			
Spikes			
Nails			

Treenails are fashioned by hand, so they tend to have polygonal sections, bolts have generally round sections, and spikes and nails tend to have square sections in northern and western Europe, and round shanks along a portion of their length, changing to square near the heads. In the "Comments" column it is important to mention the shape of the tip and whether they are clenched or double clenched.

ab. Tree morphology

All ships and boats are answers to a number of questions, and the quality and provenience of the timber are important factors to understand their shape, size and story. Forests and shipyards are connected and have influenced each other over time. Obtaining data about the ship timbers` parent trees and the employed conversion techniques allows gaining a better understanding of forest management. Including data collected from the vessel´s surviving timbers will constitute an added-value for the investigation of the wreck site and equally about the wood provenance, parent trees` morphologies, timber trade, timber transportation routes, timber conversion, timber assemblage, timber joinery and the hull shape and its requirements. Therefore, it becomes imperative to develop a methodology that intrinsically embodies a method in which shipbuilding can be analyzed in a broader context.

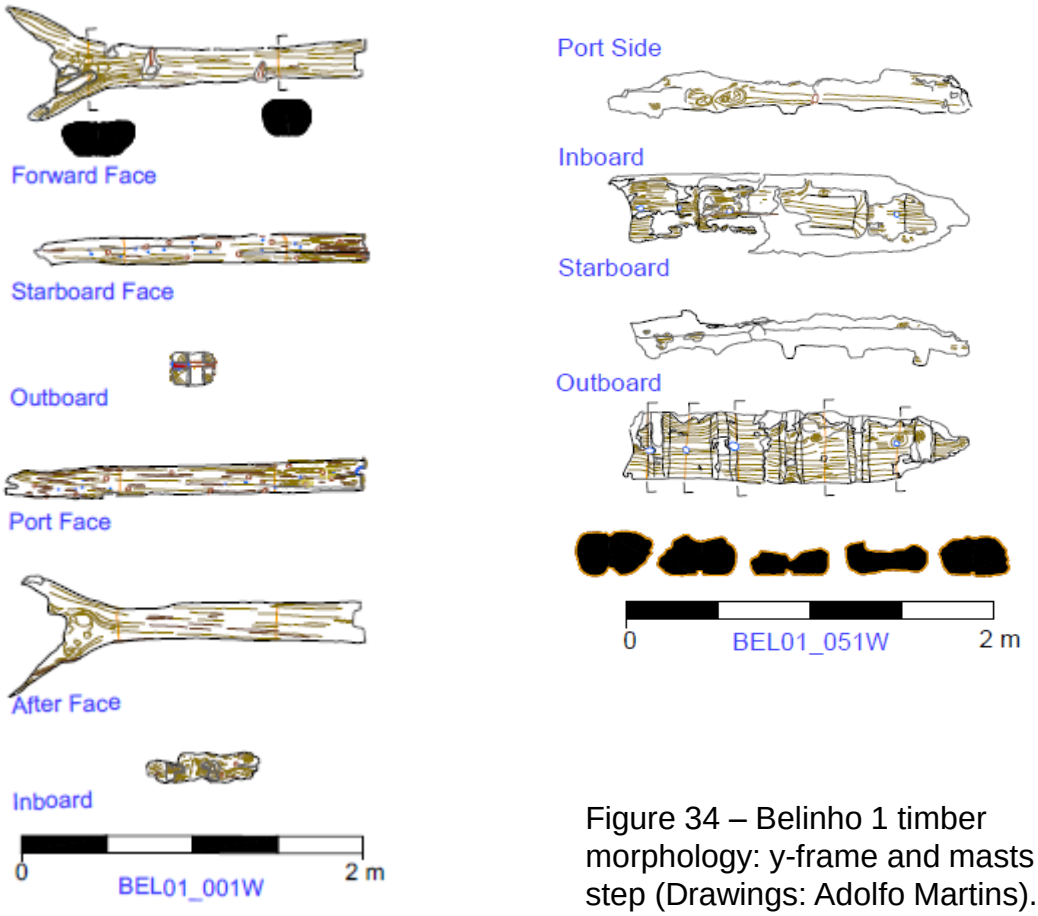


Figure 34 – Belinho 1 timber morphology: y-frame and masts step (Drawings: Adolfo Martins).

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USING THREE-DIMENSIONAL SOFTWARE TO RECONSTRUCT FRAMES OF THE PAST BASED ON ARCHAEOLOGICAL EVIDENCE

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Using Three-Dimensional Software to Reconstruct Frames of the Past Based on Archaeological Evidence

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ABSTRACT

The usage of three-dimensional representations of artefacts has been widely adopted in humanities to demonstrate how humans lived in the past. An increasing number of researchers present their results through a digital environment in which the achieved conclusions are expressed in very motivating and enthusiastic ways. On the other hand, it seems that archaeological data is being readdressed to the second level of scientific investigation. Films and other digital representations are now considered as the most efficient way for dissemination. However, how accurate and scientifically robust is the data presented nowadays? Which techniques were used to collect the data and which are the aims that driven that task? Would it be for pure dissemination purposes (revealing the existence of an archaeological site) or to report evidence following the higher standards in science?

The present article intends to demonstrate one of the potential ways of using CAD 3D software within the higher standards, by adopting specific protocols designed to record archaeological data. The study aims to identify, record and analyse evidence of forest practice and its relation to the shipbuilding industry during the Iberian Age of Discoveries. This includes a definition of clear objectives and methodologies for the recording of conserved ship timbers and underwater archaeological sites.

Key-words: Maritime archaeology, 3D recording, tree reconstruction, wood studies

RESUMO

O uso de representações tridimensionais de artefatos tem sido amplamente adotado em humanidades para demonstrar como os humanos viveram no passado. Um número crescente de pesquisadores apresenta seus resultados através de um ambiente digital no qual as conclusões alcançadas são expressas de maneira muito motivadora e entusiástica. Por outro lado, parece que os dados arqueológicos estão sendo endereçados ao segundo nível de investigação científica. Filmes e outras representações digitais são agora considerados como a maneira mais eficiente de disseminação. No entanto, quão precisos e cientificamente robustos são os dados apresentados hoje em dia? Quais técnicas foram usadas para coletar os dados e quais são os objetivos que impulsionaram essa tarefa? Seria para fins de pura divulgação

(revelando a existência de um sítio arqueológico) ou para relatar evidências seguindo os padrões mais elevados da ciência?

O presente artigo pretende demonstrar uma das maneiras possíveis de usar o software CAD 3D dentro dos padrões mais elevados, adotando protocolos específicos projetados para registrar dados arqueológicos. O estudo tem como objetivo identificar, registrar e analisar evidências da prática florestal e sua relação com a indústria naval durante a Era Ibérica dos Descobrimentos. Isso inclui uma definição de objetivos claros e metodologias para o registro de madeiras de navio conservadas e sítios arqueológicos submarinos.

Palavras-Chave: Digitalizadores para gravar madeiras de navios

1.Introduction

The use of three-dimensional digitisers to record ship timbers started during a project undertaken by a team from the National Museum Denmark in cooperation with Klaus Jensen of DKC (Hocke,r 2000: 30). Fred Hocker (2000: 8) states in the paper *New tools for maritime archaeology* that:

"(…) our [archaeologists`] task is to develop better methods of collecting and managing the raw material of archaeology. 'Better' means producing higher quality data that will allow archaeologists to answer current questions with more confidence as well as new kinds of data to enable exploration of new avenues of research. 'Better' also means finding ways to produce usable data more efficiently and to communicate the results of our research effectively. Finally, it means finding more efficient means of preserving the objects and sites we investigate so that they can continue to generate new data for future archaeologists (…)".

During the investigation of the Newport Medieval Ship, 3D digital timber recording became an established methodology shared with an international working group called FRAUG (Faroarm and Rhino Archaeological User Group. (JONES, 2008; NAYLING, JONES, 2014; RAVN et al., 2011). This project created a set methodology for recording and analysing timber assemblages using digital techniques. The recording of the complete set of timbers by using a Faro-Arm and the Rhino 3D, allowed the production of three-dimensional physical and digital solid 1:10 scale ship model by converting three-dimensional draw into "using modelling software packages including Rhino 3D and Solidworks" (JONES, 2008: 85).

In this paper three case studies will be presented to describe the techniques and technology employed to record ship timbers. The Belinho 1 ship, the Barland's Farm boat, and the Graveney boat were the subjects of investigation using 3D techniques in order to collect accurate data for the purpose of ship and tree reconstruction exclusively from the archaeological evidence.

2.Recording the Belinho 1 Timber Assemblage Using 3d Digital Technology

During the ferocious storms of 2013/4, violent waves washed ashore a remarkable ship timber assemblage and hundreds of pewter plates onto the beach of Belinho in northern Portugal. The

relevance of these artefacts triggered the establishment of an international research team comprised by experts from the Council of Esposende and the ForSEAdiscovery project. The main goal aimed to develop some innovative timber recording methodologies to allow the reconstruction of the Belinho 1 ship and its ship timbers` parent trees.

The recording strategy included the use of a 3D digitiser arm to allow accurate and detailed recording of the surviving timbers. This work was then complemented by a photogrammetric record. The first recording stage comprised the selection of ship timbers which would potentially provide relevant information in terms of ship architecture and wood morphology. This selection included the floors, Y-frames, a fragment of the keelson (mast step), a section of a keel, a stern knee and the stern post. The recording process followed the same protocol employed during the research undertaken on the Newport Medieval Ship, with minor adjustments made to the layer names in Rhino. Once a suitable work location was established, each selected timber was placed on a recording table and digitised.

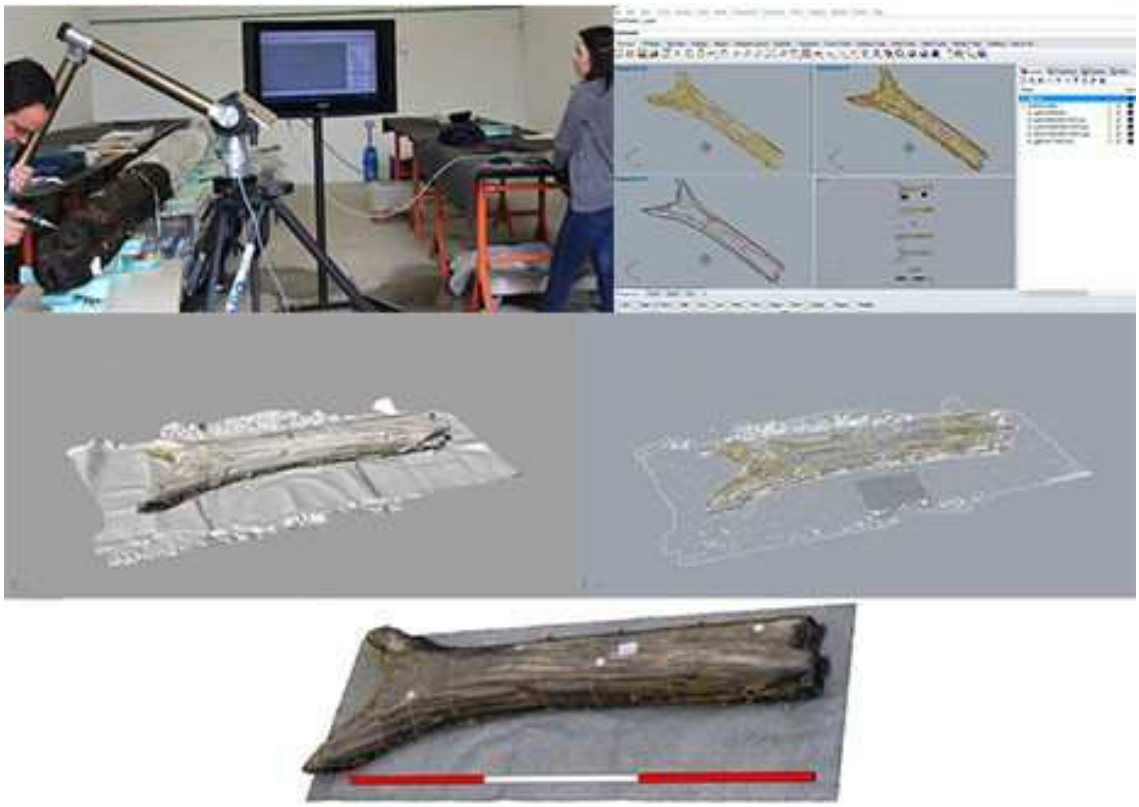


Figure 1. three stages for the recording of the Belinho 1 surviving timber – using a 3D digitiser arm to accurately record the timber surface, 3D digital drawing of a Y-frame, merging a photogrammetry model into a 3D digital drawing produced with a digitiser arm in a way to obtain an accurate record with the natural texture. **Source:** Adolfo Miguel Martins

3.3D Reconstruction of Ships and Trees

Evidence has shown that the Belinho 1 timber assemblage represents a unique shipbuilding technique. Each timber was first assessed by the archaeologist in order to identify interesting or diagnostic details about the timbers, this information was then recorded digitally, starting with the overall shape of the timber and ending with smaller details such as tool marks, fastening information and the growth pattern, using the 3D digitiser. Due to the high levels of erosion caused by site formation on the seabed and damage from the storms at the beach in Belinho, some features seemed to be lost. However, the wood features on the surviving timbers were still visible for recording. This includes information about wood morphology, such as knot

location, cracks, and indications of growth patterns such as grain, pith location and natural edges. Special attention was given to the visible annual rings on the bottom of the Y-frames and how the tree`s stem divided into two branches.

The digital drawings comprise two types of layers in which one is related to the ship timber features including evidence of fastening and joinery. The second set of layers includes the wood morphologies such as evidence of growth pattern, knots, heartwood and sapwood boundaries and the location of the pith (first annual ring). The first set was used for the ship reconstruction studies. The drawing produced from the selected timber were copied to a single Rhino 3D file and analysed to identify a potential match within the surviving timber by correlating the fastening and joinery evidence. The second set allowed to gain a better understanding of the ship timbers` parent tree and provided the basis for tree reconstruction studies.

4. 3D Contact Tracing Suitable Techniques for Archaeology

During the Belinho project fieldwork researchers adopted 3D techniques to record ship timbers. A vast variety of tasks were included in this process, which enhanced the quality of the work accomplished. Collecting data from highly eroded timbers proved to be a complex task due to the lack of data.

This technique, paired with an understanding of historical shipbuilding, means digital data can be used to reverse engineer the key characteristics of the ship and the parent trees employed in the building process.

5. Archival re-examination in rhino 3D

Digital recording in Rhino is not only useful for current archaeological ship investigations, it can also lend a new perspective to legacy archaeological data that exists in the physical word as traditional 2D drawings. Information that is both published as books and reports, and that exists in archives around the country.

This part of the paper presents a short summary of work undertaken with this type of legacy data. This work was completed in partnership with the University of Wales, Trinity Saint David. The full reports of both these case studies can be found in Ali (2012) and Ali (2016).

6. Why Re-examine Archaeological Finds?

Archaeology is an inherently destructive science. Archaeologists attempt to counter-act this destruction by creating a detailed record of what they find and where they find items in the ground. This is done through photography, extensive record keeping, drawings, and descriptions. In the best-case scenario, these records go on to inform an academic publication that summarises the finds, site contexts, and archaeological conclusions, becoming a part of the archaeological discourse.

In nautical archaeology, it is commonly held that if enough evidence of an archaeological hull form remains, a theoretical reconstruction should be attempted (IFA 2014; COATES et al., 1995).

To do this however, an accurate and detailed record of the remains *in situ* must be compiled (ibidem). This includes a 1:1 scale drawing of all the archaeological remains, achieved either through contact tracing, as in the case of the two vessels studied here, or by non-contact tracing, a methodology used on ship remains such as the Skuldelev find (FENWICK, 1978; NAYLING, MCGRAIL, 2004; CRUMLIN-PEDERSEN, OLSEN, 2002). These drawings are then generally condensed into their precise counterparts otherwise known as scaled drawings. Following this, the archaeological remains are assembled as a 1:10 scaled research model to aid in the creation of a minimum reconstruction (COATES et al., 1995).

