Maritime Archaeology

ASSIGNMENT

Course: Master Thesis

Semester: 4th semester spring/summer2010

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Date of birth: 5th of March 1982

Number of pages and characters: 126 pages and 162.233 characters

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Reconstructing the Lines of the Princes Channel Ship

A master thesis from Maritime Archaeology Programme, University of Southern Denmark by

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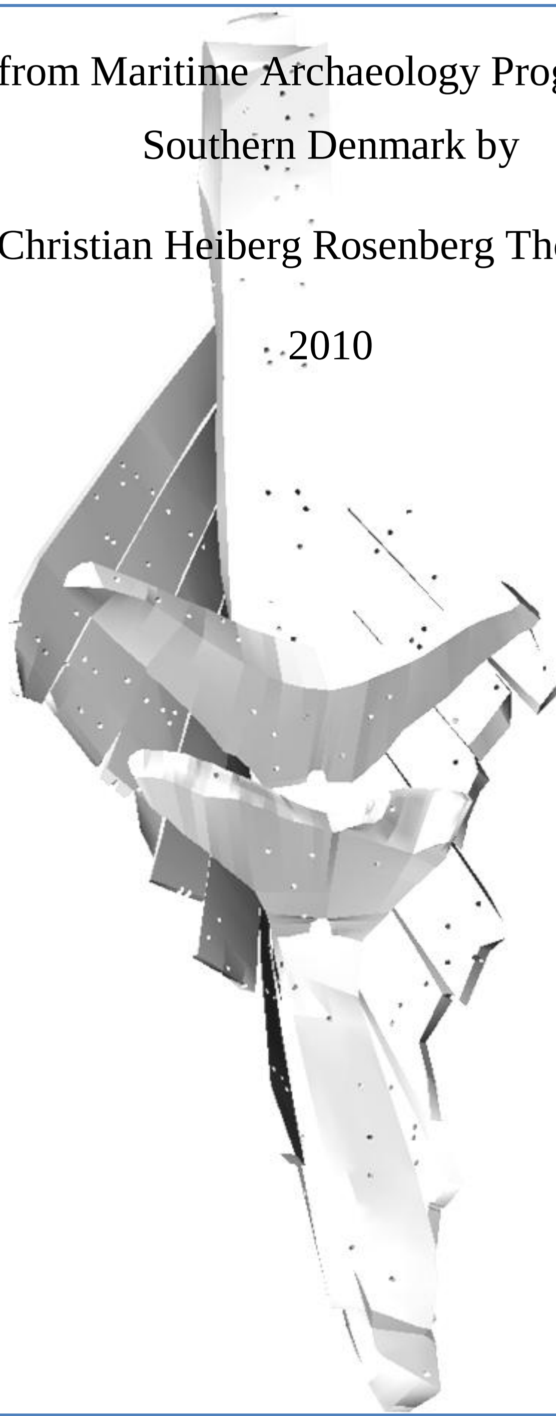
2010



Acknowledgements

I would like to use this opportunity to thank the dedicated staff of the Maritime Archaeology Programme at University of Southern Denmark for creating a dynamic and challenging learning environment of which I had great challenges and much joy. Also I would like to thank Frederik Hyttel and Toby Jones for answering my many questions and assisting me in technical matters.

Most important I would like to thank my wife Bodil for her patience and support.

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1 Introduction

During pre-dredging survey in 2003 in the estuary of the Thames, the Port of London Authority discovered a wreck. To begin with it was thought to be a barge of lesser importance, but while clearing the site, the workers from PLA got a surprise. Among other things a cannon appeared in the grab of the mechanical excavator. An archaeological contractor was called in and a series of investigations of the site was carried out in the following period. (Auer & Firth 2007, p.3)

The Princes Channel Wreck was the subject of study for the students of the master course in the Maritime Archaeology Program in the spring semester 2009 at Syddansk Universitet Esbjerg. The objective with the course was to create a 1:20 scale reconstructions of the wreck pieces and in second stage build 1:10 scale reconstructions of selected parts of the wreck, and from this exercise to gain insight in the construction of this particular wreck, and also to help the students gain knowledge of ship construction in general. The course was in many aspects a didactical success and helped in the understanding of what to do and what not to do when approaching the archaeological material. As counts for the research results of the course the gaining was more doubtful. The fragment models were simply not precise enough to give the final result enough credibility as part of a hull reconstruction. Never the less it was an eye opener to the potential of the modeling approach, and served as inspiration for this thesis.

The significance of the Princes Channel ship as contributing to the knowledge on 16th century shipbuilding should be noted. The ship is not known from historical sources, but distinctive constructional features and rebuilding of the hull makes the Princes Channel wreck an important and interesting subject to the study of 16th century English and North European shipbuilding.

1.1 Aim and objectives

The aim of this thesis is to produce a lines plan of the ship wreck from the Princes Channel. The method of reaching this is through a 1:10 reconstruction model of the ship wreck. The model will be a mean of obtaining basic dimensions of the Princes Channel ship such as length, breadth and depth of the hull. Research on the Princes Channel ship is an opportunity to get a glimpse of construction and design ideas of a merchant vessel from a period and tradition of which only little is known from archaeology.

The main part of the research and reconstruction of English ships from this period has been based on historical sources and only very fragmentally archaeological evidence. The conception of late medieval and early renaissance ships is hence largely based on these sources. Here it is the objective to take the recording of the archaeological remains, as far as possible before turning to secondary sources. Therefore the recording method of the ship wreck becomes an important aspect for the reconstruction and for discussing how it might be improved in future digital wreck recording.

Two fundamentally different modeling methods will be used for creating the research model. One is a manual manufacturing of the wreck pieces in wood and cardboard while the other is a method of reproducing the components directly from a digital reconstruction. The project will be an experimental process of combining these methods to obtain the results of making a lines plan of the Princes Channel ship.

Hopefully the reconstruction will also reveal ideas of design that the shipwright had in mind while the ship was still in its initial stages. Will it be possible to conclude anything about these underlying thoughts from the reconstruction? This is not a central aspect of this research but the reconstruction is hopefully going to be a foundation for further research of this subject.

The thesis is only a single step in a reconstruction process of a ship wreck. It will concentrate on how to get from the recorded remains of a 16th century merchant sailing vessel, to a lines plan made from a 1:10 scaled working model, ready for further research.

1.2 Terminology

The terminology of naval architecture and shipbuilding is specialized and a basic understanding of the terms necessary for understanding the content of the following. This thesis follows the terminology of Richard R. Steffy as it is given in an illustrated glossary of ship and boat terms in his book *Wooden Ship and Ship Building and the Interpretation of Shipwrecks.*(Steffy 1994, pp.266-298)

1.3 Review of reconstruction modeling as a research tool

Before presenting the methods used in the work with the Prince's Channel it will be in its place shortly and simplified to describe some methods of recording and reconstruction techniques used by established institutions and researchers. There are several finished and ongoing projects working with this subject and only a selection is mentioned here. It is mainly projects keeping close to the archaeological material, trying to reconstruct the particular vessel from the archaeological remains.

In 1993 the first of two five year grants was given by Danmarks Grundforskningsfond (Danish basic research foundation) to establish Nationalmuseets Marinarkæologiske Forskningscenter (The National Museums maritime archaeological research center). Hereby a productive environment for developments in maritime archaeology was founded. Several large research projects was formed and published from this institution, including the major publication of the Skuldelev finds, the Hedeby ship, the Iron Age wreck from Hjortspring and the excavation and reconstruction process of the B&W wrecks from Copenhagen. Much of the work at the research center was concentrated on clinker-build vessels from the Viking Age, medieval period and smaller vessels from the renaissance. The methods developed for the B&W wrecks are the ones most relevant for the study of the Prince's Channel wreck, because of the time period and construction techniques of the ships but also because of the recording methods used.

Christian Lemée´s PhD project on eight renaissance ships from Chrisitanshavn in Copenhagen was published in 2006 in the book series *Ships and Boats of the North.* The B&W wrecks were discovered in 1997 and excavated in three campaigns. The dating of the ships is between 1580 and 1738 but they mainly belong to the renaissance. The historical literature was for a long time dominant in the understanding of the renaissance shipbuilding technologies and was not widely challenged by archaeological evidence. Lemée's work shows the importance in working with the archaeological sources to renaissance shipbuilding techniques namely the ships them selves. His research included creating 1:10 scaled models of wood and cardboard and showed an effective method of dissociating the archaeological material from the stereotypical understanding of a period's shipbuilding technology. It also shows that much knowledge never mentioned in historical sources about techniques and the shipbuilders working methods can be gained from the model reconstruction of shipwrecks. Due to a severe time pressure on the excavation it was crucial to choose the right survey method. The choice was a digital survey method of recording the ship timbers using total-station combined with traditional recording methods of measuring and drawing.

The B&W wrecks were the first large scale recording of ship wrecks in Denmark using these methods.(Lemée 2006, p.82) The different constructional elements were recorded in a code system so that each component type could be recognized from the other by the code. As the wrecks were recorded in-situ, the layers of the construction had to be peeled off after recording to get to the underlying timbers. The total-station recording was a two dimensional recording system, basically recording the individual timbers outlines and so needed supplementary manual measurements of moulded dimensions and hand drawings of details traced over it.(Lemée 2006, p.87) some sections and stem constructions of the hulls were recorded manually in 1:10 drawings.

The first step of the reconstruction process was an analysis of the original building sequence of the ships. A number of preliminary models of the ships cross-sections were build in scale 1:20 to achieve the right understanding of structural details and basic shape. Also 1:20 in situ models of some of the wrecks was build from cardboard using the total-station recordings, the 1:10 hand drawings of sections and individual timbers.

When the reconstruction of the archaeological remains was finished, missing elements could then be added to the model. Strakes could be extended and frames inserted in the structure. The fragment models were then in fact converted to the full representation of the hull shapes. When the model reached a point where further work became speculative it was measured and drawn as torso drawings and strake drawings.(Lemée 2006, p.100) Also 1:10 scale models were build of larger hull sections using the preliminary theories of the building sequence to test the hypotheses.

Basically the models were made by gluing prints containing all the recorded details of the timbers onto pieces of cardboards for the planks and plywood for the frames. They are not mending to be museum display models, but their main purpose was to function as research tools.

Lemée’s work follows to some extend the research tradition that have evolved around the Viking Ship Museum in Roskilde, starting with the excavation of the Skuldelev ships in the late 1950s and early 1960s. 1:10 cardboard reconstructions were made from the 1:1 recordings of the Skuldelev ships, and the work was essential developing basic research principles and methods of ship reconstruction of especially clinker build ships.(Crulin-Pedersen & Olsen 2002)

Clearly a lot has happened within the technical recording methods since the Skuldelev excavations, and the methods used are in many aspects different from Lemée´s. The results of the reconstructions are presented in largely similar ways, putting weight on the torso and strake drawings and to show the relation between archaeological remains and the reconstructed hull as part of the scientific method of reaching and explaining the full reconstruction process.