It is always the aim to create a minimum reconstruction of the archaeological vessels. A minimum reconstruction makes the least amount of assumptions from the archaeological remains while remaining consistent with them (NAYLING, MCGRAIL, 2004; CRUMLIN-PEDERSEN, 2006; McGRAIL, 2006; COLES, 1977; COATES, 1977; COATES et al., 1995). Only objects that there is direct evidence for, or objects that are needed to form a full working boat, are included in the end interpretations (ibidem). These interpretations are traditionally presented as a series of scaled drawings and architectural lines plans (McGRAIL, 1981). Several reconstructions can be presented from the same archaeological remains, depending on the extent and survival of the remains (McGRAIL, 1986). “In the spirit of scientific inquiry” these reconstructions should be tested repeatedly to either refute or acknowledge their validity (McGRAIL, 1986: 9; COATES et al., 1995). A resource underutilised by archaeologists appears to be site archives. These excavation records can provide valuable information to the researcher. Looking at a paper archive with the aid of 3D programs such as Rhino can offer a different perspective that may validate or disprove previous hypotheses and conclusions drawn in the past.

The following study examines two such reconstructions for their validity by digitising the archaeological paper record and comparing the archaeological remains to the proposed reconstruction, in Rhino 3D. Rhino 3D is an ideal program to test ship reconstructions because Rhino objects lack the ability to interact with each other. This allows for surfaces to run through each other in a way that cannot be done with real, physical models. This is useful in determining and demonstrating the change of the archaeological remains and allows every stage of the reconstruction data to be layered a top each other digitally.

7. Research Questions

The main research question asked for this study is as follows: Does the different perspective afforded from programs such as Rhino 3D affect our understanding of archaeological boats- either in terms of construction of theoretical reconstructions? Is this a meaningful exercise? (I.e. are we learning anything new)?

8. The Vessels

The Barland’s Farm boat and the Graveney boat reconstructions are tested for validity in this study. The Barland’s farm boat is a unique example of a Romano-British vessel found in the Severn Estuary in South Wales (NAYLING, McGRAIL, 2004). The boat find consists of the remains of a flat bottom, flush laid boat with evidence of 7 port side strakes, 3 starboard strakes, 16 framing stations, 8 side frames on the port side and 1 side frame on the starboard, a stem post, and a forward mast step dated to the late 3rd century C.E. (ibidem). The Graveney Boat was excavated in the 1960’s in Kent, where the remains of a clinker constructed vessel was found

under more than 2 metres of clay. There remain 10 framing timbers, 7 starboard strakes and 8 port planks. The vessel is dated to the 10th century C.E. (FENWICK, 1978).

9. Methodology

The Graveney Boat data was gathered from the paper archive of the find, located at the National Maritime Museum in Greenwich, UK. The Barland's Farm data was gathered from the published scaled timber drawings and reconstruction drawings. These scaled drawings for both vessels were scanned and modelled in Rhino 3D. Using the archaeological site plans and the reconstruction drawings, the archaeological timbers were placed inside the reconstructed hull forms to examine whether they demonstrate a plausible progression of thought from the archaeological remains.

In the case of most boat finds, the archaeological remains are compressed and broken apart by the weight of the sediments and soil atop of them, resulting in a wider, flattened hull shape in the ground. Once the timbers are reassembled by re connecting nail holes to each other, the hull form tightens as it pulls itself together. What one would expect from placing the archaeological remains in a reconstruction, is for the remains to be flatter and run through the reconstructed hull form. This is demonstrated best by the archaeological timber R9 from Graveney that was placed in the Graveney reconstruction taken from the publication of the find (FENWICK, 1978).

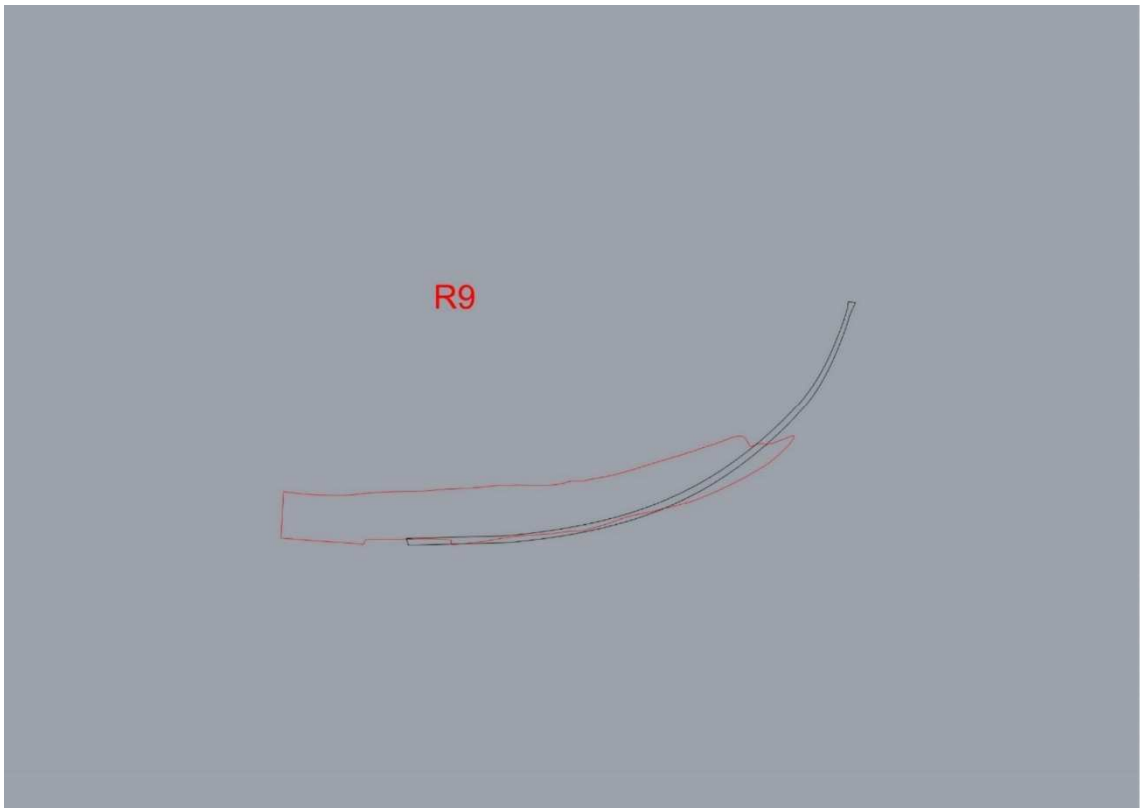


Figure 2. modelled archaeological timbers (red) placed inside published reconstructed hull form (black). **Source:** Adolfo Miguel Martins

The reconstruction allows for some tightening of the hull form and takes into account the compression of the archaeological remains. This result lends confidence to the Graveney reconstruction published by McKee in 1978. What one does not generally expect is what was found with the Barland's Farm boat.

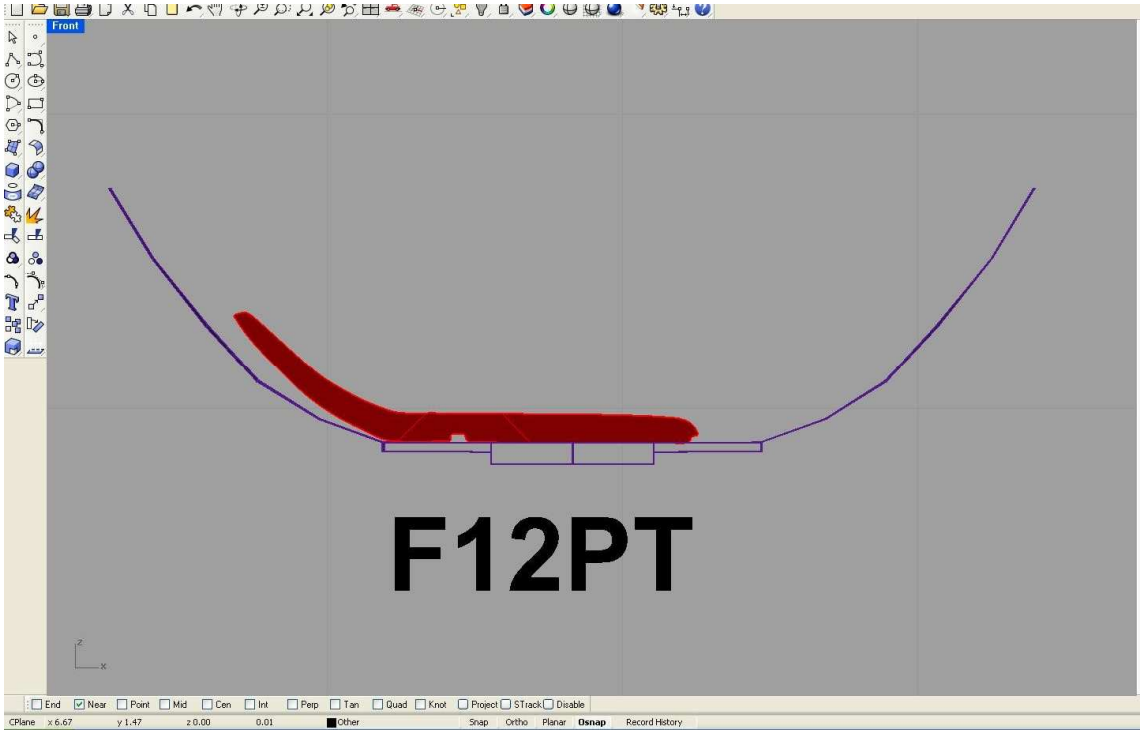


Figure 3. Modelled archaeological timbers (red) inside published theoretical reconstruction lines (purple). **Source:** Adolfo Miguel Martins

The archaeological timber F12PT is tighter than the reconstruction drawing, leading to the conclusion that the reconstructed hull form of Barland's Farm is potentially problematic, and does not follow what one would expect.

A new question arose from this finding, is there a mistake in the method of thinking for the modelling of the Barland's Farm timbers? The original 1:10 scale model used to create the published Barland's Farm reconstruction was laser scanned using a Faro ScanArm and compared to the modelled archaeological timbers created using published scale drawings. The results demonstrate that the method of modelling the timbers is sound and accurate, meaning the problematic result in the above illustration is indeed from the reconstruction lines and not the methodology.

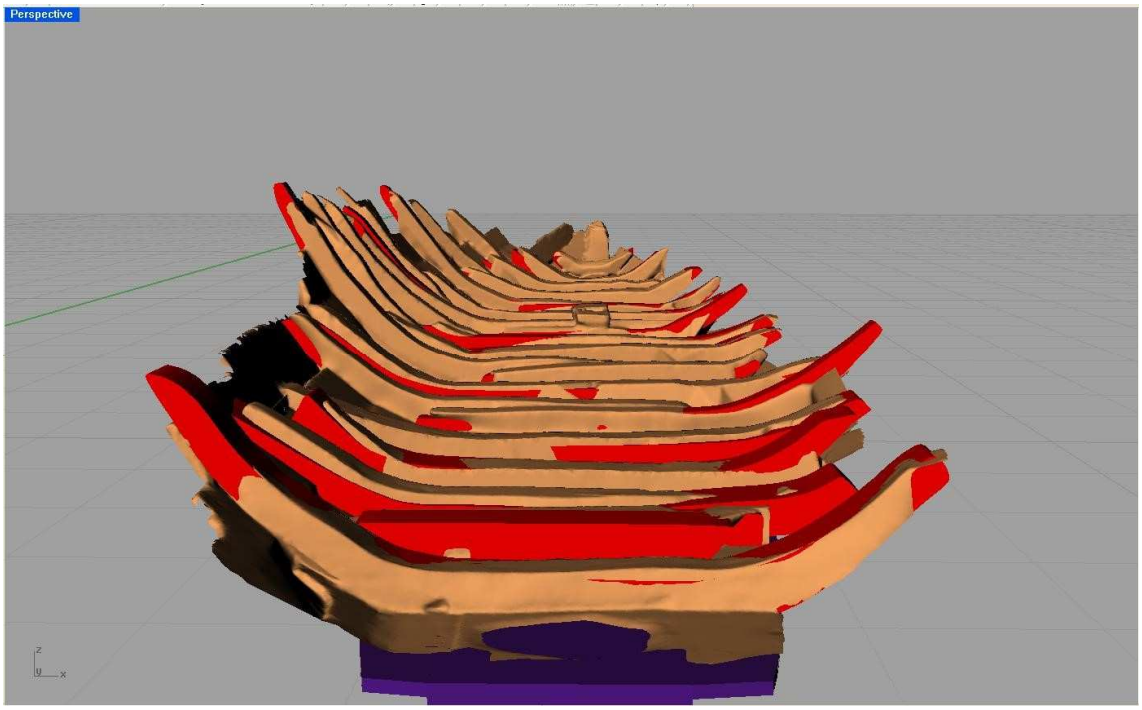


Figure 4. Reconstructed timber (Red) with Laser Scanned research model (Brown). **Source:** Adolfo Miguel Martins

10. Brief Case Study Conclusions

There are pros and cons to working in Rhino to re-examine archival archaeological information. Rhino allows the user to layer multiple data sets atop each other, without having to worry about the Rhino objects interacting with each other. It is hyper-accurate and allows the user to re-evaluate previously held conclusions about the archaeological remains. In this case study, Rhino gave further confidence to the reconstructed Graveney Boat hull form proposed in 1978 and shed light on potential problems with the Barland's Farm reconstruction, proposed in 2004 (FENWICK, 1978; NAYLING, McGRAIL, 2004). However, the 3D objects are only as good as the 2D drawings. In nautical archaeology we are often working with complex 3-dimensional objects, and the very act of condensing this information into 2D leads to a loss of data resolution and confidence. One must always keep this in mind when working with either scaled drawings or 2D drawings of complex 3D objects. In this case, the confidence of the 2D drawings were strengthened by a laser scan of a 3D research model, which confirmed our interpretation of the 2D drawings.

11. Conclusions

Digital recording, following clear and published methodologies, can allow the capture of high-resolution initial data of archaeological objects. This data can later be simplified for traditional publications, but it allows the researcher to ask a wide range of questions that previously could not be answered by employing traditional methods. By keeping complex 3-dimensional objects in 3D by recording them with digitisers, we now have the most accurate representation of the artefacts. That is not to say that these techniques are only good for 3D data. Using digital programs can also allow a fresh approach to re-examining traditional 2D data, allowing us to re-examine previously held beliefs and views of archaeological finds.

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From Forests to the Sea, from the Sea to the Laboratory: the Timbers of the Frigate *Santa Maria Magdalena* (18th century)

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Keywords: 18th century, Spain, interdisciplinarity, archives, timber

Abstract
The case study of the 18th century Spanish frigate *Santa Maria Magdalena* constitutes one of the opportunities given to the Forseadiscovery project team to approach the subject of shipbuilding and timber supply in the Iberian Empires of the early modern age, in an interdisciplinary way, through the combination of efforts of three different disciplines: history, through the research of written sources; archaeology, through the collection and study of the material evidence of ships; and wood science, though the analysis of timber samples from archaeological sites and old living trees.

Introduction
Driven by the increased demands on seafaring defense, the Spanish Crown launched the S*anta Maria Magdalena* frigate from the Esteiro shipyard of Ferrol (Galicia, northwest of Spain) in 1773. In 1810, the ship wrecked at the bay of Viveiro (Figure 1), in the context of the Spanish War of Independence (1808-1814). In June 2015, the ForSEAdiscovery project organized an underwater timber sampling campaign on this shipwreck site. Through various wood provenance studies (i.e. dendrochronology, inorganic and organic chemistry), combined with historical research in national archives and international sources such as the Sound Toll Registers, the frigate's timbers promise to shed light on late 18th century Spanish naval construction, forestry practices, and timber supply in relation to shipbuilding in northern Spain. As a highly interdisciplinary project, ForSEAdiscovery integrates research fields in the humanities and life sciences. This paper presents the joint efforts of historians, archaeologists and wood scientists to determine 1) what kinds of trees were used to construct which parts of the *Santa Maria Magdalena*, 2) their provenance, 3) the timber trade networks and state management involved in supplying wood to the Ferrol shipyard, and 4) best-practice methodologies to reach these conclusions.

Historical Background
In the early 1770's, King Charles III (1759-1788) was developing the policy of shipbuilding initiated by his predecessors as part as the so-called Bourbon Reforms. These consisted of a program of economical and administrative restructuring in which a new conception of a centralized Navy took a prominent role, as the key factor of the maintenance of a vast and spreading colonial Empire. In this context, the arsenals Cartagena, Cadiz, Ferrol and Havana became the centres of the state-controlled shipbuilding industry (Merino Navarro 1981).

In 1 August 1772, a Royal Order announced a program of construction of three *urcas afragatadas,* and one frigate to be carried out by the Esteiro shipyard (arsenal of Ferrol), and this is when the story of *La Magdalena* begins (AGS, SMA, 349, 1 August, 1772). According to payment orders of salaries to the shipwrights, its construction began in September and lasted for the next ten months (AGS,TMC, 4207: 16 October 1772; AGS,TMC, 4207: 17 November 1772; AGS,TMC, 4207: 16 December, 1772; AGS,TMC, 4208: 22 January 1773; AGS,TMC, 4208: 20 February 1773; AGS,TMC, 4208: 18 March 1773; AGS,TMC, 4208: 20 April 1773; AGS,TMC, 4208: 20 May 1773; AGS,TMC, 4208: 21 June 1773; AGS,TMC, 4208: 24 July 1773; AGS,TMC, Marina, 4208: 28 August 1773). The official launch took place in Ferrol in 7 July 1773, and the

document of its announcement described the vessel as a 26 to 34 gun frigate, 145 feet long (AGS, SMA, 350: 7 July 1773).

After 37 years serving the Spanish Navy in Atlantic waters, the *Santa Maria Magdalena* sunk in Viveiro bay (Lugo province, Galicia, Spain), along with the *bergantín Palomo*, in the context of the Spanish War of Independence (1808-1814). In November 1810, these Spanish vessels took part in an Anglo-Spanish squadron which fought against the French occupation of Santoña (Santander, Spain). On the night of 2 November, after being hit by a severe storm, the *Magdalena*, *Palomo* and a few other vessels had to evacuate Santoña and took shelter in Viveiro. The damages inflicted by the storm such as the loss of the anchors, determined the fatal outcome: the *Magdalena* collided with the English frigate *Narcissus* and later crashed against the Reef of Castelos and sunk soon after, taking the lives of 20 members of the crew (Fernandez Duro 1867: 220-225; Filliat 1976: 313).

History: Timber supply in Ferrol (1771-1773)

Historical research aimed to obtain information about the construction process and main features of the *Magdalena*, as well as the model of timber supply in Ferrol during the late 18th century.

Archival research was mostly centered on the Spanish sources of the Navy administration corresponding to the section of the Navy Secretariat (SMA) and state accounts of the court of auditors (*Tribunal Mayor de Cuentas,* TMC) from the AGS, in Valladolid, Spain.[1] In order to further investigate the subject of timber import from Northern Europe , the research involved cross reference with the Danish database of the Sound Toll Registers Online (STRO, last viewed 31 March 2017), which records the passages of merchant vessels and their products, from Baltic ports to their destinations, through the Danish Sound (Gøbel 2010).

Besides the information regarding the shipbuilding process and main features of the frigate, the researched sources did not contain any further data specifically related with the *Magdalena*, namely the timber used in its construction. Therefore, the team decided to work with historical documents dated from 1771 to 1773[2] about all the aspects of timber supply to the Ferrol Department, in order to identify the whole context of timber acquisition. These documents cover the period of construction (1772-1773) and the previous years, in which some of the timber used in the *Magdalena* might have arrived.

Thus, the sources from AGS allowed the identification of three major regions of wood supply: Northern Spain, Northern Europe, and the Caribbean. Each of these major regions provided specific species and types of ship elements, and that is related, not only to the natural habitats of the trees, but also to the economic and technological strategies behind this model of supply.

Northern Spain timber

The volume calculations[3] indicate Northern Spain as the main area of provenance of the timber used in Ferrol by the time of the Magdalena construction, corresponding to 73% (sum

[1] *Secretaría de Marina,* sub-section *Arsenales* (units 347, 349, 350), sub-section *Asientos* (unit 621), sub-section *Registros* (unit 788); *Tribunal Mayor de Cuentas,* subs-section *Marina,* Ferrol (units 4207, 4208), in a total of 97 documents.

[2] except in the case of the data from TMC and STRO that was used in the cross reference of Northern Europe timber trade, which was extended to 1770

[3] this quantification involved 58 documents from the following sections and subsections: *Secretaría de Marina,* sub-section *Arsenales* (units 347, 349, 350), sub-section *Asientos* (unit 621), sub-section (unit

of 17,020 m^3, along the years 1771 to 1773) of the total supply (23,418 m^3) (Figure 2-A). Such preponderance is expressed, as well, in the diversity of species, from oak to ash (Figure 2-B) and, specially, in the diversity of the typologies of ship pieces (Table 1). However, the quantification of pieces per units does not reflect the majority of Northern Spain timber, as this place is occupied by Northern Europe pine planking, masts and spars. In terms of units, Northern Spain timber corresponds to 35%, in a total of 19,781 pieces out 56,005 (Figure 2-B, Table 1). This discrepancy between volume and quantity is explained by the nature of the ship elements. In fact, Northern Spain timber was, by far, the preferred choice when it came to the structure of the hull and other elements below the waterline, which correspond to very voluminous elements, when compared to planks, the most abundant type of piece (Table 1).

Oak (*Quercus*) grew in Northern Spain's forests in special abundance, and this was the primary timber for those kinds of ship elements (Aranda y Anton 1990; Aranda y Anton 1999: 23-24), contributing to this region´s tradition as a strong Peninsular centre of shipbuilding, at least since the 16th century (Goodman 1997). Proximity to timber sources was an obvious criterion of choice, since it not only facilitated transport (costs and infrastructures), but allowed the close control of trees by the naval engineers and shipwrights, in order to assess quantities and quality in terms of material, shape and size (Aranda y Anton 1999: 15-16; Wing 2015: 178-187). The multiplicity and specificity of typologies of the structural elements of the hull, and other pieces to be placed below the waterline, the measurements of which varied according to the size, scantling, typology and shipbuilding technique, can be seen in the treatises, wood regulations[4] (Gautier 1769; Fernandez de Landa 1784), as well as reports of shipwrights and engineers boards. These required closer supervision than the pine planks, deals, masts and spars used in the upper works, which were massively produced and purchased from the Baltic region in varied, but rather standardized measurements, for multiple purposes (Gallagher 2016).

Following the proximity criterion, Asturias's forests appear as the main region of supply, followed (in this order) by Cantabria, the Basque Country[5] and Navarra. There was also a significant group of endogenous timber pieces with undetermined origin, which was constituted by spare timber from Guarnizo shipyard (Figure 2-B). Each of these regions had a contractor who operated the felling, carving and transport of timber by land and final delivery by boat: Andres Garcia Quiñones, António Francisco Quiñones and Juan Gonzalez Pola, for Asturias; Francisco Caetano Iglesias, for Cantabria; Real Compañia Guipuzcoana de Caracas for Guipuzcoa and Navarra.[6] Oak, the predominant timber with 14,091 units, could be found from Asturias to Navarra and was, once again, mostly used for planking (4218 units), followed by framing elements such as futtocks and beams, uncategorized pieces and then a great variety of

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788); *Tribunal Mayor de Cuentas,* subs-section *Marina,* Ferrol (units 4207, 4208); the documents exclusively used for the account are not mentioned at the final references to avoid having an exhaustive list; the quantitative data provided by the Spanish sources was unevenly presented in units and volume (*cubic cubits*); in order to calculate the volume of units, we searched for its approximate measurements in cubits, within the *Pie de Burgos* measuring system, according to piece typologies (Gautier (1769): Fernandez de Landa 1784); the volume of Nordic pine pieces was calculated according to the measurements of the masts, spars and planks listed in the informs of timber needs for 1772 and 1773 (AGS, SMA, 621: 15 November 1771; AGS, SMA, 621: 15 September 1772); for the calculation in cubic meters: Marien y Aróspide 1789:28; Aranda y Antón 1999: 107; all these calculations are merely indicative.

[4] *Reglamentos de Maderas*

[5] sources of this group of timber are unclear about the specific provenance and just refer to the contractor, who was operating in both regions

[6] references are the same used in the counting of Northern Spain timber

types (Table 1).[7] Beech (*Fagus sylvatica*) had a similar regional distribution and was used for planking, beams, and also came in as raw timber. Holm oak (*Quercus ilex*) was identified as coming from Cantabria, but its largest portion does not have any specific mention of the origin. It was used for axles of gun carriages and other non-identified applications not identified Black poplar (*Populous nigra*), walnut (*Juglans regia*), alder (*Alnus glutinosa*) and ash (*Fraxinus excelsior*) came from Asturias and were sporadically delivered in small quantities. Except in the case of walnut planking, these types of timber arrived as unprocessed timber. Pyrenean pine has a low representation within the overall Northern Spain timber accounts, corresponding to only 2% (402m^3). This supply is the result of technical experiments with the purpose of reducing dependency from Northern Europe imported pine (AGS, SMA, 349: 20 November 1771; AGS, SMA, 349: 25 July 1772; AGS, SMA, 349: 23 September 1772; AGS, SMA, 349: 14 November 1772) (Figure 2-B, Table 1).

The data indicates the secondary role of timber import through the Baltic trading networks, as these constitute 23% in terms of volume (total of 5394m^3 along the 1771-1773 period), even if, in terms of unit quantities, Northern Europe timber corresponds to 64%, with 34,550 pieces (Figure 2). This material is exclusively made up of pine, consisting of planking, the largest group of pieces, in 34,338 units[8], 45 main masts, and 167 minor masts and spars[9] (Table 1), revealing the importation of highly specialized products. In a time of economical protectionism, the Maritime Departments would limit the acquisition of exogenous raw material to timber that could not be found in the Iberian Peninsula in abundance with the proper sizes, and that was strictly necessary to build vital and substantial parts of the vessels. That was the case of the pine species from Northern Europe, such as *Pinus sylvestris* which exhibited long, wide and straight trunks making it especially suited for masts, spars and planks (Aranda y Antón 1999: 23).

This mass produced timber served the European market (Astrom 1988), and Spain became a substantial importer, purchasing this material increasingly from the 1740s (Gallagher 2016; Reichert 2016). Spanish agents took part in the timber trade networks through supply contracts with the Navy, the so-called *Asientos.* By the time of the *Magdalena's* construction, Pedro Chone, a Bilbao resident, was the provider of masts, spars and planking for the three Maritime Departments of Cartagena, Cadiz and Ferrol (AGS, SMA, 788, 2 January 1772). Aided by representatives in Spain, the contractor operated from the Baltic ports of Saint Petersburg, Riga and Danzig, negotiating with the local suppliers and coordinating the shipments through Dutch captains and merchant vessels such as *urcas* and *galeotas* (AGS, SMA, 621: 1 September 1772; AGS, SMA, 621: 29 May 1773; AGS, SMA, 621: 20 August 1773*;* AGS, SMA, 788: 2 January 1772). As the stocks seemed to be constantly running out of pine , the Navy sporadically sought alternative suppliers when the contractor was not able to fulfill the necessities in due time (AGS, SMA, 350: 15 May, 1773; AGS, SMA, 621: 16 November 1771; AGS, SMA, 621: 20 May 1773).

According to STRO there were 35 passages containing timber destined for Ferrol via the Danish sound between the years 1770 and 1773. Only seven of these[10] can be matched to records in

[7] in order to facilitate the statistic study, the piece typologies were aggregated within main functional groups, in order to avoid an exhaustive list (ex.: first and second futtocks count together just as futtocks)

[8] excluding 32 from the Pyrenees

[9] excluding 27 from the Pyrenees

[10] Sound Toll Registers Online viewed 31 March 2017: STR270070, 5 September 1770; STR257963, 23 September 1770; STR256454, 24 October, 1770; STR301893, 2 August, 1771; STR260730, 2 August 1771; ST260841, 3 August 1771; STR269696, 14 September 1772

the TMC.[11] Possible reasons for this are that the timber may have been redirected or re-exported to another port, or that the wood was purchased by someone other than the Navy. After all, timber was also needed for general carpentry, private construction, and private shipbuilding. Indeed, six of the unmatched passages contained timber that was designated for shipbuilding, such as masts and spars, or accompanying products such as hemp or sailcloth.

Of the matched records, all were carried by Dutch captains, representing Ameland, Amsterdam, Hoorn, and Warns as homeports. Three of these passages originated from Danzig, and four from Riga. Products brought from Danzig were fir deal (*fyrre dehler*), thick planks (*bohler*), and unspecified wood products (*trævahre*). Products brought from Riga were boat-hook shafts (*baadshagestager),* balks (*bielker*), ordinary deals (*gemeene dehler* or *ord. dehler*), masts (*master*), spars (*spirrer* or *raaer*), and planks (*planker*). Only two shipments matched closely with the products and numbers given in both the TMC and STR.

These discrepancies make it difficult to conclude how much Baltic timber noted in the STR was destined for the Spanish Navy. Out of 50 payment orders in the TMC for the department of Ferrol concerning the acquisition of timber within Europe between the years of 1770 and 1773, only six could be confirmed to concern timber that came directly from the Danish Sound (representing seven STR records). Only two other shipments were re-exported via Amsterdam, and thus are not reflected in the STR. This suggests that the majority of the Navy's trade with the Baltic was direct by this time, rather than passing through a "middle man" port such as Amsterdam.

An important aspect which the Sound Toll Register corroborates is that the imported timber was never oak, or any of those pieces necessary for the framing elements of the hull. Instead, they mostly consisted of spars for rigging and various sizes of pine planking, which were used in the final construction steps of a ship, such as upper hull planking, deck planking, and sacrificial outer planking.

The Caribbean supply corresponds to only 3% of the total volume with 1004m^3 and 1674 pieces (Figure 2). This timber had its origins in Cuba and Mexico, and its supply was locally operated by shipbuilding contractors of the arsenal of Havana, and then the Navy and Crown colonial officers would transfer part of this material to Spain, through the ships of the *Carrera de Indias,* among other goods in its cargoes, such as sugar, which was possible due the low volume of each shipment. Cadiz was the destination port of this route since 1717 and worked as redistribution hub, by sending material to Ferrol, as well as Cartagena (AGS, SMA, 347: 6 February 1771). Sometimes, the transport was made by charted private ships, which would deliver the material directly to Ferrol (AGS, SMA, 347: 4 May 1771; AGS, SMA, 347: 24 August 1771).

The tropical timbers such as guayacán (*Guaiacum*), cedro real (*Cedrela odorata*), chicharrón (*Terminalia eriostachya*) and sabicú (*Lysiloma latisiliqua*) are very hard, dense and resistant types of material, particularly suited for the crafting of structural pieces and those which are subject to aggressive elements, such as constant friction and exposure to corrosion by shipworms such as *Teredo navalis* (Aranda y Antón 1992: 7-31; Aranda y Antón 1999: 27). Thus, the lists of deliveries contain cedrela futtocks, stringers, wales and anchor strocks of undetermined tropical species, keels made of cedrela and chicharrón /sabicú, cederela top

[11]matches between the TMC an STR were found by looking for the captain, year, port of origin, port of destination and then at the transported products; the captain and the year are the most reliable elements for cross-referencing, since the products were categorized differently in the STR and the TMC, and sometimes show completely different numbers

timbers, guyacán logs for further carving, chicharrón/ sabicú and cedrela keelsons, among other typologies, and a vast group of undetermined typology of guayacán pieces (Table 1).

Some 1771 and 1773 documents may contain the explanation for such small deliveries, as they mention that the Spanish arsenal's stocks were already well supplied with Guayacán (AGS, SMA, 347: 19 July 1771) due to the constant shipments and low use of this material and, therefore, new shipments should be suspended (AGS, SMA, 350: 4 June 1773; AGS, SMA, 350: 10 July 1773).

Archaeology: Sampling the *Santa Maria Magdalena* timber assemblage

The remains of a vessel constitute the ultimate evidence of how ships were built (Steffy 1994). As mentioned above the frigate *Magdalena* was built in the shipyards of Ferrol and sailed for about 37 years in the service of the Spanish Navy. During that time, the vessel benefited from repairs and adjustments that made her unique in many ways. *La Magdalena*'s unique features are a testimony to a specific moment in naval history in which several countries were at war and were in direct competition for the expansion of their overseas power.

Also at this time, shipbuilding technology was shifting into the experimental. Shiprights and shipbuilders were developing and testing building techniques using wood species other than oak and pine, which had been the woods of choice for hundreds of years. According to Enrique García-Torralba Perez (2011: 257,258), the *Magdalena* was part of a test and therefore built following specific procedures. Under the same geometric plans, four vessels were constructed in the shipyards of Cartagena and Ferrol: *Magdalena*, *Margarida Marta* and *Clara*. Despite sharing the same drawings and architecture, different wood species were employed allowing shipbuilders from the Spanish Royal Navy to identify and analyse each prototype and use the most reliable as a model to replicate. In order to better understand the decisions made in the forest and in the shipyard prior to the construction of the *Magdalena*, the ForSEAdiscovery dive team undertook an archaeological campaign in Viveiro, Galicia.