A completely different approach to reconstruction of ship wrecks is used in the work with the Newport ship. It is a method of digital recording that initially was developed for recording the ships from Roskilde harbor that was adopted and developed further by the Newport Ship Project.(Jones 2009, p.113) The recording is done with a *FaroArm*, a device that is traced along the edges, curves and details of each individual timber. The recording is saved as a digital file and can be modeled afterwards in a 3d software package. With the faro arm it is possible to record large amounts of timber relatively fast and in the same amount of detail as the manual 1:1 method of tracing on drafting film. In addition to the drafting film method the FaroArm also records the actual shape of the timber in all dimensions. The FaroArm recording is a 1:1 recording but the nature of the digital recording is much easier to handle than the cumbersome full size drafting film. The Newport Ship reconstruction is in many ways a pioneer project of the method of reconstructing ship finds. This recording method gives the possibility to create a reconstruction model in 3d both digitally and physically using selective laser sintering (explained elsewhere in this paper). The individual plastic reconstructed timbers can be assembled to a coherent model of the archaeological material. Missing construction elements can also be digitally reconstructed and inserted in the model.

The FaroArm is not an objective recording method and it contains just as much interpretation as manual drawing, but it cuts away the interpretation step of manufacturing the timber in a material used for the physical model. In this way it can be assured that the physical reconstruction of the individual timber piece is identical with the interpretation that was made while recording the real timber. The smaller Drogheda Boat from Ireland has been recorded and reconstructed using the techniques developed in Newport.

There is definitely a great potential in this method as shown in the Newport Ship reconstruction Project, but naturally it has its limitations. The method is limited to larger projects with considerable budgets. It demands expensive material and specialized personnel. The recording procedure can be learned with a few weeks of practical experience with good guidance.(Jones 2009, p.114) Indoor recording facilities are required, for individual timber recording, but the FaroArm can also be used as the main recording tool in the field. Excavation projects from the Netherland Institute of Maritime Archaeology shows the potential of using the FaroArm in the field in dry excavations.

The reconstruction of the shape of the Oseberg Ship in Oslo is another example of a project based on digital recording. The Norwegian Viking Age ship was in 2006 recorded using digital scanning. The research project was carried out in corporation between the in 2004 established organization "Stiftelsen Nytt Osebergskip", (Organisation New Oseberg Ship) Kulturhistorisk Museum Oslo University and the Viking Ship Museum in Roskilde.(Bischoff et al. 2007)

Two scans in different resolutions were carried out on the ship, one high resolution photo-scan for details and carvings, and a lower resolution laser-scanning for the complete ship. From the scanning a vector drawing of the ship was created. The recordings were then the basis for a cardboard model, build in scale 1:10. 2D drawings of all the ships starboard planks were made from the 3D model. The 2D prints were glued on cardboard and cut out. The reconstruction team was able to redefine central parts of the ships hull lines by using drawings of the ships implements from research in the first decade of 20th century and from the 1950s together with the new digital recording and a continues inspections of the ship. The new reconstruction process made it possible to answer a number of questions that has been subject to much debate since a full-size reconstruction of the Oseberg Ship capsized during test sailing in 1988.(Bischoff et al. 2007, p.34) The reconstruction is also a central part of the basic research before a possible full reconstruction of the ship.

Some reconstruction projects have been made without any amount of archaeological material available but are solely based on principles of contemporary ship architecture. The Mayflower by William Baker and the Susan Constant by Brian Lavery are examples of such approaches (Baker 1983; Lavery 1988).

The problems and the conditions for such reconstructions is that you do not get much closer to the specific ship that is the supposed subject of the study. What is gained is an ideal ship defined by the treatises of roughly the same dimensions as the original. The problem is that two ships of the same overall dimensions can be very different from each other not only in shape, but in capacity, sailing abilities and individual constructional solutions and details.

From manuscripts the ideal form of a vessel can be found, but the ideal rarely corresponds to reality an as such it has difficulties of bringing new knowledge to the research. Also the manuscripts leave plenty of interpretation to the reconstructor. Such reconstructions can be good practice to understanding of the manuscripts but are problematic in terms reconstructing complete ships without other sources available. This is also discussed in the chapter on historical sources.

This is only a minor review of possible ways to deal with shipwrecks and reconstruction. There are many other approaches that can be taken ever depending on the environmental, financial circumstances, time limitation and available skills. Furthermore no single method would cover all aspects in any given case, and the research method therefore has to be carefully chosen to suit the many different possibilities and limitations of the specific project. The optimal solution is found in the ability to have a variety of tools that can be combined in different ways to overcome as many obstacles as possible

2 Background

2.1 English written sources and manuscripts on 16th century shipbuilding

As ship technology evolved the demands to the specialized shipwright changes. Increasingly complicated techniques of predesigning ships made it necessary to change the passing of knowledge on shipbuilding from an oral and practical way of transferring skills, to a partly literate tradition. The mathematic and geometrical approaches are indicators of the general search for scientific methods to control the nature in the period of the renaissance. It is argued that there was a noticeable absence in the contemporary particular English material of technical literature on shipbuilding in the renaissance, and that the development in the field only slowly picked up pace compared to for example the closely related literature on navigation.(Tebeaux 2008, p.4)

For many research subjects, there will be no such things as contemporary written manuscripts describing the processes of building ships. In these cases the only evidence is the archaeological remains and maybe some iconographic sources that is problematic for reconstruction purpose. In fact this is the case for the majority of shipbuilding history. Not before the late period of medieval Europe and the early renaissance such manuscripts exists.(Friel 1983, p.42)

In the fifteenth century the first books on shipbuilding was written in Venice. The principles in the works were based on geometrical proportions between the ships dimensions and mainly focused on visual presentations. Later works would focus more on explanatory texts.

The absence of early English manuscripts on shipbuilding should partly be explained by well established traditions of shipbuilding were not challenged to a large extend before late fifteenth and early sixteenth century where the carvel construction technique was taking over from the clinker building tradition.

The first English printed books on shipwrightry appear after 1650. The knowledge that was orally passed from master to apprentice through generations is general conservative in its nature, but it did not stay unaltered by the technological progress and new inventions. The oral tradition still prevailed to the late seventeenth century. The specialized knowledge was carefully guarded by the shipwright so it would not fall in to the hands of competitors.

All the manuscripts are dealing with the technology of pre-erected and semi pre-erected framing technique and flush planking, none of them touches upon the clinker tradition. The historical sources are only dealing with the “new” or modern technique. But what happened in technological developments of the major navy dockyards were not necessarily followed simultaneously in smaller private commercial dockyards where experimenting with new technology could be a costly affair.(Adams 2003, p.161)

Following the principles of one of the manuscripts, the presence of one known variable makes it theoretically possible to reconstruct a whole ship. The variable could either be the length of the keel, depth or the beam of the ship. There are several manuscripts all containing variations and different principles, derived from the traditions followed by the shipwright and each approach will create a different ship.(Adams 2003, p.126) Before applying the principles of the manuscripts to an eventual reconstruction, it is necessary to find the relevant rules via the archaeological material and not find the ship from possible irrelevant principles.

Beside these reservations the manuscripts are highly relevant for the process of reconstruction. If it can be proven to some certainty that the construction of a ship follows a particular set of principles known from the manuscripts, there is the possibility to reconstruct missing parts and the shape of the ship with relatively great accuracy. The texts on shipbuilding that is given attention in this case are dated between 1570s and 1670s and they do all have English origin.(Adams 2003, pp.132-134) The earliest manuscript is partly contemporary to the construction date of the Princes Channel ship.

Fragments of Ancient English Shipwrightry is a manuscript written in the period from around 1570 to ca. 1630 by Elizabeth I.´s shipwright Matthew Baker. It was the first English manuscript on the topic. Baker was born in 1530 and his father James Baker was a shipwright serving under Henry VIII, Elizabeth´s infamous father.

In 1572 Baker was appointed royal Master Shipwright at the newly developed dockyard at Chatham. Matthew Baker is seen as the main author of the manuscript but in fact a second person worked on the manuscript. At some point the manuscript was handed over to Bakers successor who worked on it until around 1630. (Barker 1986)

Baker's ideas and new approaches to shipbuilding played an important role in the renewing of the English fleet, forming the foundation of the British superior power at sea. (Blatcher 1989, p.155) From study travels in his youth, Baker had learned about shipbuilding of Mediterranean traditions and methods used in Genoa and Venice. Ideas from these foreign shipyards influenced him in his later works. Matthew Baker had a mathematical and geometrical approach of detailed designing a ship in all its aspects before it was build. The mathematical and geometrical designing of the ships is a brake with the earlier traditions of ships being designed basically in the process of construction. In that case the outcome of the ship is resting on the shipwrights skills as a craftman and his ability to control the lines of the hulls from his eyesight. This was new to North European shipbuilding but widely used in the Mediterranean, especially to Venetian shipbuilding. Baker did not simply copy the Mediterranean shipbuilding, but only the approach of the predesigned hull. According to Baker himself there are clearly other things to shipbuilding than pure mathematics and geometry.(Barker 1986, p.168)

Great changes in shipbuilding had already happened since Matthews farther had started in his trait. The loss of the great warship *Mary Rose* had turned much attention in how to arrange the gunnery of the ship. With the new design the shipwright sought to prevent the heavy cannons from tipping the balance of a ship and maybe leading to capsize. Also the method of construction of the hull had recently undergone a change from a tradition where even the largest vessels were clinker build, to carvel constructed hulls. The carvel build hull was stronger and the construction more fitting for supporting the gun ports in the ship side. (Blatcher 1989, p.157)

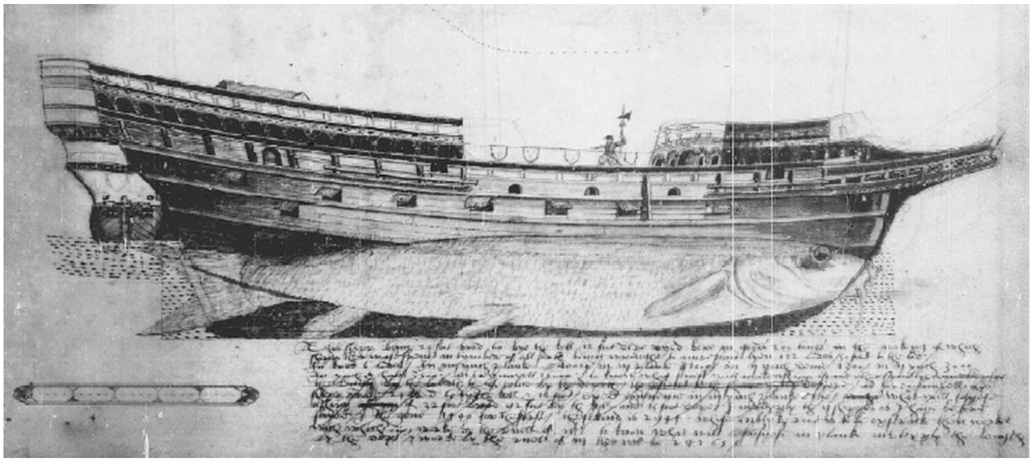

Figure 2-1: the shape of the bottom of a ship illustrated by the head of a cod and the tail of a mackerel.