Over the course of seven days in June 2015, the ForSEAdiscovery dive team removed 22 wood samples from the hull remains of the *Magdalena* at the bottom of the Viveiro Bay (Figure 3-A) in order to elucidate the circumstances of her construction – how she was built, with what kinds of wood, and from where that wood originated. In cases like the *Magdalena*, historical sources can be highly suggestive of where shipbuilders procured their timber, but taking timber samples from shipwrecks has several advantages to relying solely on the historical sources, even in well-documented cases like the timber supply for the arsenal of Ferrol. 1) Providing samples to wood scientists for further study is the only way to develop scientific methods of dendroprovenance so that they can be used in cases without historical documentation. 2) The scientific method allows for 'proofs' of provenance that frequently challenge so-called reasonable assumptions as well as historical documents made in error. 3) Timber sampling campaigns permit an individual study of elements used in shipbuilding, such as wood types, scantlings, joinery and fixings used, as well as gathering the extent of the remains and their level of preservation and risk.

One of the outcomes of the ForSEAdiscovery project is to generate a set of protocols for the removal of wood samples from historic shipwrecks, and the fieldwork done at the *Magdalena* has been instrumental in this development. The sampling protocol defined that the impact on the remains of the vessel should be as reduced as possible. Therefore, it was only after mapping, sketching, positioning and using other non-invasive recording methods were timbers finally sampled. To gain the most amount of provenance data while creating the least amount of damage to the shipwreck, certain timbers were targeted for sampling while others

remained untouched. Elements likely to represent the original structure of the vessel, such as planks, beams, and frames, were preferred to minor elements which were frequently replaced and/or which would be unlikely to contain sufficient or reliable data for provenance.

In general, archaeological evidence of Iberian ships (Oertling 2001; Castro 2008) demonstrates a common practice of utilizing the parent tree's growth pattern for the required timber shape. This technique alone promises to help gain a better understanding of the relationship between Iberian shipbuilding and forest management. For one, it demonstrates that shipbuilders were well aware of the properties of the wood they selected, and that this knowledge at the disposal of the shipbuilder to create more reliable vessels (although this is not to say that this knowledge was always actually put to use). For example, fast-grown deciduous oak was frequently used for vertical elements like frames, while slower-grown oak could be used for horizontal elements. Because oak is ring-porous, each ring represents a potential breaking point, so the more rings a tree and its derivative timber have, the more vulnerable it is to splitting with vertical pressure, as would be experienced by frames and stanchions (cf. Rich et al., this volume). Horizontal elements on the other hand do not experience the same kind of pressure against the cross-section. Therefore, to provide samples to wood scientists reliant on high numbers of annual growth rings (e.g., dendrochronology), planks were targeted over frames, the latter of which tended to represent the parent tree well but were often only a couple decades old when felled. Figure 3 is a sample of ceiling planking that was converted from a slow-grown pine tree and preserves 146 annual growth rings, which made it an ideal candidate for wood provenance analyses. Another factor in its suitability for our study is that even after 200 years underwater, this wood sample is very well preserved with very few bore-holes introduced by *Teredo navalis* and other xylophagic organisms that would increase the difficulty of taking accurate measurements of tree-ring widths or of chemical composition.

Each of the 21 samples taken from the *Magdalena* was treated as an artefact. They were cleaned, measured, photographed, drawn, and entered into the ForSEAdiscovery database before being stored in fresh clean water and delivered to their destination – the wood science lab. The recording of each sample was performed with a tablet and stylus to produce detailed record sheets to hand over to the wood analysts along with the samples themselves, which are often destroyed over the course of analysis. These primary records are also retained in the database for studying the scantlings, tool marks, and joinery methods of sampled ship components, as well as the conditions of the wood when it was sampled, which may be useful for future conservation and site formation process analyses.

Wood Science: aiming to establish the provenance of the wood

Once the shipwreck samples arrived at the laboratory of dendrochronology of the University of Santiago de Compostela (Spain) a selection was made, setting aside the best preserved samples (i.e. showing the least amount of galleries caused by *Teredo navalis*) to divide them into subsamples that would be used for organic and inorganic geochemical studies of wood composition and characterization. The main aim of the wood science team of the ForSEAdiscovery project is to develop reference methodologies and datasets to enable establishing the provenance of Iberian ship timbers. These comprise tree-ring-based datasets (ring-width, earlywood, latewood, vessel, and latewood density chronologies), stable strontium isotopic data, and data about the organic composition of different wood species in different areas. All these datasets have been developed for pine (*Pinus nigra* and *P. sylvestris*) and oak species (*Quercus robur, Q. petraea, Q. faginea* and *Q. pyrenaica*) in key areas of the Iberian Peninsula that supplied timber for shipbuilding during the early modern period (Domínguez-Delmás *et al*. in prep.). The techniques used for organic and inorganic wood characterization have been conducted in a smaller group of samples of the trees used for

dendrochronology and wood anatomy. Once the reference datasets have been concluded, it has been possible to cross-check the shipwreck timbers with them in order to try and identify the origin of the wood. In this work we present results of the dendrochronological analyses and preliminary data from infrared spectroscopy on the Magdalena shipwreck samples, researches carried out at the University of Santiago de Compostela (USC, Spain).

Dendrochronology: finding out the date and provenance of the wood through tree rings

Samples from 21 different timber elements of the *Magdalena* shipwreck were sent to the laboratory of dendrochronology of the department of botany at the USC.

A preliminary inspection was carried out to determine the suitability of the samples for dendrochronological dating. Such samples should contain a sufficient number of tree-rings to allow for sound statistical results (e.g. 80 to 100 tree-rings). Exceptionally, timbers with as little as 30 tree-rings could be researched to attempt cross-dating with other samples from the same structure, and thus all timbers with more than 30 tree rings were analysed in this study. The transverse surface of the samples was cleaned with razor blades from the inner- to the outermost ring to perform a ring count and register the presence of pith and sapwood. This preliminary inspection also served to identify samples corresponding to the group of deciduous oaks (*Quercus* subg. *Quercus*), and chestnut timbers (*Castanea sativa*), as both present large earlywood vessels placed in a ring-porous disposition, although the deciduous oaks show large multiseriate medullary rays that distinguish them from the chestnut. These characteristics make them distinguishable by the naked eye. The identification of other species was attempted through observation with an Olympus BX40 microscope of wood anatomical features on thin slices of the radial and tangential section of the wood, and using the identification key proposed by García Esteban et al. (2003). Ring-width acquisition was done with a TimeTable measuring device (University of Vienna) coupled with PAST5 software (SCIEM).

Wood identification and dendrochronological results

Fifteen samples were identified as deciduous oak (*Quercus* subg. *Quercus*), five as conifers (four of which are *Pinus sylvestris/nigra*), and one as chestnut (*Castanea sativa*) (Table 2). The oak samples MAG01-001W-01S, MAG01-005W-01S and MAG01-020W-01S, as well as the chestnut sample MAG01-004W-01S were discarded for tree-ring analysis, as they contained less than 30 tree rings (Table 2).

Crossdating with oak and pine reference chronologies from Spain, central and northern Europe resulted in the absolute dating of three samples: MAG01-018W-01S (dated after 1667 C.E.), MAG01-019W-01S (after 1716 C.E.), and MAG01-021W-01S (after 1702 C.E.) with chronologies of *Q. petraea* of the north of Spain, being a *Q. petraea* composite chronology (made with 17 trees from Cantabria and 2 trees from Asturias, QUPE19MC, Domínguez-Delmás unpublished) the one providing the best statistical results (Figure 4). The provenance of these timbers is therefore some forests in the north of Spain (regions of Asturias, Cantabria or Basque Country), but the dendrochronological results do not allow to pin-point an exact location. The absence of sapwood in the samples hampers estimating the felling date of the trees, hence the dates can only be presented as *terminus post quem* (dates after which the tree was cut). The tree-ring series of those samples have been averaged into the object mean curve MAG3MC that spans the period 1590-1716. The rest of the samples did not produce statistically sound results between them nor with the reference chronologies, therefore their date and provenance remain uncertain.

Geochemical fingerprinting of Magdalena shipwreck: relevance of the initial FTIR results

Wood is a complex polymeric material composed by polysaccharides and lignins. These lignocellulosic macromolecules are responsible for most of the physical and chemical properties that result on differences between wood types (Hedges 1989). The variety of wood types is not only associated to the taxonomies and the environmental factors of the growing location, but also to decay factors associated with the storage environment, particularly for archaeological woods (Fritts 1976, Hedges 1989). The characterisation of the molecular structure of wood chemistry allows detailed understanding of wood properties. Although considerable studies have been done using diverse types of techniques, still much more effort needs to be done to get understanding on the preservation of the chemical composition of archaeological wood (Pandey 1999).

Fourier transform infrared spectroscopy (FTIR) is a widely used vibrational technique for wood analysis (Colom and Carillo 2005, Traoré et al. 2016). Contrary to conventional chemical analysis, it has the advantage to be time efficient and does not require sample destruction (an important aspect when analysing archaeological artefacts). It has been used to differentiate between soft- and hardwood, showing that softwood lignin is essentially composed by guaicyl moieties, whereas hardwood lignin is composed by guaiacyl and syringyl moieties (Evans 1991, Colom and Carillo 2005). FTIR has been more often used to evaluate archaeological wood in order to choose the appropriate conservation method. It is a useful technique to study chemical changes occurred during decay process undergone on ancient wooden artefacts. In this work we applied FTIR on some wood fragments from Magdalena shipwreck timbers, in an attempt to evaluate the potential of this technique to allow the identification of the provenance of waterlogged samples.

Four *Pinus* sp. (MAG02, MAG03, MAG15 and MAG16) and two *Quercus* sp. (MAG10 and MAG21) fragments were analyzed by FTIR. The samples were oven-dried for two weeks at 30ºC, and then the surfaces were cut in order to visualize tree rings. Measurements were performed on consecutive individual rings, from the outer part (recent rings) to the inner part (older rings) of each fragment. The FTIR-ART equipment used was an Agilent Cary 630 FTIR Spectrometer equipped with a single-reflection diamond crystal. The spectra were collected in the absorbance range from 4000 to 400 cm−1 over 100 scans per sample, at a resolution of 4 cm^{-1}. To get a first impression on the collected data, average and standard deviation spectra were calculated on the relative absorbance spectra. Average spectra reflect the dominant spectral bands, whereas the standard deviation indicates which are the largest relative variations (Traoré et al. 2016). For the purpose of this study, the samples were grouped according to the wood specie.

Figure 4 represents FTIR spectra of the two type of wood. The average spectra showed several peaks at identical bands for the two types of wood but according to the relative peak intensity there were differences. Very high peaks with lower intensity for oak woods were recorded at band near 1030 cm^{-1}, which is attributed to C-O stretching in primary alcohol in cellulose (Popescu et al. 2007). Moderate absorption peaks were recorded near region assigned to symmetric CH_2 valence vibration at bands 2925 and 2860 cm^{-1} (Schwanninger et al. 2004). Several lower peaks were presented at region for bands absorption associated to aromatic molecular structures vibrations with lower intensity for pine woods at 1590 cm^{-1} and lower intensity for oak sample at 1690, 1510 and 1260 cm^{-1} (Colom and Carillo 2005). The standard deviation spectra showed higher variability in pine wood than in oak wood. The largest variabilities in pine wood were highlighted at bands near 2925, 2860, 1690 and 1030 cm^{-1}. These bands are due to absorption respectively C-H stretch, carbonyl bond vibration in carboxylic structure and C-O bond vibrations, these bands are main peaks for terpenoid

compounds (Faix and Böttcher 1992, Schwanninger et al. 2004). The highest variability in oak woods was presented at band near 1120 cm^{-1} a related typical syringil unit C-H bond vibrations (Popescu et al. 2007).

Conclusions

Despite the lack of data specifically related with the wood used in the construction of the *Magdalena,* written sources provide exhaustive information about the overall supply to the arsenal of Ferrol. These allow the characterization of the context within which the frigate was constructed, and therefore, give relevant clues for the archaeologists and wood scientists about the species, provenance and application of timber in the crafting of different ship elements. In fact, the results of the analysis of the historical documents indicate the high probability of the remaining framing elements of the hull and other elements placed bellow the waterline of containing a majority of Northern Spain timber, particularly oak, followed by the other less represented endogenous species, as well as a minor usage of tropical timber. On the other hand, aside from sacrificial planking, any Northern Europe pine timber that might have been used in the ship's construction, was most likely applied in the upper works and thus has been destroyed through erosional and biodegradational processes over time in the archaeological wreck site. The documental evidence about the use of Pyrenean pine is a significant factor for the identification of the provenance of the extant pine elements.

To supplement the historical data and to provide a scientific basis for the relationship between forestry and shipbuilding practices in 18th-century Ferrol, an underwater archaeology campaign was enacted. A primary aim of the campaign was to remove wood samples from *La Magdalen*a's remaining hull timbers for dendroprovenance. In accordance with the protocols for *in-situ* ship timber sampling (currently in development), specific timbers were targeted based the likelihood that they would be able to provide sufficient provenance data to justify their removal from the shipwreck assemblage. Qualifying factors included the timbers' function within the ship (i.e., original structural elements such as planks, frames, beams, etc.) and their condition (i.e., lowest levels of biogenic degradation). Timbers were fully recorded before sampling, and the 22 samples retrieved were treated as artifacts and equally recorded in great detail; these primary records are held in the ForSEAdiscovery database for further research into Iberian shipbuilding methods. The wood samples were then dispersed to partner laboratories for dendroprovenance.

Carrying out an appropriate sampling protocol is crucial for the success of dendrochronology. In the case of *La Magdalena* shipwreck, 11 out of the 21 samples retrieved presented almost 80 rings or more, and three of them could be absolutely dated, with a provenance in the regions of Asturias, Cantabria or Basque Country in the north of Spain. This provenance is consistent with the information found in the historical archives about the origin of part of the wood supplying the Ferrol shipyard when *La Magdalena* was built. The lack of internal matches between more oak samples could indicate that the wood was sourced from different areas, which is also consistent with the archival information.

The preliminary results from the application of FTIR to *La Magdalena* shipwreck show the potential of using this technique to study waterlogged woods. The use of the average and standard deviation spectra enable to get details about the chemistry of shipwreck timbers. From these results we can conclude that the combination of FTIR with powerful statistic methods is promising, and may allow the identification of organic markers for the distinction between species and provenance of wood from shipwrecks.

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Captions

Figure 1: Viveiro Bay

Figure 2: Volume and number of pieces per origin, Ferrol - 1771-1173 (AGS, SMA, 347, 349, 350, 621, 788; AGS, TMC, 4207,4208)

Table 1: Number of pieces per specie and type, Ferrol - 1771-1773 (AGS, SMA, 347, 349, 350, 621, 788; AGS, TMC, 4207,4208)

Figure 3: Sampling the *Magdalena* timber assemblage: A-2015 underwater archaeology campaign. B- Sample of pine ceiling planking

Table 2: Results of species identification and tree-ring analysis. Species: 1, *Quercus* subg. *Quercus*; 2, *Pinus sylvestris/nigra*; 3, *Castanea sativa*; 4, conifer (unidentified); pith: present (+1) / absent (-); bark edge (WK): present (+) / absent (-) / estimated; MRW: mean ring width (cm); σ: standard deviation (cm).

Figure 4: A - Oak samples from the Magdalena shipwreck dated by dendrochronology. Their tree ring series has been averaged into the mean curve MAG3MC, which dates against a *Quercus petraea* composite chronology (QUPE19MC). Legend: TBP: Student's *t* adapted according to Baillie and Pilcher (1973); asterisks represent the signification level of GL (*, *p*<0.001); GL: percentage of parallel variation as defined by Eckstein and Bauch (1969), and indicated by the shaded background; CC: correlation coefficient; OL: overlap between the series; X-axis: calendar years. B- Average (a) and standard deviation (b) spectra obtained by FTIR.**

TITLE

Reconstructing trees from ship timber assemblages using 3D modelling technologies: evidence from the Belinho 1 shipwreck in Northern Portugal.

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ABSTRACT

During the winter of 2013/14 a number of violent storms and related surges exposed a remarkable shipwreck site, tentatively dated to the early of mid-16th century, containing a timber assemblage and hundreds of pewter plates and other artefacts on Belinho beach, near Esposende, in the North of Portugal. An international team was assembled including archaeologists from the Esposende city council and researchers from the ForSEAdiscovery Project. The objective of this project was to join a number of different experts and explore innovative methodologies to record and analyse ship timbers with forest management and timber supply networks in the Age of Discoveries.

A key recording strategy included the usage of a Faro-Arm digitiser to record wood grain and timber conversion, together with photogrammetry, which was used to represent the timber surfaces. The compounded digital models were processed with Rhinoceros 3D modelling software.

The collected data allowed researchers to model and develop reconstructed parent tree shapes from each ship timber, and try to better understand tree growth patterns, possible forest management activities, and timber selection for one of Iberia's major post-medieval industries: shipbuilding.

The Belinho 1 Project is an ongoing experiment where an array of techniques is being tested with the involvement of the local community, in order to help us understand the Iberian shipbuilding world, share our discoveries as widely as possible, and let the technologies utilized interact and invite new questions and ideas, and hopefully produce a methodology to

identify tree selection methods, conversion techniques, and shipbuilding practices and philosophies.

KEYWORDS

Maritime archaeology, dendrochronology, tree reconstruction, computing, shipbuilding.

INTRODUCTION

During the winter storms of 2013/2014, unusually large storms impacted the north coast of Portugal, provoking pronounced erosion along some stretches of sandy beach. These storms exposed a remarkable archaeological find and sent a large collection of ship timbers and artefacts ashore (Figure 1).

These artefacts were first discovered by sculptor João Sá when looking for raw material during a walk on the beach. The artist accidentally spotted human-made shapes in the timbers nested among the rocks. With the help of his family Mr. Sá started to collect a variety of artefacts at low tide. Given the relevance of the artefacts found he contacted local and national authorities.

Archaeologists from the city council of Esposende promptly ensured the recovery and protection of the artefacts washed ashore. Soon after the trove it became evident that the artefact collection encompassed two chronological horizons:

- Belinho 1: A Post-medieval (disarticulated) site including the remains of a ship's hull, pewter plates, copper alloy plates with figures in relief, and a small number of personal artefacts, possibly dated to the middle of the 16th century.
- Belinho 2: Hundreds of Roman amphorae fragments.



Figure 1 - GIS map indicating where the timbers were found at the Belinho beach (GIS Map provided by the Council of Esposende).

PREVIOUS WORK.

In 2014 researchers from the Portuguese Centro de História d'Aquém e d'Além-Mar (CHAM), from Universidade Nova de Lisboa, undertook a preliminary study of the post-medieval artefact collection under the direction of José Bettencourt, focusing on the key structural timbers that included the keel, stern knee, stern post, several floor timbers and hull planks (Bettencourt *et al.* 2014).

CHAM's team concluded that:

1. The surviving architectural signatures on the Belinho 1 ship timbers are consistent with early modern Iberian shipbuilding technology (Oertling 2001; Castro 2008).
2. One curved timber was used to connect the keel, stem, and stern posts (*couce* and possibly *coral*).
3. The keelson was almost surely notched over the floor timbers and the mast step was an enlarged portion of the keelson.

Following the announcement of the finding of the Belinho 1 shipwreck site, historian Amândio Barros conducted an archival investigation to identify potential historical events related to the Belinho 1 loss. His research focused on the Esposende area, near to the beach of Belinho, during the late-16th and early-17th centuries. The research yielded an interesting candidate: a small merchantman with 70 to 80 tons of capacity, named *Nossa Senhora da Rosa*, lost in

the area during the winter of 1577. This ship was built at Massarelos, a parish of the nearby city of Porto, using trees from the surrounding forests, by the carpenters Fernão D'Aires and António Eanes. Further research uncovered documents that mention the salvage of part of the cargo on March 14 of the following year, from the Belinho beach. *Nossa Senhora da Rosa* was sailing from the Canary Islands to nearby Vila do Conde, with a cargo of pitch and Madeira wine (Barros 2016).

The artifacts found since on this site are no longer consistent with this hypothesis. The copper alloy plates seem to indicate a northern origin for the ship, the pewter plates have crowned hammer marks typical from the German Swiss region, and the guns seem to suggest a tentative date for this shipwreck somewhere between the first and the third quarters of the 16th century (Almeida et al. 2017).

BELINHO 1 RESEARCH PROJECT

Given the relevance of the Belinho 1 artefact collection, the city council of Esposende invited a team of maritime archaeology and wood sciences experts from Marie Curie project ForSEAdiscovery (2013-2017; Grant agreement no.: 607545) to continue CHAM's preliminary study in the summer of 2015.

The evaluation of the Belinho 1 timber assemblage was carried out with four main objectives in mind (Martins *et. al* 2015):

1. To establish a date and provinience for the ship and its cargo;
2. To reconstruct the parent trees from the archaeological evidence, in order to try to understand timber growth patterns and ranges of shapes preferred by shipbuilders;
3. To develop dendrological studies on the Belinho 1 timbers (wood anatomy and dendrochronology);
4. To develop a three-dimensional digital ship reconstruction based on timber shapes and other archaeological evidence.

The project was designed in accordance with Historic England's guidance on project design (Historic England) MoRPHE and the Direção Geral do Património Cultural (DGPC) archaeology code of practice.

The methodology was chosen to maximise efficiency given the short available time for fieldwork. Thus, multiple work-stations were established in the area where the municipality stored the timbers in specially designed tanks. Archaeologists and wood scientists implemented a set of parallel activities to record and interpret both timbers and artefacts.

The pewter plates were photographed, drawn, and scanned for maker's and possession marks under the microscope. The timbers were tagged, separated by function and recorded. The recording was carried out in three separate ways:

1. Morphological analysis: a fiche was filled for each timber and its conversion and special characteristics noted;
2. Wood grain: a FARO-Arm was used to record the most prominent grain patterns apparent of the timber surface, and digital photography to create 3D meshes of the timber surfaces with PhotoScan software;
3. Construction features: the shape, measurements, scarves, fastening patterns, and caulking solutions were manually recorded at a 1:10 scale, photographed, and described in individual fiches.

This methodology allowed different teams of researchers to rotate the timbers and work full time. The comprehensive documentation and recording process of individual timbers entailed unique labelling and the use of timber recording sheets (TRS) (Nayling and Jones 2014: 243); traditional recording techniques (Mckee 1978; Mardsen 1978; and Tremain 1978); three-dimensional meshes (Jones, Nayling and Tanner 2013); computer vision photogrammetry (Yamafune, Torres and Castro 2016) and the collection of timber cross-section samples by hand-sawing. This workflow resulted in:

1. The recording of 11 key-structural hull timbers – seven Y-frames (BEL01-001W, BEL01-032W, BEL01-036,037W, BEL01-039W, BEL01-040W, BEL01-043W) keel (BEL01-071W), mast step (BEL01-051W), stern knee (BEL01-072W), stern post (BEL01-073W), and one floor timber (BEL01-003W) – with a FARO-Arm in a format adapted from the manual produced by Toby Jones (2014);
2. All the 75 timbers that composed the collection were photographed and recorded using direct measurements, computer vision photogrammetry, and hand sketches;
3. Twelve oak samples were collected from timbers displaying more than 50 rings.

Post-recording laboratory analysis undertaken by ForSEAdiscovery Project researchers led to the development of a dendrochronological report (Domínguez-Delmás *et al.* 2015a: 1; Domínguez-Delmás *et al.* 2015b), a detailed catalogue of the timber assemblage (Castro *et al*. 2015) and the editing and printout of the eleven individual timber´s 3D digital models, essential to develop advanced studies on tree and ship reconstruction of the Belinho 1 (Martins *et. al* 2015).

DATA ANALYSIS

The digital models of each of the selected timbers were used to produce working files that better represented the morphology and the final shape of each of the eleven key-structural hull timbers.

The original 3D files were first edited in *Rhinoceros* to remove irrelevant lines and ensure that all lines were associated with the correct layers, both in terms of the faces represented and

the attributes assigned. The edited files provided clearer 3D reproductions of the eleven individual timbers and were used as the basis for another series of new files.

In order to produce 2D traditional drawings, each face was projected onto an orthogonal plane. This task produced a set of 2D orthographic projections of each timber face, complemented with cross-sections (Figure 2).

The drawings developed were produced by merging the 3D models with the photogrammetry data, and adding the information collected through inspection on the timber recordings sheets, and fieldwork notes. This task aimed at highlighting construction features in each timber, namely the fastening patterns, scarves, caulking arrangements, sections and shapes.

Although none of the then 75 timbers washed ashore in connection with any other timber, the angles of some of the outer planks' hoods and the position of some of the fasteners allowed the matching of nineteen individual timbers, forming a portion of the ship's runs (Castro *et al*. 2015).

A fourth type of drawing was produced from the edited files and used in the tree reconstruction process. On these files, the layers containing the wood conversion were hidden, and the natural wood features were highlighted (this process will be explained in detail in the section on tree reconstruction below). In this way, the drawings obtained reproduce a set of diagnostic features with precision, revealing growth patterns, natural edges, branches, and knots.



Figure 2 - Timbers BEL01-001W Y-frame (3D edited drawing produced using a 3D digitizer arm, 2D printout and 3D drawing merged with photogrammetry files), mast step BEL01-051W

(developed files having extruded fasteners) and keel BEL01-071W (3D developed drawing and 2D printout files). (3D digital drawings by Adolfo Miguel Martins and photogrammetry merged against 3D drawing by Nigel Nayling).

SAMPLE COLLECTION, WOOD IDENTIFICATION, AND DENDROCHRONOLOGICAL RESULTS

After completion of the recording process, a selection of timbers was sampled by either coring or sawing, yielding a total of 15 samples. Sampling was performed with care, to minimise its impact on the timbers. Increment borers were used to sample timbers which possessed good dendrochronological potential, namely substantial number of tree-rings and presence of sapwood, but which would lose integrity if sampled with a saw. The remaining elements were sampled by sawing their ends, thus mitigating the impact on the integrity of the timbers. Wood samples were sent to different laboratories within the ForSEAdiscovery network where they undertook a variety of analyses, particularly for dating, wood anatomy studies, and geochemical analysis purposes.

The visual inspection of the samples allowed the identification of 12 of them as deciduous oak (*Quercus subg. Quercus*). Two other samples correspond to conifer species, although the observation of anatomical features with a microscope in the radial section has not led to the identification of the timber species. Finally, one sample from a timber of uncertain origin (possibly not part of the ship structure) was found to belong to a tropical species and was excluded from further analysis.

Only five of the 12 samples identified as belonging to the oak group were considered for dendrochronological analysis, as they contained more than 80 rings, with six samples having less than 60 rings (Figure 3). Two of the samples (from plank fragments BEL01-013W and BEL01-024W) with most rings showed a very strong statistical and visual crossdating with each other (correlation coefficient: 0.64; Student's *t*-value: 8.95; percentage of parallel variation, %PV: 74.5%; significance level of the %PV: $p<0.001$; overlap: 104 years). This indicates that the timbers very likely to derive from the same parental tree possibly fragments from the same timber). The lack of more internal matches with and between the other samples, together with the strong variability in growth rates (i.e. mean ring widths in the oak samples range from 0.60 mm to 2.62 mm per year), indicates that the wood could have been sourced from different areas, or from a large area where tree growth rates varied. Another explanation for the lack of matches between the timbers could be that the samples are not contemporary, i.e. some timbers could be repairs. Furthermore, the fact that the ship timbers had washed ashore hinders the certainty that all timbers here examined are part of the same wreck. This makes drawing conclusions challenging, especially for the tropical timber present among the samples, which cannot be regarded with certainty as a part of the ship's assemblage (Domínguez-Delmás *et al.* 2015b).

The comparison of all the tree-ring series with European reference chronologies and oak chronologies from the north of Spain failed (for the moment) to produce statistically sound

results. Therefore, all samples remain for now undated, and the provenance of the wood remains unknown.

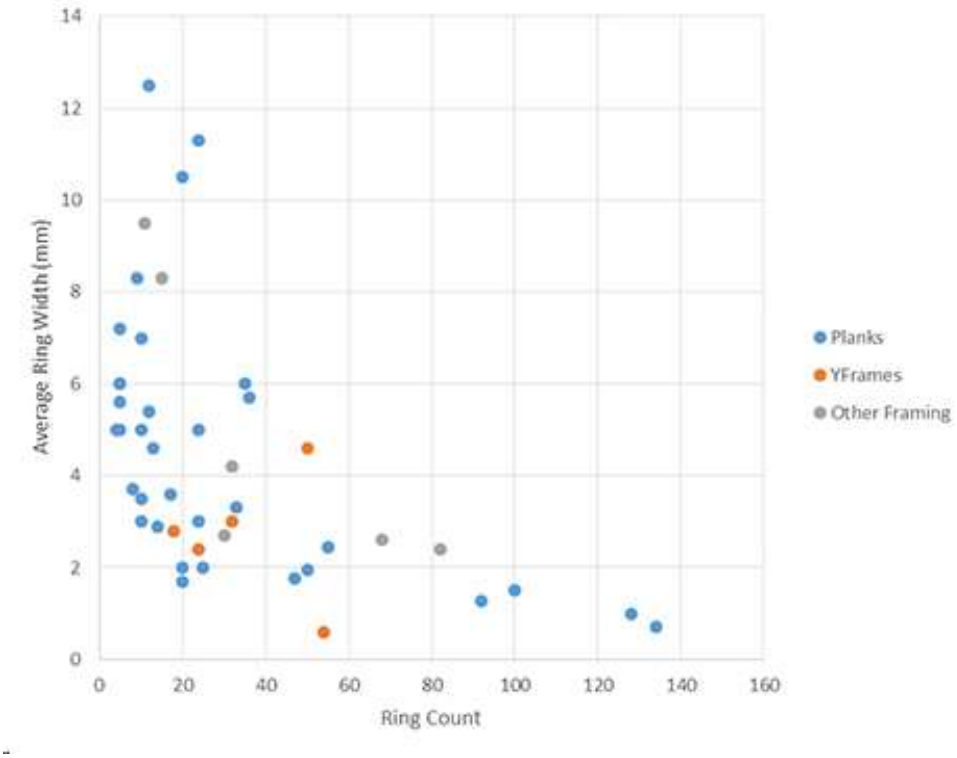


Figure 3 - Statistical analysis on the average ring width and ring counts of timbers (Graphic developed by Adolfo Miguel Martins upon date collected by Nigel Nayling, Peter Groenendijk and Marta Domínguez-Delmás).

SHIP TIMBERS

Due to the high-level of erosion caused in the site formation process, some key features, such as scarves, timber edges and original surfaces were eroded in many timbers. Despite this problem, the characteristics of some timbers and the fastening patterns suggest a possible origin for this ship in the north of the Iberian Peninsula. Below is a quick characterization of the ship timbers recorded in the summer of 2015:

Hull Timbers

A total of 75 timber fragments washed ashore from 2013 to 2015. As mentioned above, they were divided into five groups, according to their purported structural function (Castro *et al*. 2015).

Longitudinal structure

The first group consisted of timbers from the longitudinal structure and encompassed portions of the keel (BEL01-071W), sternpost (BEL01-073W), stern knee (BEL01-073W), and mast step (BEL01-051W).

The keel segment preserved was rabbeted (around 8.5 cm), measured 879 cm in length and its section was 22-24 cm sided and 19 cm moulded. There were no signs of scarves on either end of the keel segment. Twelve 2.7 cm circular bolt holes were preserved along with the timber length, connecting some floor timbers to the keel, spaced around 70 cm on average, if we exclude the distance between bolts 5 and 6, which was 115 cm. The bolt heads, with diameters around 5.5-6 cm, were lodged in countersunk holes 6-7cm in diameter, and 2.5 cm deep. Marks of 1.1 cm square iron nails, fastening the garboards to the keel, were preserved along the rabbets, and spaced 70 cm on average.

The fasteners' pattern on the planking suggested a room and space around 35 cm and indicated that the keelson was bolted to this portion of the keel through every other floor timber, except between bolts five and six, where there were probably two-floor timbers between bolts.

The *sternpost segment* was preserved along 290 cm, and its section was 20 cm sided and 21 cm moulded. Three 2.7 cm bolt holes were preserved, spaced 70 cm and 53 cm, which correspond to the spacing of the bolt holes preserved on the stern knee (*coral*). The deep rabbets (31.4 cm deep) presented 1.1 cm square nail holes and 2.5 cm preserved treenails, which fastened the hood ends of the hull planks to the sternpost. These fastening holes allowed the re-positioning of seven hull planks, which had washed ashore separately. The after face of the stern post preserved nail marks that suggest that the sternpost was covered with sheathing, and a protruding tenon with two diagonal nail holes the function of which is not yet clear.