Matthew Baker's skills were both theoretically and practically founded. He definitely had a mathematical theoretical education, but years at sea and working as a carpenter also contributed to his superior skills as a shipwright. The reinventing of the warship from being a mobile fighting platform at sea to mainly being a ranged weapon relying on the firepower of its cannons as well as speed and maneuverability is also clearly demonstrated in the manuscript.

The manuscript explains a method of designing the midship section of a ship that consists of a series of arch tangents. Both a four arch method and a three arch method are described by Baker. The manuscript contains several plots and calculations for unknown ships together with geometric drawings of hull sections.

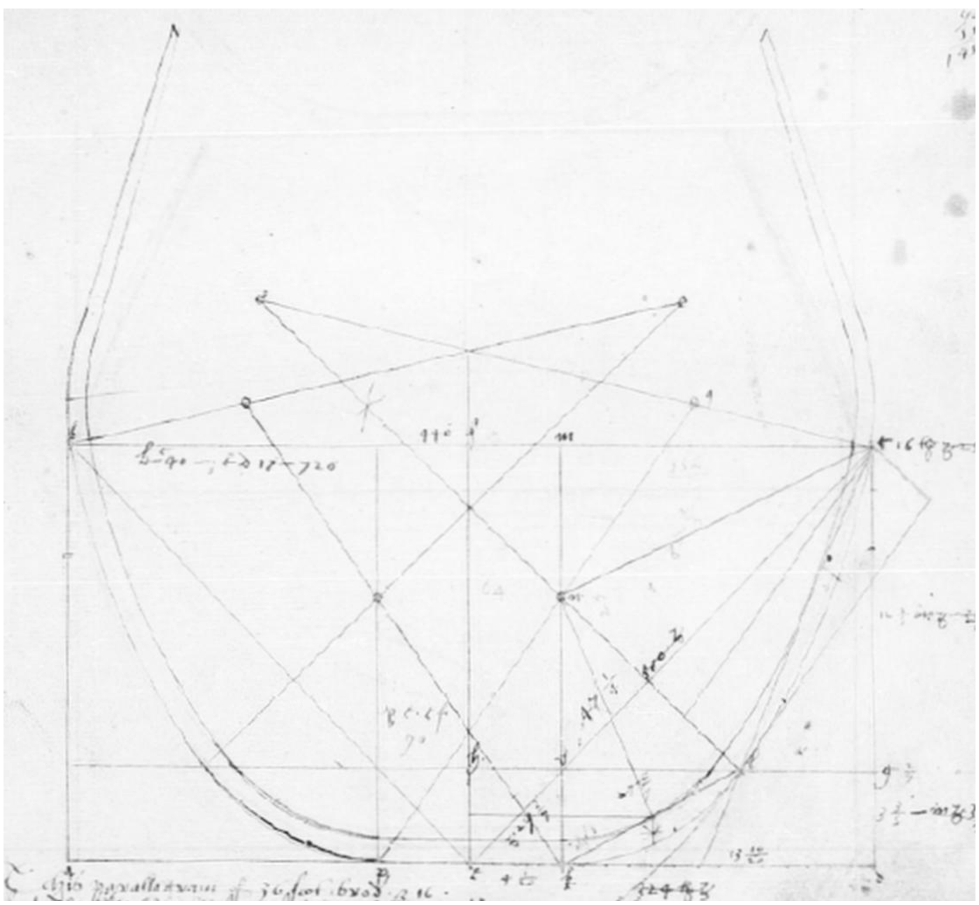

Figure 2-2: Midship mould from *Fragments of Ancient English Shipwrightry*.

Several times Baker refers to rules of other shipwrights or from other regions of shipbuilding and then argues why his own design is better or more appropriate for a certain ship. The ships of Matthew Baker had an extended breadth/length ratio compared the design of contemporary shipwrigths and his ships were longer and narrower than what was usual at the time.(Blatcher 1989, p.163) Matthew Bake also presents a method of calculating tonnage of ships, a method that was used as the standard rule of English ships until 1630.

Fragments of Ancient English Shipwrightry started out as a presentation volume but was at some point turned into notebook form. It contains publication ready artistic illustrations as well as quick sketches, calculations and explaining text, but the manuscript was never made accessible to a wider audience.(Barker 1986, p.161)

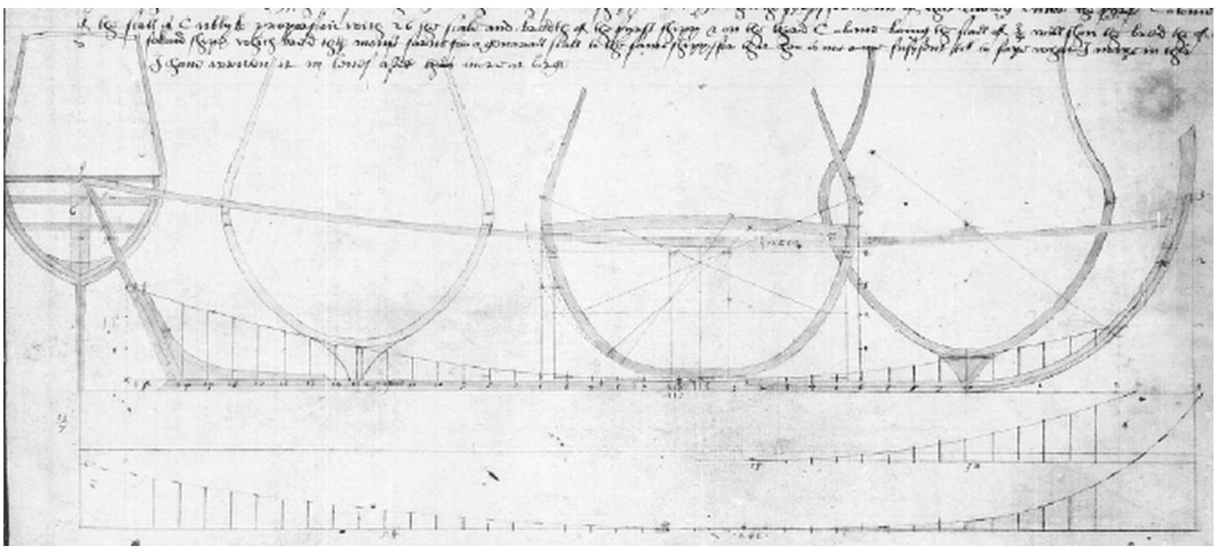

Figure 2-3: the predesigned frames erected on stations along the keel. From *Fragments of Ancient English Shipwrightry*.

A Treatise of Shipbuilding is written around 1620 by an anonymous author. Compared to *Fragments, A Treatise* is a rather compact text concentrating on the principles of ship dimensioning and proportions. It does not contain information that isn´t directly connected to the subject and is as such strictly composed.

In the case of *A Treatise of Shipbuilding* the central section of the ship is divided into sweeps of arches with different radius placed on appropriate places on lines deducted from the key dimensions of keel, width and depth. The manuscript mentions the issue of wrongly designed middle sections that eventually leads to furring of a ship (discussed in the section describing the furring on Princes Channel).

The lower hull of the middle section of a ship made from the principles of *A Treatise on Shipbuilding* is constructed from three sweeps of arches; the first sweep is called the sweep of the wrong head, the second is called the futtock sweep and the third is the upper sweep. The wrong head sweep is calculated from a perpendicular line from the extreme of the floor line, the place where the flat floor ends and the first curve begins. The suggested optimal proportion is one third of the hull depth and the difference between half the beam breadth and half the floor breadth. The depth is measured from the midship beam line to the upper edge of the keel.(Mainwaring & Perrin 1922, p.4) The example of calculation as given in the manuscript is as follows; the depth is 15´ 6´´, the difference of half the beam and half the floor is 13´6´´ added together is 29´0´´, 1/3 of that is 9´8´´. The center of the first radius must be placed 9´8´´ along the vertical axis from the floors edge to the beam.

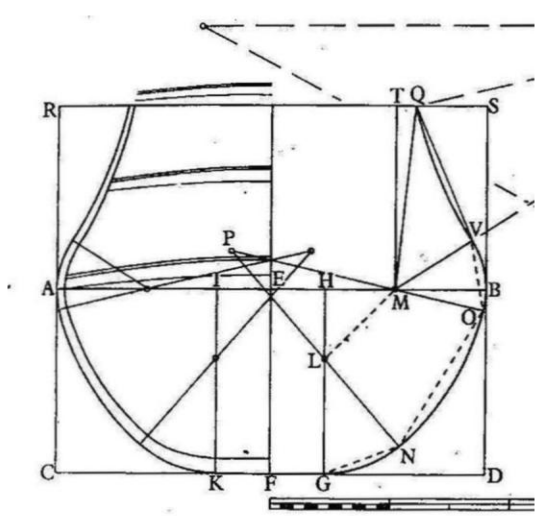

Figure 2-4: shows the sweeps of arches that makes out for the master frame. F-G is the width of floor. G-N is the wrong head sweep, N-O is the futtock sweep and O-V is the upper sweep.(Salisbury & Anderson 1958, p.17)

The futtock sweep includes the centre of both the wrong head sweep and the upper sweep. The lines from the centre of the futtocks sweep runs through the center of the other arches and connects them in the bend of the hull. The radius of the futtock sweep must be more than half the breadth and less than the whole breadth. The optimal proportion is 6/10 of the breadth. Of a ship 36´ broad the radius of the futtock sweep should be 21´8´´. The center of the radius is placed prolonged from the extreme of the wrong head sweep. The upper sweep or the breadth sweep must have its center along the breadth line; it can be equal to the lower sweep but not more. Commonly it is ¼ of the breadth but the optimal proportion is 15/19 of the wrong head sweep radius, in this case it is 7´8´´. The hollowing sweep of the upper hull should be similar to the breadth of the hull.

The description here is a simplification but summarizes the calculation of the central sweeps of the ships middle bend. After this the drawing of the arches is done by making a parallelogram based on the breadth, depth and the complete height of the middle section.

The arches described above represents the outside of the timbers and the inside must be drawn as well. Thereupon follows' the placing of orlop deck beam, gun ports and the upper decks until the middle bend is completed. Molds are then made from the middle bend that is used to create the rest of the ship´s framing. After the middle section has been designed the creation of a side view plan is explained, placing the keel, and the raking of the posts.

Dean´s Doctrine of Naval Architecture published in 1670 is an extensive and maybe the most important book on shipbuilding in the seventeenth century. This book is a clear example that naval architecture has moved away from the traditional safeguarded family knowledge and towards becoming a scientific discipline.(Tebeaux 2008, p.18) It mainly focuses on English naval ships and suggests a high literacy level of the people in charge of the building process. The literature is no longer easy readable pocket books for the shipwright or carpenter.

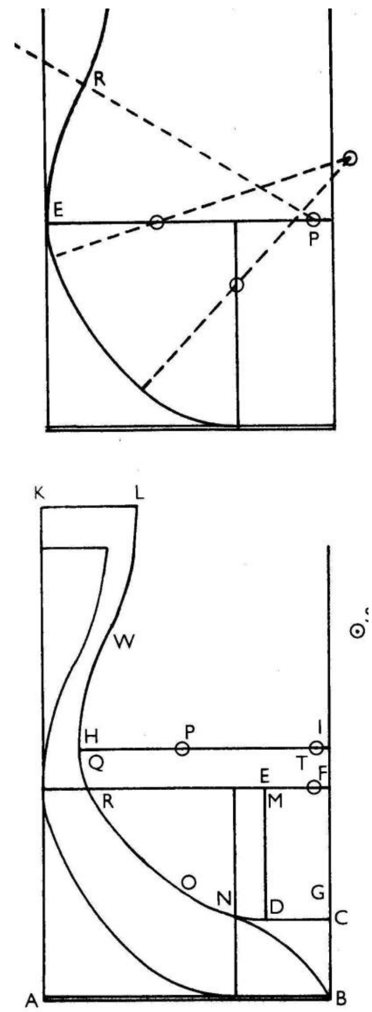

Figure 2-5: top: sweeping arches of master frame. Bottom: raising the moulds.(Lavery 1981, p.69)

The *Doctrine* is written about one hundred years after the construction of the Princes Channel ship and it is mainly concerned about naval ships where the ship wreck from Princes Channel is believed to be an armed commercial trading vessel. Why the *Doctrine* is still relevant for this ship is that it shows the "final" stage in a development from the traditional way of passing knowledge of naval architecture to the "scientific" mathematical approach that was to form the foundation of modern ship engineering. A development in English shipbuilding, which seems to have started with Matthew Baker who was building ships at the same time and region as where the Princes Channel ship was build.

Written sources with relevance, other than the ones shortly described above are shown in the table below.

Name of source	Period	Summary of subjects
Of proportions in building of Shipping, William Borough (Roberts 1998)	Ca 1600	Proportions for short chubby merchant vessels.
A Treatise on Shipbuilding. (anonymous) (Salisbury & Anderson 1958)	1600-25	Closely related to *Fragments of Ancient English Shipwrightry*. General rules on relations between length, depth and breadth and other proportions.
Sutherland: *Shipbuilders Assistant*	1711	Aspects on the whole-moulding technique. No source before Sutherland touches directly on whole molding.
Fragments of Ancient English Shipwrightry, Matthew Baker (The Pepysian Library MS. 2820) (Barker 1986)(Barker 2003)	Written between1570s and 1630	Geometrical rules of correspondence between ships dimensions.
The Compleat Ship-Wright, E. Bushnell (Barker 2003)	1664	Describes the two-arc method. Instructions in basic geometry of shipbuilding.
The Compleat Modellist: Shewing the True and Exact Way of Raising the Model of Any Ship, Thomas Miller:	1676	Building ships from models and principles of rigging.
Deans Doctrine of Naval Architecture, Anthony Dean (Lavery 1981)	1670	A scientific mathematical approach to ship design.

Table 2-1: table of written English sources on the subject of naval architecture in 16th-18th century.

The Princes Channel ship is closest in time and context to Matthew Bakers *Fragments of Ancient English shipwrightry* and it would therefore be tempting to assume that the methods used to build the ship could be similar to those of the manuscript. This is a hypothetical statement that maybe the model reconstruction can help us confirm or reject. Unfortunately the manuscript is not published in its full extend and is therefore only limited accessible. A publication of *Fragments* would be great contribution to ship research of this particular period.

Other historical sources for shipping in the 15th and 16th century are inventory lists and taxation documents from harbor authorities. These lists and documents concentrate on goods and movable equipment and rarely reveals anything in detail about the ships construction and are therefore only of limited value for reconstruction purposes.(Friel 1983, p.43) The lists are though very usable for reconstructing the rigging of ships since that part is rarely preserved in the archaeological evidence, but the components are mentioned in the inventory lists.

Iconographical sources are also problematical in terms reconstructing specific ships but might be helpful to get an insight of the contemporary layman's conception of ships. The iconographical material needs to be divided in two different groups. The first group consists of picture made by artists with out particular knowledge of ships and where the ship is a symbolic figure and maybe not the central subject of the image.

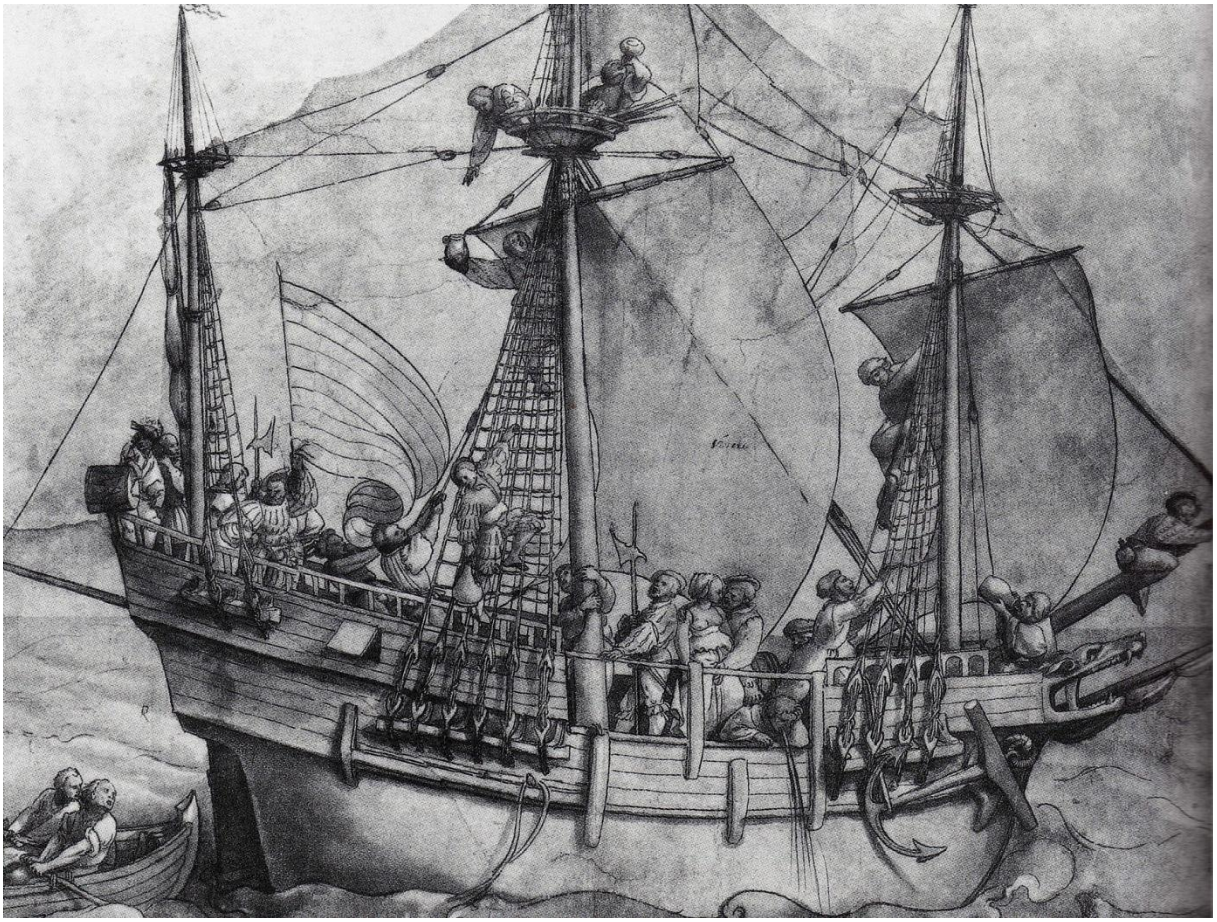

Figure 2-6: soldiers and sailors onboard a ship. Pen drawing from 1532 by Hans Holbein the Young. (Bill & Rieck 1997, p.236)

The second group is more closely related to the scripts mentioned above. Here the intention is explanatory and tutorial for the shipwright and his pupil. From the viewpoint of reconstruction the latter is the most interesting of the iconographical material. Here the dimensions are proportional and it is the ship as a structure that is in focus. Such illustrations can be helpful when for reconstructional purposes and when trying to understand how a ship was designed. Most of these early technical illustrations are part of the literate presentations on shipbuilding.

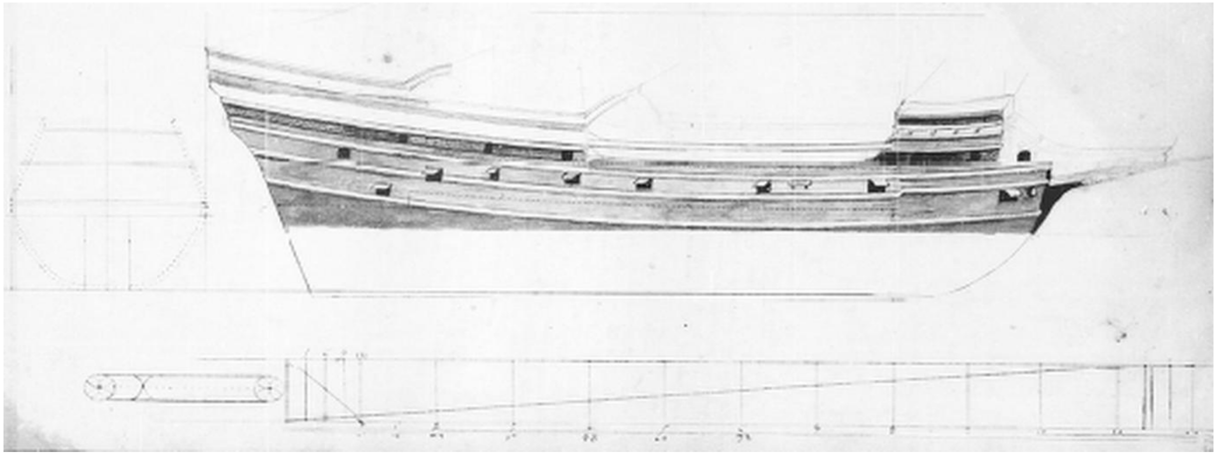

Figure 2-7: illustration of a hull from *Fragments of Ancient English Shipwrightry*.

2.2 Archaeological remains of shipbuilding traditions in the Atlantic region in the 15th – 16th

To find comparable archaeological material for the Princes Channel Ship the search has to be expanded to regions outside of British waters. Contemporary ships from different European shipbuilding traditions need also to be looked at. In this case namely Atlantic Iberian ships and ships from the Netherlands give us the best comparable material. There are some known contemporary British vessels of similar size to the Princes Channel Ship, but in general comparable archaeological material is very sparse. Most research on shipbuilding and naval architecture concentrates on large naval ships and not so much on the smaller and medium sized trading vessels like the Princes Channel Ship.