A *stern knee* washed ashore as well, 281 cm long and 20 cm high. Its moulded dimension varied between 12.3 cm and 8.7 cm and its sided dimension was 20 cm. Four iron bolts indicate that it was fastened to the keel although the spacing of these bolt holes does not correspond with those found on the surviving fragment of the keel. In contrast, three bolt holes on the upper part of the stern knee match those on the sternpost. Again, two or three 11 mm square nail holes, and two 25 mm treenail remains indicated the fastening pattern of the hull planking to the stern heel side faces.

The remains of a *mast step* bear signs of long exposure to the actions of marine life and were heavily eroded. It is an expanded portion of the keelson, 197 cm long, 45 cm sided, and 30 cm moulded. The step mortise is 86 cm in length, 18 cm sided, and 10 cm deep. Two bolt holes allow a tentative positioning of this portion of the keelson between the 7th and 8th bolt holes of the keel. The mast step is notched to fit over the frames.

<u>Transversal structure</u>

The second group of timbers found at the Belinho 1 site included seven Y-frames (*picas*), five floor timbers, three frame fragments that appear to be the lower extremities of first futtocks, two timbers that were tentatively identified as fragments of deck knees, and a broken frame fragment.

The central framing timbers presented square sections around 18 cm sided and moulded, and the same pattern of nails and treenails for the fastening of the hull planking. They showed central trapezoidal limber holes positioned slightly to the side of the keel axis, and some had dovetail joints in the preserved extremities, in the area overlapping with the futtocks. The floor/futtock fastening pattern seems to have been two treenails and two iron nails.

Floor timber BEL01-045W did not have an apparent dovetail scarf on its preserved arm but showed a step on the face opposite to the futtock, where a nail was inserted, in a manner similar to those found at Highborn Cay (Oertling 1989).

Floor timber fragment BEL01-041W presented a foot with a central limber hole and only one treenail mark, on its foreword and after faces. One of its arms seems to have been around 30 cm long, suggesting that this timber may have been a reinforcement placed between the inner extremities of two first futtocks, reinforcing the floor timber in the keel area.

Floor timber BEL01-042W presents similar features to the timber described above. The maximum length surviving has 321 cm, and its section was 17 cm sided and 18 cm moulded. On one of the sides this timber has a dovetail scarf measuring 23 cm on the top and 28 cm on base. Evidence shows that at least one nail was inserted on the futtock through is step. The floor timber also possesses an inscription “II”, which probably indicates its location on the framing system.

The futtock extremities preserved varied in length, mostly near 1 m, and presented sections 16-18 cm sided and moulded. Some of the futtocks showed dovetail scarves with a pattern of two or three nails and two or three treenails in the floor/futtock connection.

The two purported deck knees are eroded pieces with fastening patterns and notches that suggest this function, but so far it is not possible to definitely identify them as such.

Stern planking and other longitudinal timbers

The third group of timbers washed ashore at Belinho included a portion of a waterway, three fragments of port side hull planks with their aft hoods preserved, four fragments of starboard hull planks with their aft hoods preserved, and five plank fragments difficult to position at this stage.

Planks BEL01-053W, BEL01-056W, BEL01-060W, and BEL01-059W angles, fastening holes, and dimensions match the marks and angles on the starboard side of the sternpost. Similarly, planks BEL01-055W, BEL01-054W, and BEL01-057W match port side angles and fasteners’ marks of the sternpost (Castro et al. 2015).

A curious feature observed in these hull planks is that they were carved with triangular notches 5-7 mm deep, and grooved on their outer surfaces, coated with a resinous substance, and sheathed with either lead or sacrificial wood, although no traces of lead were picked up in several XRF analyses performed on coating samples (Castro et al. 2015).

Has expected, the planking conversion type presents evidence of tangential conversion, although at this time it is not possible to identify which tools were used for the process. The level of erosion affected the timbers' surfaces, and made difficult to identify tool marks, although some carpentry marks, such as the number "II' on floor timber BEL01-042W.

The group of the twelve best preserved hull planking timbers was cut from oak trees bearing a maximum of 128 tree-rings and a minimum of 36 annual rings. One of the eroded timber fragments from this group (BEL01-061W) was sampled for dendrochronological analysis. It was not possible to identify the *Quercus* sub-species at the present stage of the project. Planks BEL01-053W, BEL01-056W, BEL01-060W, BEL01-059W, BEL01-055W, BEL01-054W and BEL01-057W, already mentioned above, do not show evidence of large knots, suggesting that they were cut from straight stem trees.

Plank Fragments and unidentified wood

The fourth group of timbers consisted of 27 small fragments of planks, impossible to place in any particular position in the hull at this stage of the project (Castro *et al.* 2015).

A fifth group consisted of 11 small fragments of wood from unidentified timbers, also impossible to a position at this stage of the project (Castro *et al.* 2015).

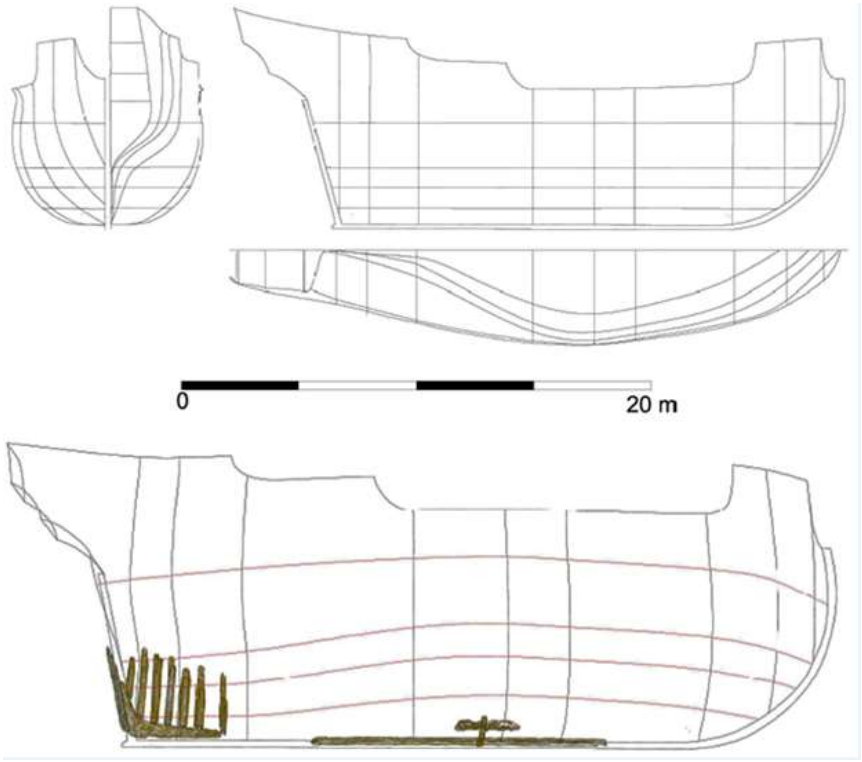


Figure 4 - Geometric plans from the Belinho 1 ship (above) and the timber assemblage in correlation to the 3D model of the vessel (conceptualization and drawings by Adolfo Miguel Martins and Filipe Castro).

TREE RECONSTRUCTION

As already mentioned, the Belinho 1 timber assemblage suffered significant levels of erosion, which increased the difficulty of the recording process. Despite this, the timbers analysed offered relevant data for advanced dendrological studies. The seven Y-frames, a complete floor timber, the stern knee, the sternpost, a portion of the keel and the fragment of the keelson (mast step) were selected for careful recording using digital techniques due to their potential to provide relevant data for tree reconstruction.

Evidence of knots, cracks, and growth patterns was used to plot the location of the timber pith along the full length of each timber. The tree rings visible at end of the Y-frames clearly indicated the points where the tree stem split into two or more branches. The grain lines on the floor timbers were useful for identification of the curvature of the parent tree.

The timber recording methods employed, both manual and with a FARO-Arm, reproduced with precision the wood features that led to the tentative tree reconstructions. The 3D digital models produced followed specific recording protocols, which enabled the identification of exact angles of curvature, and potentially diameter of the parent trees, in comparison with the shape and size of the selected individual timbers. This method proved to be effective and allowed us to identify the particularities of the parent tree of each timber, namely ring widths, grain curvature on the main stem, as well as position, density, and angles of branches.

As mentioned above, once the 3D digital models were edited and re-inspected, it was possible to hide the layers related to the work performed by the carpenters with *Rhinoceros* software. The resulting models represent only the wood features, which give a clear view of the wood anatomy on each timber surface. The grain lines and the inclination of the knots are essential to identify the direction of the tree (roots and canopy). Once the growth direction is identified, the next step is to find the pith location in the stem and branches, which was possible in the case of the stern knee and Y-frames. The maximum width can be defined by the pith and the preserved waney edges on the timber surface. The ring-width and natural heartwood edges can also provide additional information. After achieving the maximum width on each surface and identifying the growth direction, it is possible to recognise the shape of the tree and some of its morphological characteristics. Sapwood was only observed on timber BEL01-001W, which made it impossible to identify the maximum diameter of each timber. Either bark and sapwood removed during woodworking, in keeping with the advice given in broadly contemporary shipbuilding treatises, such as the *Liuro da Fabrica das Naos* (Oliveira c. 1580), or the *Livro Primeiro da Architectura Naval* (Lavanha c. 1600), or it was lost, eroded after the shipwreck.

The Belinho 1 ship timbers were tangentially cut from the parent trees and then shaped using a variety of tools to meet the required shape.

The Y-frames presented shapes consistent with the transverse and longitudinal angles of the hull. The y-frames' feet were cut at angles that fit over the stern knee where they stood, and their height formed a plausible shape of the transition between the ship's runs and the wider portion of the upper hull in that area. The progression of the angles of branches of each of the Y-frames positioned on the inboard face of the stern knee showed a consistent pattern and formed a smooth, fair and thus plausible shape of that part of the hull:

- Y-frame BEL01-037W angle of the branches is 3°, the length of the stem 99.2 cm, abundant knots along the stem.
- Y-frame BEL01-036W angle of the branches is 8°, the length of the stem 148.3 cm, not having knots along the stem.
- Y-frame BEL01-039W angle of the branches is 12°, the length of the stem 145.7 cm, abundant knots along the stem.
- Y-frame BEL01-001W angle of the branches is 22°, the length of the stem 149.2 cm, not having knots along the stem.
- Y-frame BEL01-040W angle of the branches is 24°, the length of the stem 127.1 cm, abundant knots along the stem.
- Y-frame BEL01-043W angle of the branches is 21° but reduces the length of the stem to 83.9 cm, abundant knots along the stem.

- Y-frame BEL01-032W angle of the branches is 15°, the length of the stem 184.6 cm, not having knots along the stem.

The longitudinal structural timbers revealed the following features:

- To shape the stern knee carpenters needed a tree with a larger stem and branches having an angle of about 105º between each (in comparison the timbers previously mentioned);
- To obtain the keel carpenters needed a long tree with the minimum of 900 cm in length and 22.3 cm in width. This timber also presents a larger branch on its inboard face. Many other relatively small size branches can be observed along each surface of the keel full extension.

Evidence has also shown that to build the Belinho 1 ship carpenters needed at least four types of trees:

- Y-frames – straight stemmed oak trees ending with at least two branches in the canopy forming symmetrical angles from vertical;
- Floor timber and futtocks – long stem or branches having a smooth curvature;
- Stern knee – large stem and branches with an angle closer to 105º;
- Keel – long straight stem having the minimum of 900cm in length.

At this stage, this study allowed the following conclusions:

BEL01-001W (Y-frame):

- Minimum diameter of the stem is 74 cm, minimum diameter of the port side branch is 18 cm, angle of the stem to the branch is 15º, the minimum diameter of the starboard side branch is 21.4 cm, the angle stem to the branch is 156º, and the maximum length of the stem with the absence of knots is 149 cm;
- The absence of knots along the main stem;
- Specific V-shape of the canopy;
- The width of the stem is consistent with the other timbers in the ship´s stern;
- The pith, growth pattern and the split of the stem into two branches provided the shape required for ship construction;
- The growth rate (i.e. average ring width) is consistent with higher levels of moisture (precipitation/groundwater levels);
- The sapwood was removed to shape the timber, but the heartwood seems to preserve its maximum extent (some traces of sapwood).

BEL01-003W (floor timber):

- Clear growth orientation of the timber (crown/stem).
- The abundance of knots at one end.
- The curvature of the timber is consistent with the natural curvature of the tree.
- Fast-growing timber suggests a landscape abundant in water and minerals.
- The grain at the lower end of the timber suggests the existent of forest practice to encourage the growth of multiple branches (pruning/pollarding).
- At the bottom of the timber, the growth pattern is consistent with forest management techniques.

The process of tree reconstruction involves a complex data analysis in which every wood feature needs to be carefully inspected. In this particular case it is a still ongoing study, undertaken within author Miguel Martins' doctoral studies as a Marie Curie - ForSEAdiscovery Project fellow.

Timber analysis requires that archaeologists acquire experience in both shipbuilding characterization and dendrology. The recording process should aim at acquiring compounded information related to shipbuilding and wood anatomy. This study is a contribution to the development of a methodology that will hopefully become mainstream in nautical archaeology within a few years. The recording protocols we will develop in the incoming years will allow for new forms of 3D recording, manual samplings, visual observation, and any other methods available, such as X-rays or magnetic resonance. The 3D digitizer arm proved to be an extremely efective tool, mostly when compounded with *Rhinoceros* software. Budget and fieldwork time constrains most probably dictate that only a selection of timbers will be digitally recording and analysed (as was the case in the Belinho 1 Project).

We opted to convert the 1:10 scale drawings into 3D digital representations later, in order to manipulate the timbers and try to match them against an hypothetical model of the hull, developed from the only diagnostic measurements we could obtain from the archaeological data: the flat of the floor timber near amidships, and the probable height of the ship's runs. Our reconstruction is hypothetical and should looked upon as a preliminary attempt at making sense of the timbers that washed ashore at Belinho in 2014 and 2015.



Figure 5 - Tree reconstruction process base on the evidence collected on the Y-frame timber BEL01-001W (above) and Floor-timber BEL01-003W (bellow) showing different forest management practices (drawings and tree reconstruction by Adolfo Miguel Martins).

CONCLUSIONS

The main conclusions of this study can be summarized along two main lines. The first is that this study setup clearly the need for protocols to standardize the recording of both nautical information (Castro et al. 2018), and that these protocols must include dendrological analysis. The second is that although at this time neither archaeological nor dendrological evidence have shown a strong correlation between the Belinho 1 timber assemblage the shipwreck discovered in the archival research, there is no reason to change our methodology. Dendrochronological evidence has not yet yielded any matches, and the artefact collection doesn't seem consistent with the ship's route.

The studies carried out on the Belinho 1 ship timbers allowed us, however, to conclude that from the 12 samples that underwent dendrochronological research, both framing and planking elements presented fast and slow growth rates, suggesting that there was an unspecific selection of trees in terms of growth types for the construction of this ship. Although in order to draw conclusions relative to the quality of the timber supply we will need to carry out further analysis, this is an important piece of information the incomplete multidimensional puzzle that every shipwreck presents.

The tree reconstruction attempts carried out on the Y-frame BEL01-001W and floor-timber BEL01-003W allowed to characterise their parent trees with a good degree of certainly,

yielding information on the forest where the timbers originated from. Straight stems with a low number of knots were sought by shipwrights for their strength and are typical of trees that have grown in high-density stands.

The structural timbers analysed presented evidence of having been selected in accordance with the wood grain flow orientation to avoid cracking by tension and show that both straight and compass timber – trees and branches – were available in the forests where they were cut.

The sample of deciduous oaks showing variable growth rates and lacking internal cross matches suggests that the wood was sourced from different areas or an extensive area where tree growth was variable. The growth pattern seemed to be consistent with oak trees of about 60 years (average of annual 50 rings plus rings lost by erosion, or removal sapwood and bark). The Y-frames also seem to be consistent in terms of growth pattern, and the floor timber and futtocks present the same correlation within each typology. Equally, the absence of a significant number of knots along the timbers presented evidence of the areas in which the trees were planted. The ring-width average has also demonstrated in which extent trees were supplied with abundant water and minerals (precipitation/groundwater levels).

As already mentioned, given the relatively small number of timbers sampled there is a possibility that some of the analysed timbers may not be contemporary, corresponding to possible repairs. Again, this piece of information is relevant for the ongoing study of the ship.

Although the nature of the Belinho 1 shipwreck site, located in a high energy area which poses serious risks to diving, has determined the slow pace of this study, mostly commanded by the atmospheric conditions and the natural movement of sediments of the bottom, the information already gathered allows us to emphasize the importance of this site. The ship timbers shape and assemblage techniques are consistent with an Iberian architectural provenance, and even though the tentative chronologies established for the artefacts do not permit a tentative dating within a few decades, it is likely that this ship dates to the second quarter of the 16th century, making it a precious testimony to the European shipbuilding techniques of that time.

ILLUSTRATIONS.

Figure 1 GIS map indicating where the timbers were found at the Belinho beach (GIS Map provided by the City council of Esposende).

Figure 2 Timbers BEL01-001W (3D edited drawing produced using a 3D digitizer arm, printout and 3D drawing merged with photogrammetry files), BEL01-051W (development files having extruded fastening cavities) and BEL01-071W (3D drawing development and printout files) represented in 3D digital drawings (3D digital drawings by Adolfo Miguel Martins).

Figure 3 Statistical analysis on the existent number of rings on individual timbers (Graphic developed by Adolfo Miguel Martins upon date collected by Nigel Nayling, Peter Groenendijk and Marta Domínguez-Delmás).

Figure 4 Geometric plans from the Belinho 1 ship (above) and the timber assemblage in correlation to the 3D model of the vessel (conceptualization and drawings by Adolfo Miguel Martins and Filipe Castro).

Figure 5 Tree reconstruction process base on the evidence collected on the Y-frame timber BEL01-001W (above) and Floor-timber BEL01-003W (bellow) showing different forest management practices (drawings and tree reconstruction by Adolfo Miguel Martins).

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The Bremen Cog – Environmental Issues

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Abstract

The Bremen-Cog was dated by dendrochronology in the 1960s when the discipline was in its infancy. The felling date of winter 1378/79 in the Weser Uplands was established and confirmed in 2007. In 2016 a new comprehensive analyses of the ship was made possible. All analysed samples are from trees likely felled in the last quarter of the 14th century in the direct hinterlands of Bremen. Further, an attempt of tree-morphology reconstruction and a detailed investigation on the trees growing features were carried out, revealing a poor timber quality which was originally rather not intended for the purpose of shipbuilding.

Keywords:
Medieval Ship, Northwest Europe, Dendrochronology, Dendroprovenance, Timber quality

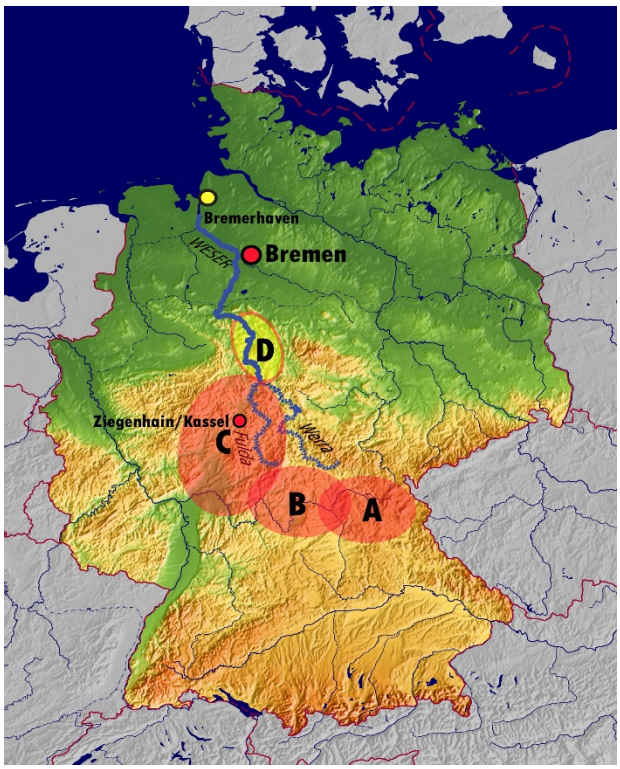


Fig. 1: Map of Germany with the Weser passing through Bremen and Bremerhaven in the North German Plain. Its headstreams Fulda and Werra are uniting in the southern part of the Weser Uplands (D). The Regions producing the samples for the South German main curve are Upper-Franconia (A), Lower-Franconia (B) and Hessen (C) with Ziegenhain/Kassel (Graphic: M. Belasus using a ginkgomaps.com base map).

1. Introduction

After its recovery from the Weser River in 1962 just four kilometres West of Bremen's Medieval centre the *Bremen-Cog,* a late 14th century ship built in the Bremen-Type shipbuilding method[1], was primarily seen as a technical monument for the heydays of the Hanseatic League. Even though it was rebuilt in the German Maritime Museum in Bremerhaven, which opened its gates in 1975, it took many years before the construction of the ship was analysed using an archaeological approach.

During the project "From the North Sea to the Norwegian Sea – Interdisciplinary research on the Hanse" funded by the Leibniz Association at the German Maritime Museum the ship became the focus of ship archaeological investigation when the question about the technical basis of Low German shipwrights for the building of sea-going ships was raised. A generous contribution of the support society of the museum[2] enabled a comprehensive dendrochronological analyses of the building timbers of the ship. This analysis could

[1] "Bremen-Type" refers to the shipbuilding method defined on the base of the Bremen-Cog. It is used here to avoid the term "Cog/Kogge" for the archaeological/technical definition, which causes contradictions and misunderstandings (Belasus 2017).

[2] Förderverein Deutsches Schiffahrtsmuseum e.V.

connect to the ERC funded project "TIMBER", in which the research on the ship is currently continued and could be extended with the analyses of the timber quality and a trial on the reconstruction of tree morphology patterns on the base of outboard planking. Apart from still being the best preserved late medieval cargo vessel in Northwest Europe after more than 50 years since its discovery and the base for the technical definition of a particular shipbuilding method, the Bremen Ship also played a role in the development of a reliable oak chronology in this part of the continent. While dendrochronology here was in its infancy during the 1960's, the *Bremen-Cog* turned out to be the first archaeological find of the area, which timber's provenance could be established on the base of dendrochronology (Haneca et al. 2009, p. 6).

2. Early Dendrochronology

At this point there were no reliable chronologies for the North German Plain. While in South Germany climate signals were distinctly visible in the ring growth pattern of oak trees, the situation in the North proved to be more difficult and at the time of the ship's discovery there was no reliable coverage of master chronologies.

Yet, all in all three samples from the ship could be dated on the basis of the, at the time, recently built South German master chronology made using more than 1000 analysed dendrochronology samples from upper and lower Franconia and Hessen (fig. 1). Of all samples, one provided a bark edge, dated to winter 1378/79. The comparison with a site chronology from Ziegenhain/Kassel (Bauch 1969, p. 125) and a historical investigation by J. Delfs (1952), which gives evidence for timber rafting on the Weser to Bremen already during the 13th century, narrowed the origin of the dated building components down to the Weser Uplands about 200 kilometres upstream from Bremen (Liese and Bauch 1965; Bauch 1969). In 2007 the published data on this early analyses was reanalysed on the base of a widely extended base of chronologies and confirmed dating and provenance for two of the three early dated samples (Daly 2007, pp. 115-116).

3. New dendrochronology[3] and investigations on timber morphology

During the archaeological investigations between 2015 and 2018 the opportunity was taken to carry out a new comprehensive dendrochronological analyses of the ship's timbers that benefitted from an extensive coverage of oak chronologies for the North German Plain. This was developed since the original dating of the ship over a period of more than fifty years (Daly 2017). The aim of this new analyses was to discover information on timber procurement for shipbuilding purposes in Bremen.

The strategy for the new analysis of the Bremen Ship was to sample as much as possible a wide variety of the ship's constructional components. Sampling was carried out by coring, using a specially designed borer that bores a hole in the timber 16mm in diameter, and to a maximum depth of 30 cm. The core extracted is 6mm wide. The position of the coring is aimed at maximizing the number of rings retained in the core, from outermost towards the original centre of the tree. The timbers are assembled in the reconstructed ship, so sampling took place, during 19-22 April 2016, on in situ timbers chiefly inboard in the hull, but a few were also taken of hull planks from outboard. Care was taken to spread the sampling around the hull, so that a representative sample of timbers was achieved.

Of 78 analysed timbers 55 have been successfully dated (including the three from Bauch's analysis). In most timbers, only heartwood was observed, and estimating the felling date for the trees from which the

[3] Dendro.dk report 46: 2017, Dendrochronological analyses of timbers from the Bremen Ship, Germany. On file at the German Maritime Museum, Bremerhaven/Germany.

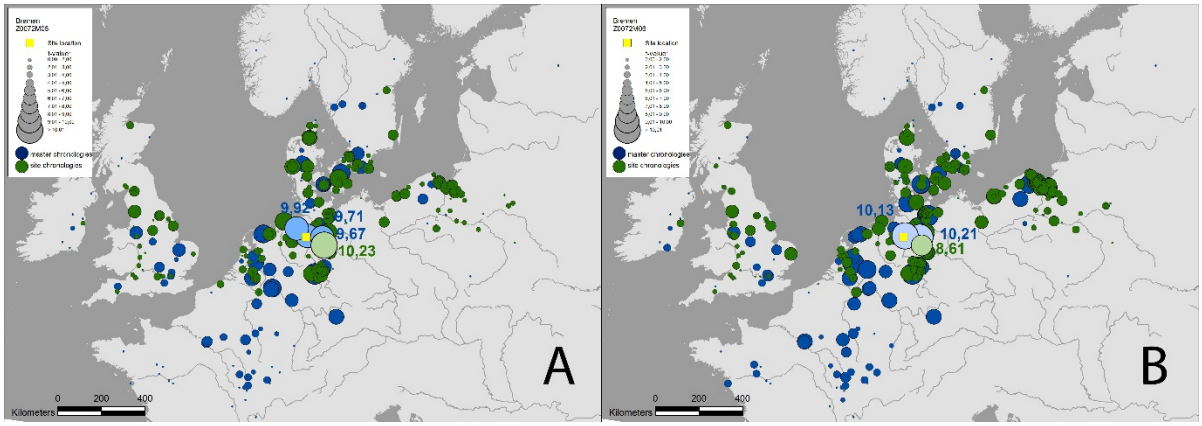


Fig. 2. Maps showing the correlation between the two dendrochronological groupings of timbers from the Bremen Ship (A: Group 1; B: group 2). The correlation statistic, Student's t-test, is plotted using circles. The higher the t-value is the larger is the circle. The average for each group is compared with an extensive tree-ring dataset for oak in Northern Europe. The blue circles represent large regional master chronologies while the green circles represent local site chronologies (See Daly 2007 for a detailed explanation of the method) (Graphic: A. Daly).

samples come was in agreement with Bauch's estimated building date for the Bremen Ship, at around AD 1380. In other words, no evidence of later additions to the ship has emerged in this analysis. This underlines the interpretation that this ship was not an old ship when it sank.

Of all the dated samples, just three have sapwood preserved. One of the timbers sampled by Bauch had complete sapwood to bark edge, but this was not the case for any timbers examined in this analysis.

Using the correlation between every dated tree-ring curve with every other, the material can be divided into a small number of groups. Averages for each group have been calculated. The groups are a mixture of different components from the ship. No apparent differentiation can be made between the outer planks of the hull and its inner timbers.

Group 1 is the largest group and it is made from the tree-ring curves of 34 timbers. It is 243 years in full length, but a version of the average version is made with a minimum of five trees in depth, and this is 164 years in length, and covers the period AD 1186 to 1349. The correlation between the average for this group and a wide range of site and master chronologies is mapped in fig. 2 A. The group is achieving highest correlation with datasets around the Bremen hinterland. This seems to indicate that the bulk of timber for the building of the ship was harvested local to the ship-building site.

Group 2 is made from just ten trees. Most are framing-timbers, but a pair of ceiling planks are also assigned to this group. The full length of the average for group 2 is 262 years, but again a reduced version, only including the period where at least 5 trees are represented, is made and this is 156 years long, covering the period AD 1163 to 1318. As the correlation between this group and site and master chronologies indicates again a source area within the Bremen hinterland is most likely (fig. 2 B). The remaining timbers that have not been assigned to a group are all dating with chronologies for Lower Saxony. To conclude, the provenance analysis of the Bremen Ship presents no evidence of long distance transport of timber for its construction, apart from the two earlier analysed timbers by Bauch. Rather, we are seeing that the Bremen Ship is chiefly built of timber from the Bremen hinterland.

The result of the dendrochronological analyses prompted questions about the available timber quality and tree morphology in the direct hinterland of a town like Bremen. With the aid of structure-from-motion technology[4], a portable coordinate measuring

[4] Reflex camera and AGISOFT software.

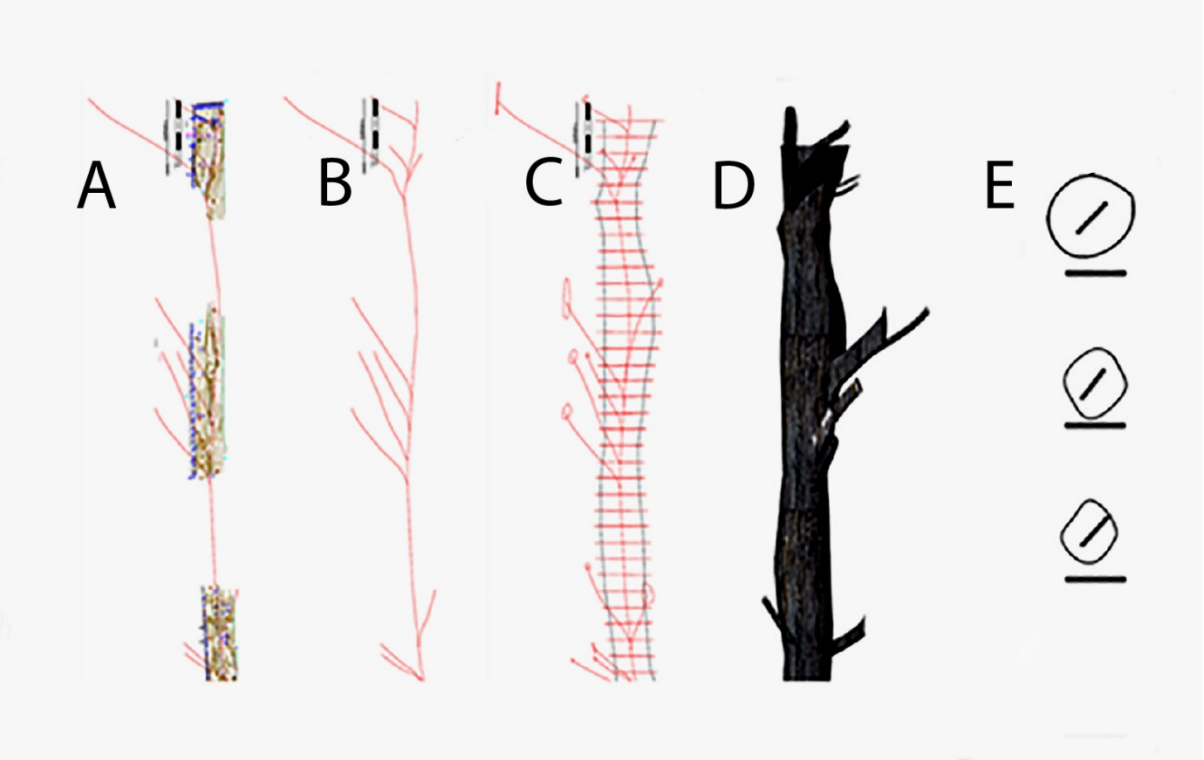


Fig. 3: An Example for the reconstruction of a tree's morphology from a plank. In this example a portable-coordinate-measuring machine (here: FARO-Arm) was applied to document all the important features where they were accessible (A). The positions of branches and their growing directions are established (B). The shape and circumference of the original tree trunk is estimated (C) and combined with the assumed size of the evident branches at the time of the trees felling (D). From this information, the position of the plank in the original tree is established (E) (Graphic: A. M. Martins).

machine[5] and 3D modelling software[6] three selected planks from the ship were documented and their morphological features (grain direction, tree rings, position of the pith and traces of branches) used to reconstruct a general morphology of the original trees and to allow us to describe their original nature (fig. 3) (Martins 2017; Colson 2017). The results of this attempt of reconstructing trees from planks gave enough information to characterize the trees' morphology and shed light on their growing conditions. The main characteristic is the number and position of branches, which are distributed all over the trunk. A tree creates branches to have its leaves catch sunlight for photosynthesis. In a dense population of trees the branches would be concentrated in the upper part of the trunk. The lower part would be for the most part branch-less, as leaves here would not get enough light to thrive. When a tree grows in a rather open landscape and catches light from all directions it will produce branches all over its trunk as is the case with the trees used for the building of the Bremen Ship. It is therefore to assume that the trees present in the ship's outer planking were growing in a rather open landscape. However, the trees were not short but rather tall and wide offering enough material for the production of planks with an average width of 0.506 m and up to 9.52 m long.