2.3 Iberian-Atlantic tradition

The Princes Channel Ship has from early after its appearance been linked to the Iberian-Atlantic tradition, and this calls for an explanation. The Atlantic Iberian building tradition is formulated as a series of constructional characteristics.(Oertling 2001)

The method is thought to be wide spread building tradition of the Atlantic coast with its origin in the Mediterranean, more specific in Genoese or Venetian ship building. The concept of building from molds is depending on building frame first. The frames constitute a series of cross sections that is determined by the master frame. With the Princes Channel ship there is an opportunity to compare the Biscayan ship building technique with that of the contemporary English tradition.

The concept of whole-molding is not completely clear. Some places it means that the whole midsection of the ship is created by one mold, in other occasions it is the complete hull that is based on one master mold created from sweeps of arches.(Oertling 2001) The Mary Rose has in the literature been used as archaeological comparison to the Iberian tradition. It should be mentioned that Biscayan and Iberian tradition is not defined by any particularly difference, but must in fact be viewed as the same. (See fig.11 below for Oertlings characteristics on Atlantic vessels.)

In the Atlantic Iberian tradition it is possible to present largely contemporary vessels with the Princes Channel Ship. The Studland Bay from Dorset in England is described as a vessel of the Atlantic Iberian tradition. Finds from the site dates the ship to the first half of 16th century and suggest an Iberian origin. There are no successful dendrochronological samples to give a more certain place of origin and date, and the conclusion of Iberian origin from the various pottery found on the site is problematic, but the regularity of the framing pattern resembles that of the Iberian tradition. Frames aft of the mast step are constructed so that the first futtocks are connected on the aft side of the floortimbers and for of midship the futtocks are connected to the forward side of the floortimbers. This pattern is one of the key features of the Atlantic Iberian tradition.(Thomsen 2000, p.72)

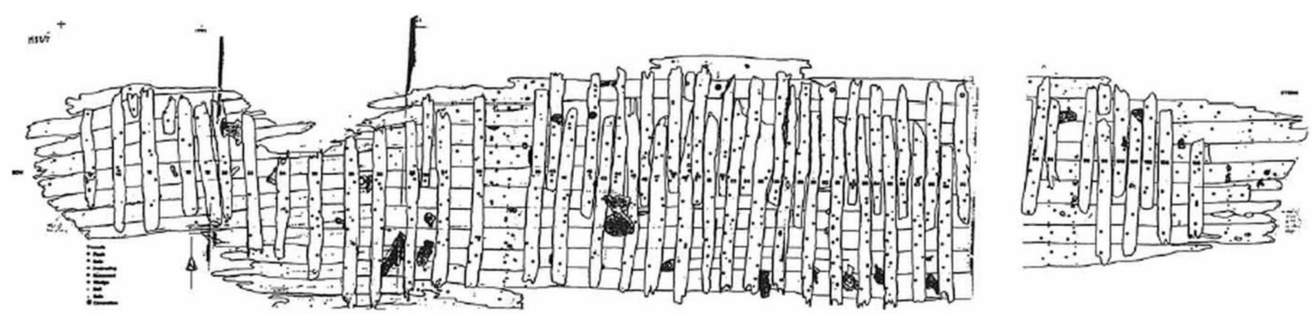

Figure 2-8: drawing of wreck site in Studland Bay. (Thomsen 2000, p.74)

The overall dimensions are close to what is expected of the Princes Channel ship approximately 22-25 m long and 7m wide. There are similar problems in reconstructing the Studland Bay wreck as to reconstructing the Princes Channel ship. A large piece of the starboard side is preserved but it fails to connect to the bottom part of the ship since none of the first futtocks has survived. A reconstruction of the hull shape has been made from contemporary treatises that made it theoretically possible to place the large side piece relative to the bottom part.(Thomsen 2000, p.80) Luckily the Studland Bay Wreck has a large piece of the keel, floortimbers and bottom planking preserved, that give important information on the overall dimensions. The sternpost assembly is only partially preserved, but enough to establish the original rake of the sternpost.

A Basque whaling ship from the 16th century that was found in the harbor of Red Bay in Labrador is another example of a ship of the Iberian tradition. The ship is identified with the galleon or naos *San Juan* that sank in 1565 and is with this dating the oldest European vessel found in America north of Florida. The ship had a keel length of 14,73m and a deck length of 22m. The Red Bay wreck is extraordinary well preserved with both the stem and sternpost almost fully intact. A large part of the hulls starboard side is also preserved.

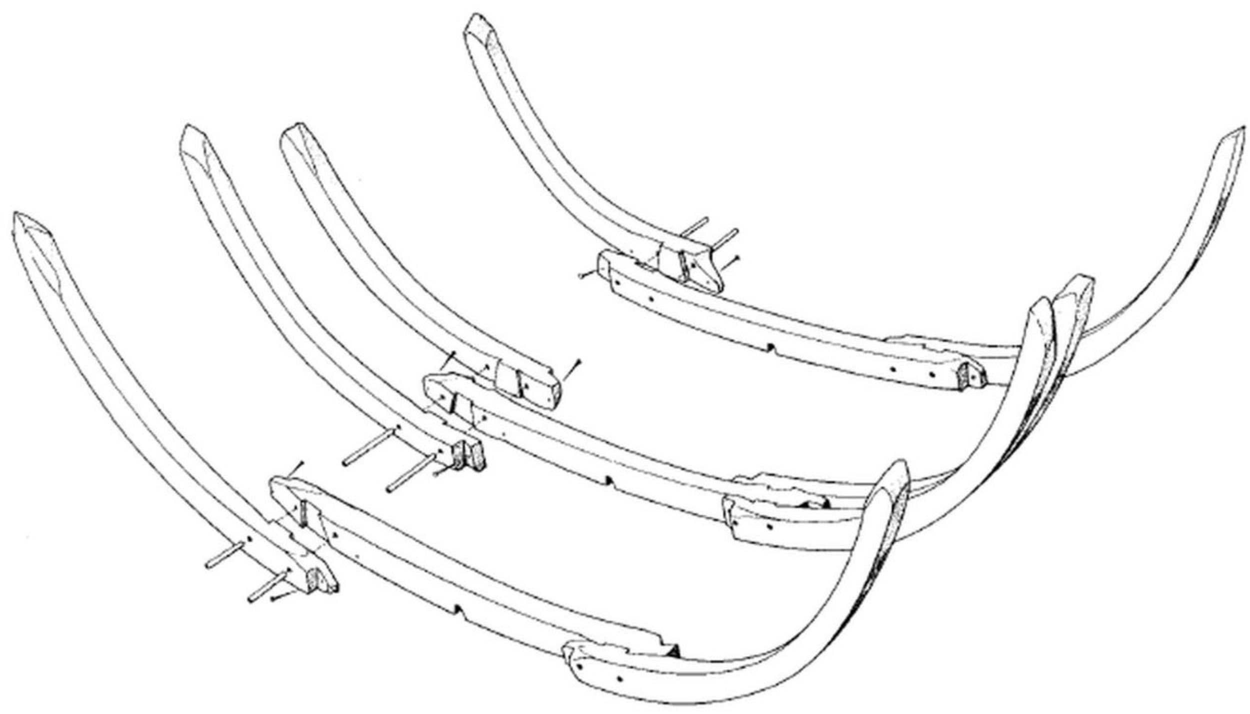

Figure 2-9: exploded view of the central framing of the Red Bay Basque whaler. (Grenier 1998, p.277)

A significant feature of the Red Bay wreck is that it is equipped with a carved keel with integrated garboard strakes.(Grenier 1998, p.276) The floortimbers are sandwiched between the first futtocks in a tight lock of dovetail joints and secured with treenails and iron spikes. The complete flat transom of the stern is also preserved, with planks in a diagonal pattern. The regularity of timbers and fastenings reveals high quality materials and craftsmanship.

A heavily armed wreck found at the Molasses Reef in the Turks north of the Hispaniola is believed to be the oldest European wreck found in the New World. It probably sank within the first twenty years after Columbus' discovery of America. The wreck was sparsely preserved and had also been vandalized by treasure hunters before research began in 1982. Only a few planks and fragmentary pieces of the framings first futtocks have survived. Ceiling planks and the pattern of filler pieces between the futtocks is a feature that the Molasses Reef wreck shares with the wrecks from Red Bay, Cattewater and Highborn Cay. (Oertling 1989b, p.232) The futtocks are joined to the floor timbers with dovetail joints fastened with two treenails and two iron nails, but the male part of the join was on the floor timber and the female in the futtock, exactly opposite to the other three wrecks. In size the Molasses Reef wreck is closest to Highborn Cay wreck dating to early 16th century. Both are relatively small vessels, around 19 m long and less than 6 m in beam.

The Highborn Cay wreck is much better preserved than Molasses Reef wreck. The complete length of the keel and the width of the floors could still be observed during the excavation of the wreck. These measurements were the key figures for reconstructing the basic dimensions of the ship from a contemporary manual on shipbuilding.(Oertling 1989a, p.250) The reconstruction was made with awareness of the problems in using the manuals fixed formulae of dimensions and can only be assumed to be ideal relative dimensions and lines rather than the actual ships measurements.

The B&W 7 dating to 1575-1600 is a medium sized vessel build frame first with dovetail joints between floortimbers and futtocks. The aftermost preserved fragments of the framing show, that in the aft of the hull the floortimbers and futtocks were not joined. The B&W 7 is described as being build after an Iberian tradition but showing local or regional variations. (Lemée 2006, pp.271-82)

The Iberian-Atlantic ships from the 16th century are interesting comparable material for the Princes Channel ship, but the main conclusion from the comparison is that the ships belong to different variations of the building tradition. The sequence of construction is the same, with preerected master frames placed on the outlaid keel and secondarily planked fastened with treenails and iron nails at the plank ends. One of the main differences is the character of the framing. The regular framing and fastening pattern of floor timbers and futtocks of the here mentioned Iberian-Atlantic vessels is not found in the Princes Channel ship. The framing corresponds more to the much larger ship from Villefranche dated to early 16th century and is most likely of Genoese origin.(Steffy 1994, p.134) The fastening of frame elements is done with lapped dovetail or knuckled joints and held together by diagonal horizontal nailing. The midship frame of the Villefranche is constructed in similar way as the Iberian-Atlantic vessels mentioned. Futtocks are attached to both sides of the floor timber but the ship is general ascribed to the Mediterranean building tradition, which also influenced English shipbuilding as shall be touched upon later. The Atlantic-Iberian tradition is not a strictly homogeneous building tradition, but forms a general outline of construction and contains variations of constructional solutions. Not all characteristic is necessarily included in a ship of this tradition.(Oertling 2001, p.234) The terminology and key concepts of the Atlantic-Iberian tradition is well established in the research of renaissance shipbuilding, but the variation in the archaeological material forcefully insists of different branches in the tradition but that is a subject that needs further research elsewhere.

	Criteria of Iberian-Atlantic ships	RY	SJ	PI	HC	MR	CW	ST	EP	RA	WL	SJ	AG	NS	CD	CS	BW7	PC
1	Pre-assmbled central frames,dovetailed mortises, transverse nails	-	-	-	Y	Y	Y	Y (1)	Y	Y	Y	-	Y	Y (3)	Y	-	Y	Y (1)
2	Planking spikes: Treenails per Plank/frame join at midship	0:?	2:2	Stern 2-3:0	-	2+:2	2:2	2:1-2	2:1	2:1	?	3:2	?	2:0	2:0	Stern 2:1	-	2-3:2-3
3	Sternpost scarfed To upper arm	-	Y	Y	-	-	-	Y	N	Y	Y	-	?	-	-	Y	N	-

	of keel knee																	
4	Single stern deadwood knee	-	Y	Y	-	-	-	Y	Y	Y	Y	-	?	-	-	Y	N	-
5	Crook timbers notched to deadwood	-	Y	Y	-	-	-	N	Y	N (4)	Y	N	Y	-	-	Y(4)	-	-
6	Keelson notched over floortimbers	Y	Y	-	Y	-	Y	?	Y	Y	Y	-	Y	-	-	-	-	-
7	Mast step is expanded part of keelson	Y	Y	-	Y	-	Y	?	Y	Y	Y	-	Y	-	-	-	-	-
8	Buttresses and stringers	Y	Y	-	Y	-	N	?	Y (5)	Y (4)	Y (4)	-	Y	-	Y	-	-	-
9	Ceiling and filler boards	Y	Y	-	Y	Y	Y	Y	Y	N	Y/ ?	-	Y	-	Y	-	Y	Y
10	Rigging chain assembly	-	Y	Y	Y	Y	-	Y	?	N	?	Y	-	N	N	-	-	-
11	Flat transom, sternpost proud of stern panel	-	Y	Y	-	Y	-	Y/ ?	N	N	Y	-	Y	-	-	N	-	-
12	Carved garboard	-	Y(2)	Y	-	Y	N	N	-	N	?	-	?	N	-	Y(6)	-	N

Table 2-2:wrecks compared to characteristics of 16th century Atlantic vessel. (Oertling 2001) Updated with B&W 7 (Lemée 2006, p.278) and with the Princes Channel ship.

Identification Key for figure 3	
- Information not available (portion of the wreck was either not preserved or not found. **? Information was not recorded, but could be recovered later** **Y/N yes/no** **RY Vessel A, Rye Sussex** **SJ San Juan, Basque whaler from Red Bay, Labrador** **PI San Esteban of 1554 New Spain Fleet, Padre Island, Texas** **HC Highborn Cay wreck, Exumas Island, Bahamas** **MR Molasses Reef wreck, Turks & Caicos Island** **CW Cattewater wreck, Plymouth, England**	ST Studland Bay wreck, Poole, England EP Emanuel Point wreck, Pensacola Bay, Florida RA Ria de Aveiro wreck, Portugal WL Western Ledge wreck, Bermuda SJ St. John's Bahamas wreck, Bahamas, BWI AG Angra D wreck, Azores NS Nossa Senhora dos Matirez CD Cais do Sodré wreck, Lisbon, Portugal CS Corpo Santo wreck, Lisboan, Portugal BW7 B&W 7 wreck from B&W site, Copenhagen, Denmark PC Princes Channel ship, Princes Channel, Thames Estuary, England.
(1) Although not always dovetailed, the floor and futtocks are scarfed together and fastened transversely (2) San Juan Possessed an unusual carved keel which had a T-shaped profile at midships and a V-shaped profile at its ends obviating the need for a garboard	(3) The mortises in this case are not dovetailed in to the frames (4) There are no notches; frames are toenailed into the deadwood (5) In this case the buttresses do not touch the stringers (6) The garboard has a carved top internal edge

Table 2-3: explains abbreviations of the previous figure.

As seen from the table it is only possible to answer positively to two of the Iberian-Atlantic characteristics listed, several are unfortunately left unanswered because of the preservation state. The characteristics are largely worked out from the bottom structure and around the keel. This is due to the general preservation of archaeological wrecks where it often only these parts of the hull that remains as archaeological evidence.

2.4 Dutch shipbuilding in the 15th and 16th century

The oversea activity of the Dutch East India Company (VOC) resulted in a significant technological development in Dutch shipbuilding that was to influence European ship technology in centuries. The Dutch shipbuilding tradition that developed in the 15th to 17th century was combinations of local and foreign traditions forged to new ships optimized for the new purposes.

Spanish, Portuguese, French and English shipbuilding technologies influenced on the local traditions and formed the foundation for the success of the VOC.(Duivenvoorde 2008, p.14) The method of flushed laid planking was present in northern and western Europe the centuries before this period, expressed in the flat bottom of the cog. In the late fifteenth century the flush planking was extended above the bottom section of the ships, but the complete frame based method of construction including the preerected master frames was not necessary for the Dutch carvel build ship. An archaeological example of this is the B&W 5 dated to around 1630 which evidently shows a method of construction where the framing is build up together with the planking of the hull.(Lemée 2006, p.174)

The earliest archaeological evidence of the carvel-plank technology in the Netherlands is a fishing vessel dated to 1570 but historical sources mention carvel build ships from 1439. Carvel planking became increasingly used for ocean going ships but did not completely replace lapstrake planked ships.

The traditional Dutch shipbuilding was a bottom based method that combined elements of shell-first and frame- first construction.(Duivenvoorde 2008, p.15) In this method the planks are held in place with temporary cleats while inserting the framing elements. Afterwards the cleats were removed and wooden pegs were hammered in the nail holes.

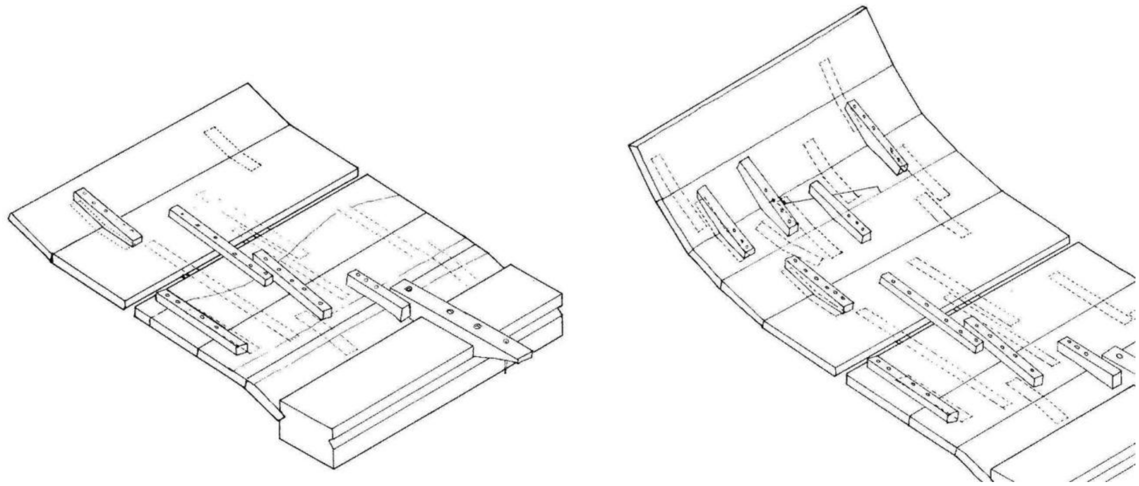

Figure 2-10: Shaping the hull by the use of temporary cleats.(Lemée 2006, p.172)

The method is not an intermediate state between shell-first and frame-first, but has been used in northwestern Europe since at least the Roman age. This method could support even large ship construction and it was therefore not necessary to adopt or develop new technology to participate in the race for oversea dominance.

In the 16th and 17th century the shipbuilding industry in the Dutch region had reached and enormous extent and exported finished ships and labor to the rest of Europe. In 1640 1000 ships were being built annually. For this production 2500 hectares of oak forest nearly 320.000 cubic meters of wood was needed each year. The import of wood and the invention of the wind-driven sawmill played important parts in the development of the industry (Duivenvoorde 2008, p.16)

The Dutch ships build bottom based did not have to be predesigned like the whole mold technology demanded. The shipwright would have a general idea of the ships finished shape and together with general rules of proportion and the dimensions demanded from the purchaser he was able to build the ship. No documents dealing with detailed ship construction before Nicolaes Witsen published *Aeloude en Hedendaagsce Scheeps-bouw en Bestier* in 1671 has survived to the present and probably the master-apprentice relationship carried the trait from generation to generation. Witsen is a scholar not a shipwright but he explains both foreign methods and the Dutch bottom-based method of construction. In contrast to the naval architects in England and France who had been experimenting with the designed whole mold construction of the Mediterranean tradition and writing documents on the method for one century and practiced in the Iberian region even longer.(Duivenvoorde 2008, p.35) No doubt the Dutch shipwrights knew about frame-first methods used in the surroundings countries.

Around 1650 the frame-based method was being introduced in the Dutch shipyards and the bottom-based and the frame based method were probably practiced side by side. By the 18th century the frame-based method was getting more established in all major shipyards in the Dutch region.(Duivenvoorde 2008, p.57) Cornelius van Ijk came from a family of Dutch shipwrights and published the book *Nederlandsche Scheeps-bouw-konst open gestalt* in 1697. Van Ijk describes the Dutch variation of the frame-first construction method. Here the garboard is attached to the keel before two identical master frames were erected. The first frame is placed on the keel, half the length of the hull plus half the length of the stem, measured from the stem. The second frame was placed one quarter of that distance further towards the stem. A main ribband was placed over the two frames and attached to the stempost and transom frame at deck level. More ribbands were then installed below the main ribband for determining the run of the strakes. The main ribband could be reused for other ships of similar size. A