Further detailed investigation of the outer planking unveiled a poor timber quality. Already from the detailed descriptions of all surviving timbers by Werner Lahn (1992) it becomes clear that over 50% of the outer hull planking was repaired during the building process. In some cases, dead branches (knots) were cut out and a rectangular patch was placed to fill the hole, waterproofed with the aid of moss caulking and secured with clamps.

[5] FARO-Arm.

[6] RHINOCEROS 3D.

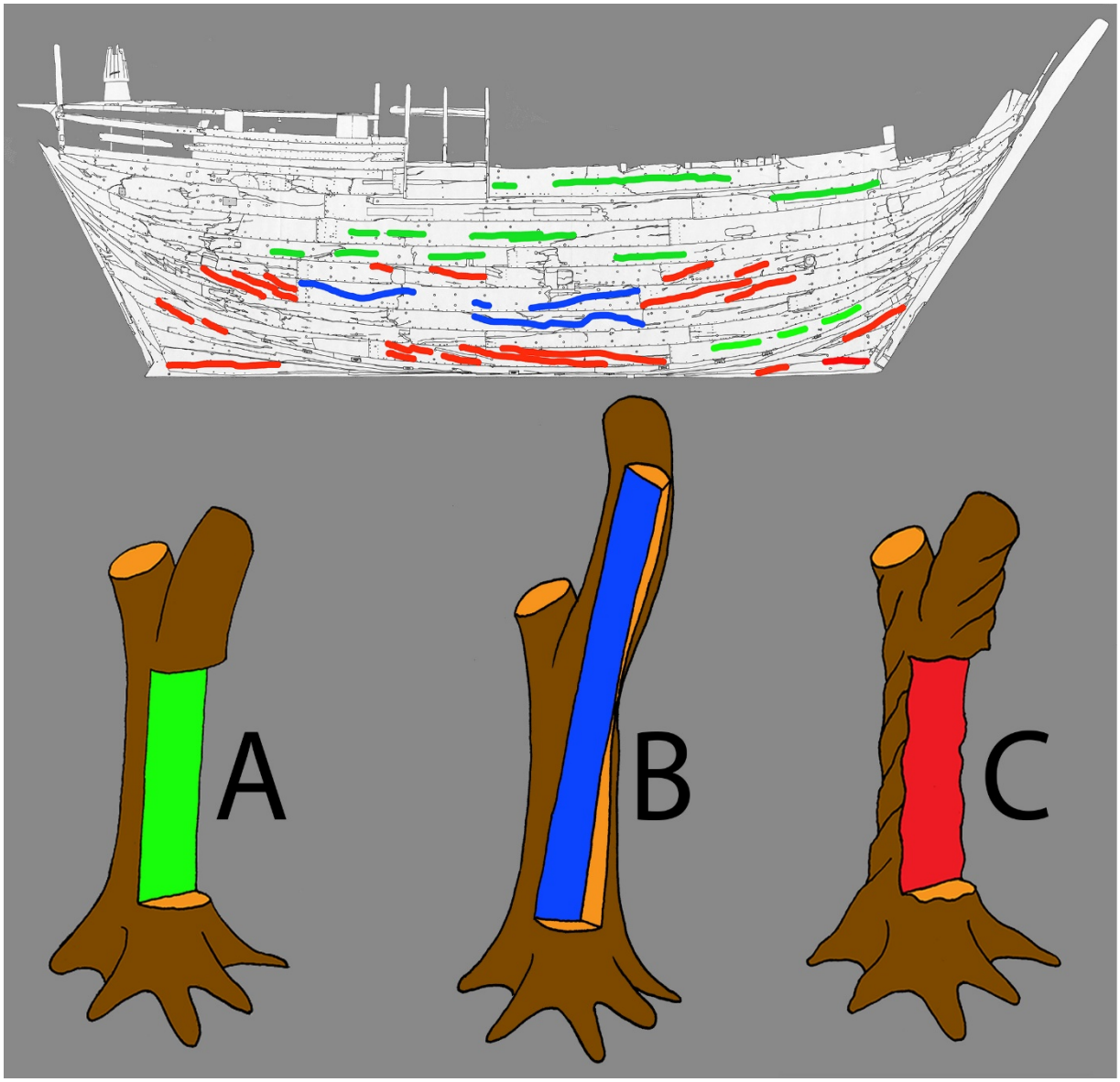


Fig. 4: Distribution of different grain courses in the tangential sawn planks of the Bremen Ship and their origins in the tree. A: Planks sawn from the trunk of a straight-grained tree. B: Planks sawn from a crooked tree or a cut that was extended into a main trunk for the production of longer planks. C: Planks cut from trees with spiral grain (Graphic: M. Belasus using the 1980 University of Hannover's/German Maritime Museum's photogrammetric recording of the ship).

Other repairs were needed of cracks that appeared in the planks. These were repaired using moss caulking and iron clamps. The investigation showed that not all dead branches were patched up and these fell out at a later point. They are evidence of ingrown deadwood, which occurs when it takes a tree too long to incorporate a broken or cut off branch. In other areas the trees produced clusters of branches giving evidence for a repetitive removal of branches at the same spot. Apart from creating a weakness in the planks' strength all branches have in common is that they divert the trees grain in a straight trunk. When the tree is converted into about 0.05 m thick planks, by means of tangential sawing, the fibres are cut regardless their direction. The cut fibres create weaknesses, which often cause the planks to crack and as they were built into a ship's construction while the timber was still green (unseasoned), tension is created as they shrink during the drying process. The cracks are following the direction of the fibre.

That cracks that occur in the outer planking have to be repaired is not an unusual

observation on tangentially produced planks and can also be seen in other ship finds, e.g. in Doel 1 or Poel 11. While Doel 1 is built from tangentially sawn oak planks, Poel 11's planks were produced from tangentially cleft pine trunks (Vermeersch and Haneca 2015; Belasus 2017b). In most cases these cracks appear longitudinal and rather straight and can easily be repaired without greater consequences. In the case of the Bremen Ship longitudinal cracks appear to be a minority (fig. 4 A). Other repaired cracks appear curvy indicating a crooked trunk or they are straight until they curve away at one end revealing the extension of the planks by cutting well into an adjacent main branch (fig. 4 B). Yet, the most numerous cracks in the ship's construction are the most disturbing. These cracks travel diagonally through the planks, in the worst cases cutting the plank in two from the plank overlapping above to the plank overlapped below, reducing the longitudinal strength the strake should have given to the hull structure and being inaccessible for proper repair. These cracks are the result of a twisted growth of the oak it was cut from (fig. 4 C). Twisted growth of trees is a phenomenon that can be genetic. However, often it is the result of severe injury to the trees phloem, a thin layer of cells just under the bark, which purpose is to transport water and nutrients vertically from the roots up to the branches. When this phloem is cut in one area, the tree is able to prevent the parts of the tree directly above the injury to be cut off from nutrients by creating alternative diagonal cell connections to bridge the injury. This causes a 're-programming' of the phloem's cell structure. Each new layer in the following years will circle diagonal around the trunk. The phloem becomes sapwood and, in the years to follow, hardwood with twisted grain (Kubler 1991). Spiral grain is not necessarily weakening the timber. As long as it is used as a full block and the angle of the twist is not exceeding 37˚, it is even adding strength to the timber (Leelavanichkul and Cherkaev 2004, p. 134). This is, for example, the case with the recovered capstan of the vessel.

4. Conclusions

The recently carried out extensive dendrochronological analyses of the building timbers of the *Bremen-Cog* did not change their previous dating to a felling in winter 1378/79. Neither did the components of the ship, which were successfully analysed before, experience a change in their provenance in the Weser Uplands during the re-examination of their published curves. Nevertheless, now that we have a massively extended dataset of regional oak chronologies for the North German Plain, we can state that all trees in the new analysis have their origin in the hinterland of Bremen, an area that was directly influenced by the town's interests. The trees were far from being ideal for shipbuilding. The reconstruction of their basic morphology with branches all over their trunks from below to above places them into a rather light-flooded park-like landscape. Their considerable size indicated by the lengths and widths within the planks indicate their location at the edge of a forest or in small patches of woods in the countryside. Ingrown deadwood indicated by the dead, patched up or fallen out dead branches confirm that they received no maintenance to secure quality timber. Yet, the trees were most likely used, during their growth. Clusters of knots confirm a repetitive removal of branches or twigs and the evidence for twisted grain in many of the outer planks speak for severe damages to their trunks already early in their life.

The evidence speaks for woods whose main purpose was not as a source for quality timber but for other purposes e. g. providing acorns to feed pig herds, as a hunting ground or for collecting firewood. Why they were finally felled and converted into planks and if these planks were originally intended for the purpose of shipbuilding is yet unknown.

5. Acknowledgements

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APPENDICES 2 – APPENDED DIGITAL DATA ATTACHED TO THE PRESENT THESIS.

List of digital files:

a) Folder **Corpo Santo Wreck** containing:
    a. Folder Corpo Santo Wreck Sternpost and coral photogrammetry files:
        i. Folder Corpo Santo Wreck Sternpost and coral photogrammetry files:
            1. Metashape file Corpo_Santo_Wreck,
            2. Folder Corpo Santo Wreck Photographs:
                a. Folder Corpo Santo Wreck Coral Port Side Photographs:
                    i. JPG files.
                b. Folder Corpo Santo Wreck Coral Starboard Photographs:
                    i. JPG files.
                c. Folder Corpo Santo Wreck Sternpost Port Side Photographs:
                    i. JPG files.
                d. Folder Corpo Santo Wreck Sternpost Starboard Photographs:
                    i. JPG files.
    b. Folder Corpo Santo Wreck Sternpost and coral obj files:
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        ii. Folder Coral Starboard Surface:
            1. OBJ File Corpo_Santo_Wreck_Coral_SB.
        iii. Folder Sternpost Port Side Surface:
            1. OBJ File File Corpo_Santo_Wreck_Sternpost_PS.
        iv. Folder Sternpost Starboard Surface:
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        ii. Folder Corpo Santo Wreck Coral Starboard Surface:
            1. PDF File Corpo_Santo_Wreck_Coral_SB.
        iii. Folder Corpo Santo Wreck Sternpost Port Side Surface:
            1. PDF File Corpo_Santo_Wreck_Sternpost_PS.
        iv. Folder Corpo Santo Wreck Sternpost Starboard Surface:
            1. PDF File Corpo_Santo_Wreck_Sternpost_SB.
    d. Folder Corpo Santo Wreck Rhinoceros 3D files:
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        ii. 3dm file Corpo_Santo_Wreck_Sternpost_Grain_Lines,
        iii. 3dm file Corpo_Santo_Wreck_Sternpost_Tree_Morphology.
    e. Folder Corpo Santo Wreck Timber Recording Photographs.
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    c. Folder Highborn Cay Wreck T0817 pdf files:
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c. Folder VOC Batavia pdf files:
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vi. Metashape file BEL01_040W,
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iv. PDF file BEL01_001W_tree,
v. PDF file BEL01_003W,
vi. PDF file BEL01_013W_development,
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viii. PDF file BEL01_032W_printout,
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xxii. PDF file BEL01_072W_edited,
xxiii. PDF file BEL01_072W_tree_rendered
xxiv. PDF file BEL01_073W_develpment,
xxv. PDF file BEL01_073W_edited,
xxvi. PDF file BEL01_073W_printout.

c. Folder Belinho 1 Wreck Rhinoceros 3D files:
i. 3dm file BEL01_001W_development_within_ship_structure,
ii. 3dm file BEL01_001W_edit,
iii. 3dm file BEL01_001W_printout,
iv. 3dm file BEL01_001W_tree,
v. 3dm file BEL01_003W_edit,
vi. 3dm file BEL01_003W_printout,
vii. 3dm file BEL01_003W_tree,
viii. 3dm file BEL01_004W_2D_to_3D,
ix. 3dm file BEL01_013W_development,
x. 3dm file BEL01_032W_edit,
xi. 3dm file BEL01_032W_printout,
xii. 3dm file BEL01_036W_edit,
xiii. 3dm file BEL01_037W_edit,
xiv. 3dm file BEL01_039W_edit,
xv. 3dm file BEL01_040W_edit,
xvi. 3dm file BEL01_041W_2D_to_3D,
xvii. 3dm file BEL01_042W_PolylineOnMesh,
xviii. 3dm file BEL01_043W_edit,
xix. 3dm file BEL01_051W_edit,
xx. 3dm file BEL01_051W_printout,
xxi. 3dm file BEL01_057W_edit,
xxii. 3dm file BEL01_071_001W_development,
xxiii. 3dm file BEL01_071W_edit,
xxiv. 3dm file BEL01_071W_printout,

xxv. 3dm file BEL01_071W_tree,
xxvi. 3dm file BEL01_072W_angle,
xxvii. 3dm file BEL01_072W_development,
xxviii. 3dm file BEL01_072W_edited,
xxix. 3dm file BEL01_072W_printout,
xxx. 3dm file BEL01_072W_tree,
xxxi. 3dm file BEL01_073W_develpment_with_keel_Stern_knee,
xxxii. 3dm file BEL01_073W_edited,
xxxiii. 3dm file BEL01_073W_printout,
xxxiv. 3dm file BEL01_073W_tree,
xxxv. 3dm file Belinho_1_ship_reconstruction,
xxxvi. 3dm file Carvel template 4 sided fore and aft 10 April 2013 R4,
xxxvii. 3dm file Carvel template 4 sided upper lower 10 April 2013 R4.

d. Folder Belinho 1 Wreck Wreck SimLab Composer:
    i. SIM file BEL01_001W,
    ii. SIM file BEL01_003W,
    iii. SIM file BEL01_072W.
e. Folder Belinho 1 Wreck Wreck Documentation:
    i. JPG file BEL01_004W_scale_drawing,
    ii. JPG file BEL01_041W_scale_drawing.

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APPENDICES 3 – LIST OF PRESENTATIONS GIVEN WITHIN THIS DOCTORAL STUDY.

Ali, S. 2016. Digital Recording in Boat Archaeology.

Martins, A.M.B.P.S. 2014a. Dendrochronology: an approach to the Golden Age of shipbuilding.

Martins, A.M.B.P.S. 2014b. Tróia 1, a Journey into the time and sea. Shipbuilding & the shipwreck.

Martins, A.M.B.P.S. 2015a. Maritime Routes and Shipwrecks at the edge of the Iberian world: Interrogating ship timbers.

Martins, A.M.B.P.S. 2015b. Ship Timbers from the Belinho Shipwreck: Recording and Provisional Analysis.

Martins, A.M.B.P.S. 2015c. Technological Advances in Archaeological Approaches to Wood Science.

Martins, A.M.B.P.S. 2015d. The Anatomy of Trees & Ships: How can we see trees in timbers?

Martins, A.M.B.P.S. 2016a. Engineering and reverse-engineering in wooden shipbuilding: The analysis of data collected from archives and seabed using a 3D CAD approach.

Martins, A.M.B.P.S. 2016b. Engineering and reverse-engineering in wooden shipbuilding: The analysis of data collected from archives and seabed using a 3D CAD approach.

Martins, A.M.B.P.S. 2017a. "Interrogating" ship timbers to reconstruct the past woodlands.

Martins, A.M.B.P.S. 2017b. Reconstructing Trees from Ship timbers: data analysis and schematics.

Martins, A.M.B.P.S. 2017c. Using three-dimensional software to reconstruct frames of the past based on archaeological evidence.

Martins, A.M.B.P.S. 2018a. A construção naval e as florestas no reconhecimento do Atlântico.

Martins, A.M.B.P.S. 2018b. Reconstructing Ship Timbers` Parent Trees: Methods of Analysis for Ships and Woodlands.

Belasus, M., Martins, A.M.B.P.S., & Daly, A. 2018. The Bremen Cog - Environmental Issues.

Martins, A.M.B.P.S. 2019. O contributo de Monchique para a construção naval do séc. XV.

Trindade, A.R. 2016. From Forests to the Sea, from the Sea to the Laboratory: the Timbers of the Frigate Santa Maria Magdalena (18th century).