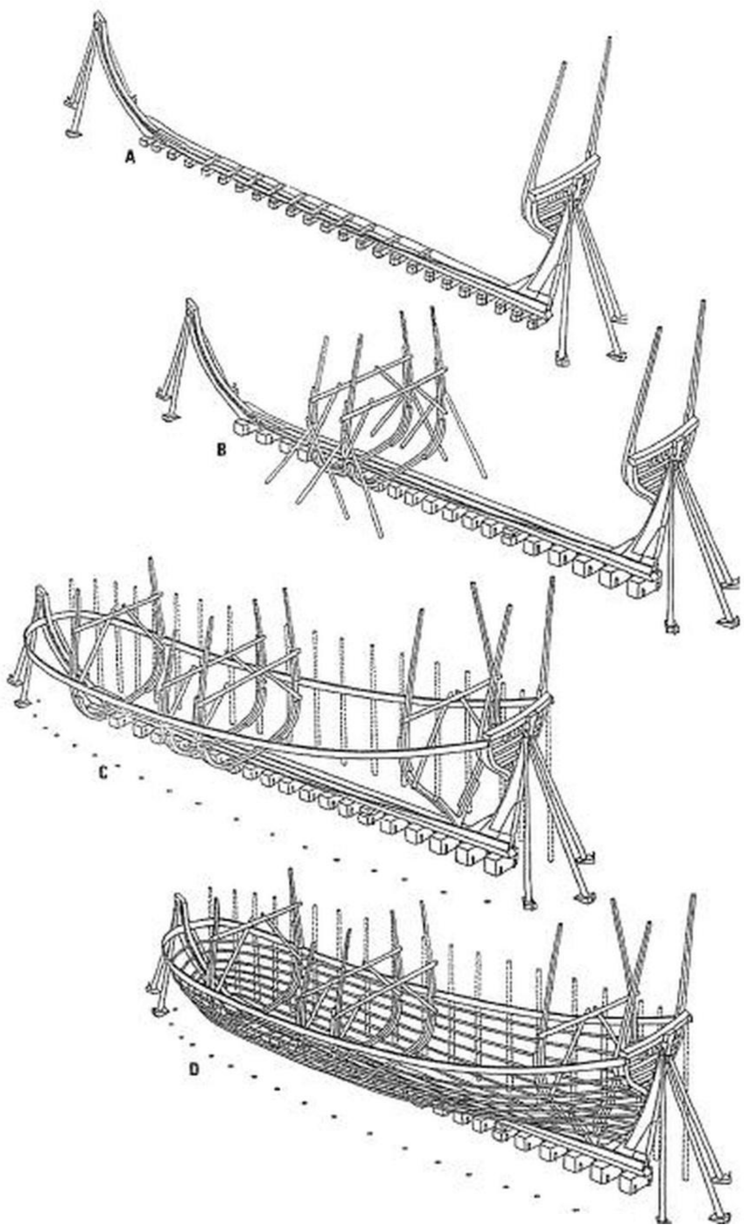

Figure 2-11 schematic drawing of Dutch frame-first construction technique as explained by van Ijk. (Duivenvoorde 2008, p.55)

closer description of how the frames were designed is not presented by van Ijk, but here the main factors for creating the shape was defined from the beam and depth dimensions of the ship and from the eye of the shipwright. Duivenvoorde argues that if the Dutch whole-mould was done partially depending on the eye of the shipwright, the bottom-based method must have done the same.(Duivenvoorde 2008, p.54) This contrast to some extend the more strictly designing of the frames known from the English, Iberian and Mediterranean manuscripts on shipbuilding. Whether the actual construction of ships always followed these formulas is debatable. Probably the eye of the shipwright was more involved than implicated in the manuals.

2.5 The English tradition

It is not clear exactly from where and when the first carvel ship came to England, but Genoese and Venetian traders regularly visited British ports since the 14th century. There are records of the Regent from 1489, the first large English warship build in this way.(Barker 2003, p.2) In 1511 the great ship Mary Rose was launched build with a carvel planked hull. The actual term, "whole-mold" is not registered before the 18th century, but what ever it was called in the early post-medieval period in England, the basic concept was the same.

There is no clear typology based on archaeological observations that defines English carvel shipbuilding in the 16th century. Most of what is known origins from the historical manuscripts on naval architecture, and maybe it is not the right approach to try and formulate an exact set of characteristics to define the English tradition of shipbuilding. Analysis of more archaeological evidence is needed to make a clearer distinguishing between possible different basic approaches to shipbuilding in the period.

Adams analysis of the bottom of the Sea Venture concludes a building sequence that is closer to the Dutch bottom-based method than the preerected master frame that is given in the Iberian-Atlantic tradition or even the methods explained in the English documents on shipbuilding.(Adams 2003, p.124) In the case of the Sea Venture the stem and sternpost is erected on the keel and the floor timbers are fastened to it. A ribband was then attached connecting the ends of the floor timbers, before the first futtock at each control frame was fastened to the floors. In comparison with the Dutch bottom based method the garboard strake and possible more strakes was fastened before placing the intermediate frames but it is not the planking as such that is shaping the ship. The first futtocks are not fastened directly to the floor timbers but are only overlapping or temporarily fastened. The planking would have provided support while the futtocks were positioned. The method of construction used in building the Sea Venture did not include a complete pre erected skeleton. Adams uses the term *frame-led* as opposed to skeleton build about the construction method. The latest research concerning the Mary Rose shows that it was build using a similar *stepwise* sequence as found with the Sea Venture. (Marsden 2009, pp.50-53) That the Sea Venture and the Mary Rose, build with approximately 100 years between shows a fairly similar building sequence, suggests that we might be looking at ships build within in a regional tradition. Despite the building sequence the ship was predesigned using geometrical-based rules that were probably brought to England by foreign shipwrights. Another possibility is that similar rules had been used for constructing large clinker build vessels prior to the carvel tradition.(Marsden 2009, p.51) Other examples of English 16th and early 17th century shipwrecks are only few and the remains only sparsely preserved. Thorough research of their building sequence is often not possible above the level of the floor timbers.

Site/Name and reference	Date and origin	Comparable features and comments
Studland Bay wreck (Thomsen 2000)	Early sixteenth century, suggested Basque, Iberian origin.	12,5 meter preserved keel. partially preserved hooked keel-stempost scarf, and partially preserved sternpost assembly. The sternpost rake 110º. Iberian framing pattern, but without the typical dove-tail joints. Semi-preframed construction.
Sea Venture (Adams 2003)	Build 1603. Lost 1609. Probably British.	Cross section of keel is close to what could be expected on Princes Channel, 15.5 m preserved and 18 floor timbers. Width of keel midship is 34,1-34,6 cm. suggested keel length 22-23 m. Horizontal keel-stem scarfs. Mainly treenail fastenings 33mm.
Alderney wreck (Roberts 1998) (McElvogue 1998)	Lost 1592, British origin	Sternpost rake between 105-110º Probably 16º/106º rake.

Sparrowhawk (Adams 2003, p.122)	Lost 1626	Somewhat smaller ship than P. C. The sternpost has survived.
Rye wreck (Goodburn 1990)	Very uncertain dating to late 15th century or later.	Only very fragmentarily preserved. Carvel-build small ship or large boat. Planks max 32cm wide x 6-7cm thick.
Warwick wreck (Adams 2003, p.123)	Lost 1619	No available material except a short summary in Adams 2003. Large parts of the ships side has survived, and future publication of the ship would probably be important comparison material for the P. C. wreck.
Cattewater wreck (Redknap 1984)	Second half of 15th century, unknown origin but usually ascribed to Atlantic-Iberian tradition.	Similar dimensions of planking to Rye. Lap-dovetail floortimber to futtocks fastenings.

Table 2-4: summarizing list of wrecks best comparable to the Princes Channels ship.

3 Description of the Princes Channel wreck

The wreck of the Princes Channel ship was discovered as two large wreck pieces. During recovery the pieces broke apart and were labelled as the pieces 1, 2, 3a, 3b and 4. One part was the bow section and the rest were parts of the port side of the hull. As an introduction to the anatomy of the ship the different parts will be described in relation to their position of the hull and what they consist of. The description is based on measures from the interim report from Wessex Archaeology and the archaeological records.(Auer & Firth 2007)

The Princes Channel ship contains a unique constructional feature that needs special attention. This ship is the first archaeological evidence on *furring*. Further this chapter will concentrate on the different constructional elements of the ship, dating of the timbers, technology and a tradition.

3.1 The concept of furring

To understand the unique anatomy of the Princes Channel ship an explanation of the concept of "furring" is required.

A major change of the ships shape was made when the planking was stripped from the side of the ship, from around the turn of the bilge and up. Additional timbers were then added on the outside of the futtocks and the planking was replaced. When stripping the planking from the ship, the lowest wale at the height of the orlop deck was left in place and mortises were carved out in the new framing to make space for the sandwiched wale. To make a smooth transition from the furring frames to the original frames for the planks to be attached on, a triangular plank was placed at the end of the furring frames for filling in the otherwise abrupt ending of the furring. The double framing widened the ship with approximately 30 cm on each side and in this way it was possible to change the shape and thereby also the ships sailing abilities.

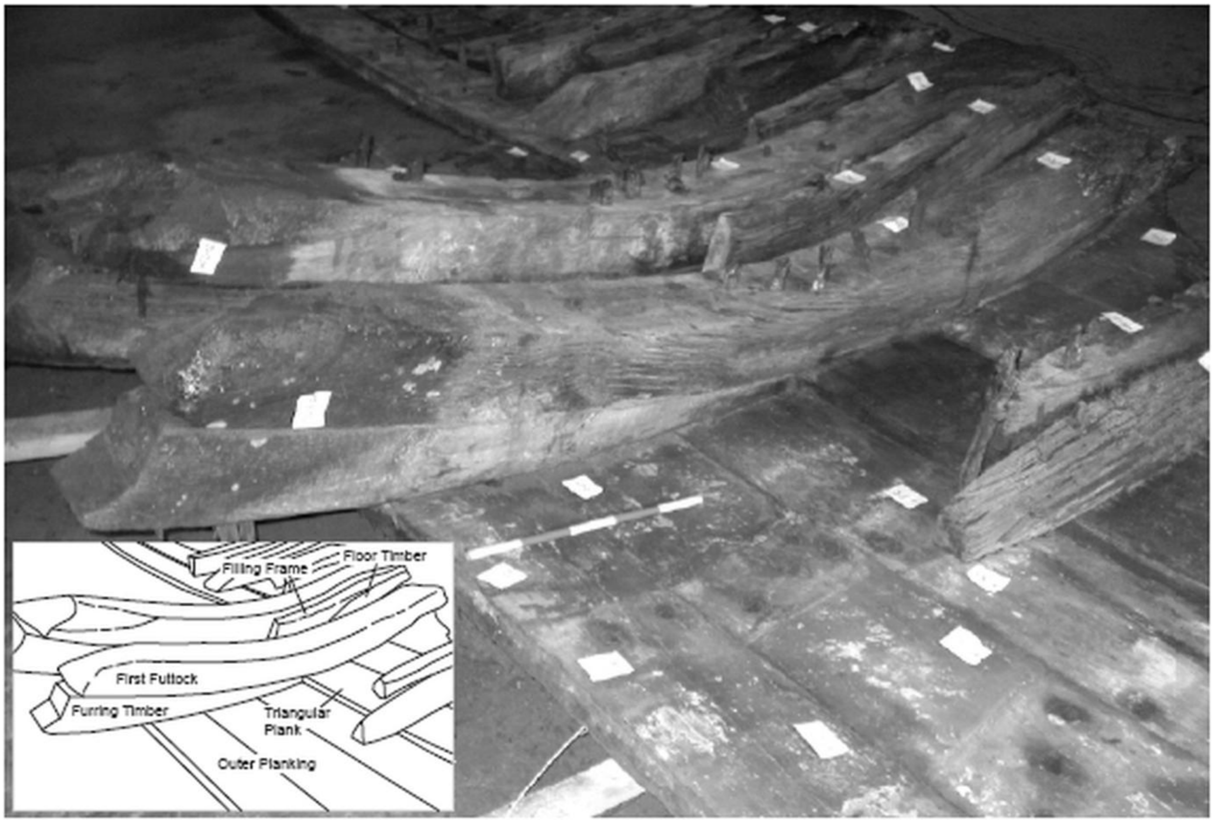

Figure 3-1:sketch showing the principal construction of the furring attached to the first futtock.(Auer & Firth 2007)

Previous to the discovery of the Princes Channel ship, little was known about the practice of furring. Only a few references in literate sources are known but the attention first came to this matter after it was established on the ship from Princes Channel. Furring is mentioned in Sir Henry Mainwaring's *Seaman's Dictionary* from composed in the early 1620ies and the description fits exactly on what happened to the Princes Channel Wreck:

The other, which is more eminent and more properly furring, is to rip off the first planks and to put other timbers upon the first, and so to put on the planks upon these timbers. The occasion of it is to make a ship bear a better sail, for when a ship is too narrow and her bearing either not laid out enough or too low, then they must make her broader and lay her bearing higher. They commonly fur some two *or three strakes under water and as much above, according as the ship requires, more or less. I think in all the world there are not so many ships furred as are in England, and it is pity that there is no order taken either for the punishing of those who build such ships or the preventing of it, for it is an infinite loss to the owners and an utter spoiling and disgrace to all ships that are so handled.*(Mainwaring & Perrin 1922)

From Mainwaring we learn that the practice of furring was, if not common, then at least widely known to English shipwrights, and that it was more common here than in other countries. The explanation of why it is done is also given. It is simply to widen the ship to lie higher in the water and be able to set a larger sail. He also mentions that it is a petty for the ship and a loss for the owner, but there must be a fairly good reason for the owner to let the ship undergo such an extensive rebuilding. Mainwaring's description would make one think that only poor sailing ships would be submitted to this kind of rebuilding.

Another explanation for the reason of furring is found in a *Treatise of Shipbuilding*. (Salisbury & Anderson 1958, p.16) The concept of furring a merchant ship after construction is mentioned in connection with the flat of the floor of the ships mid-section. "*Merchants covet to have great floors in their ships for gaining of stowage, but thereby they spoil the ship's bearing for most of them grow tender sided and after they are built come to be furred.* The construction flaw that led to the furring of the ship is from this text obviously related to the flat of the floor timbers in the ship. The flat of the floor is too wide compared to the curvature of the amidships bend. Both sources mentions that the ship is too narrow or tender sided, but only the treatise place it in relation to relative proportions in the design of the master frame.

Exactly when, in the serving period, the ship was rebuild is not certain, but it is possible that the default in the hull design was discovered and tried rectified after a test launch of the hull. Maybe with more dendrochonological samples this could be certified and help understand the rebuilding of the ship. The reconstruction might also be helpful to determine the reason for the furring of the Princes Channel ship.

3.2 The wreck pieces

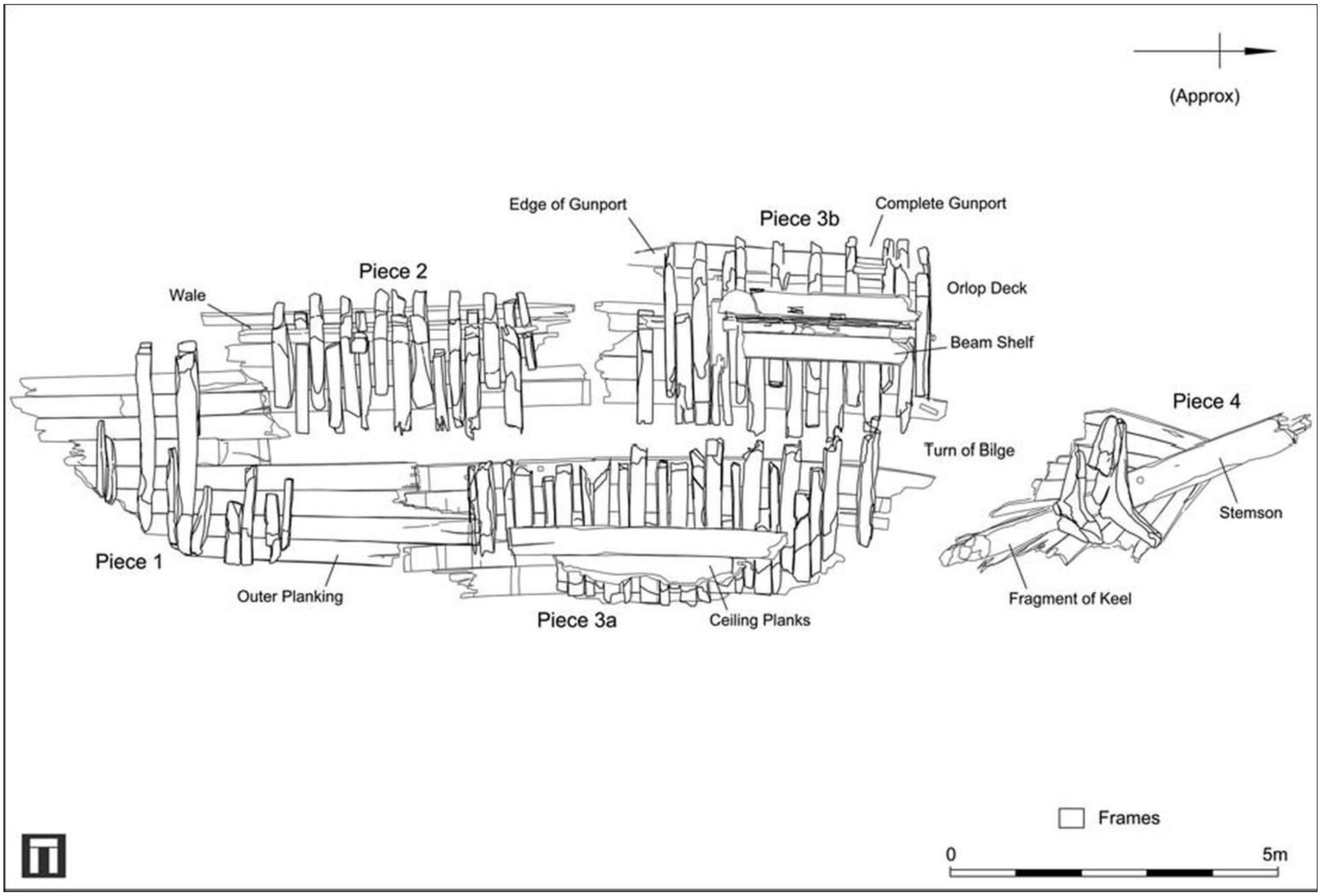

Figure 3-2: overview of the wreck site of the Princes Channel ship.(Auer & Firth 2007, p.6)

3.2.1 Piece 1

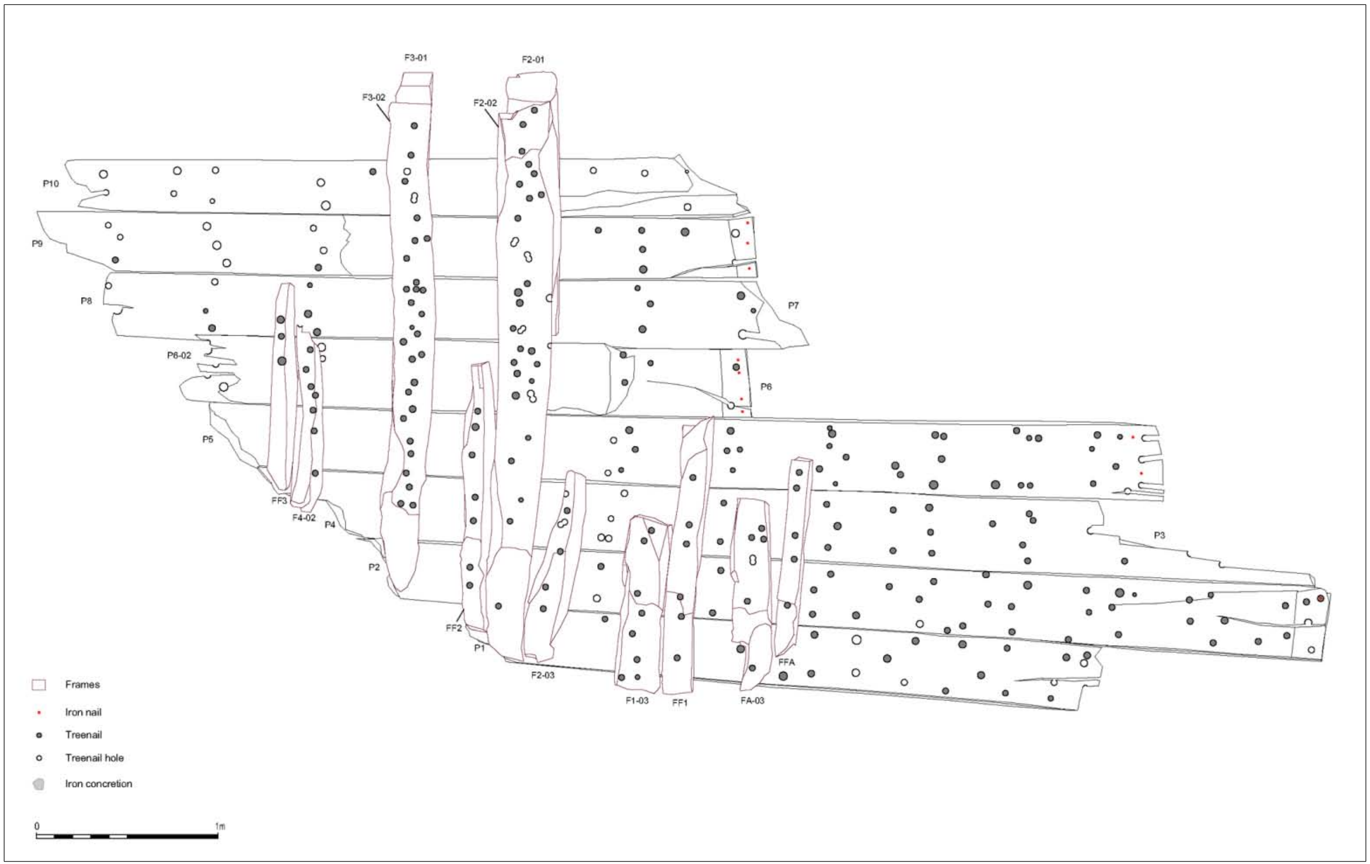

Figure 3-3:inside view of wreck piece 1.

This is the aft most preserved piece of the hull and it was originally connected to piece 2 but broke apart during lifting. The piece is 7,48m long and 3,4m wide. It consists of eight strakes that are held together by two upper fragments of floor timbers, four extensively preserved futtocks with attached furring timbers and several fragments of filling frames. Impressions on the inside of the planking reveal that additional five floor timbers and eight futtocks had been ripped from the planking. Two of the futtocks that were in place when the outside of the piece was recorded had fallen off when the inside face was recorded. The rising of the heads of the floor timbers shows that the piece was located near the stern and the steep rise of the futtocks also indicates this. The upper end of the futtocks and the furring frames had broken off where the original lower wale ran through the furring.

3.2.2 Piece 2

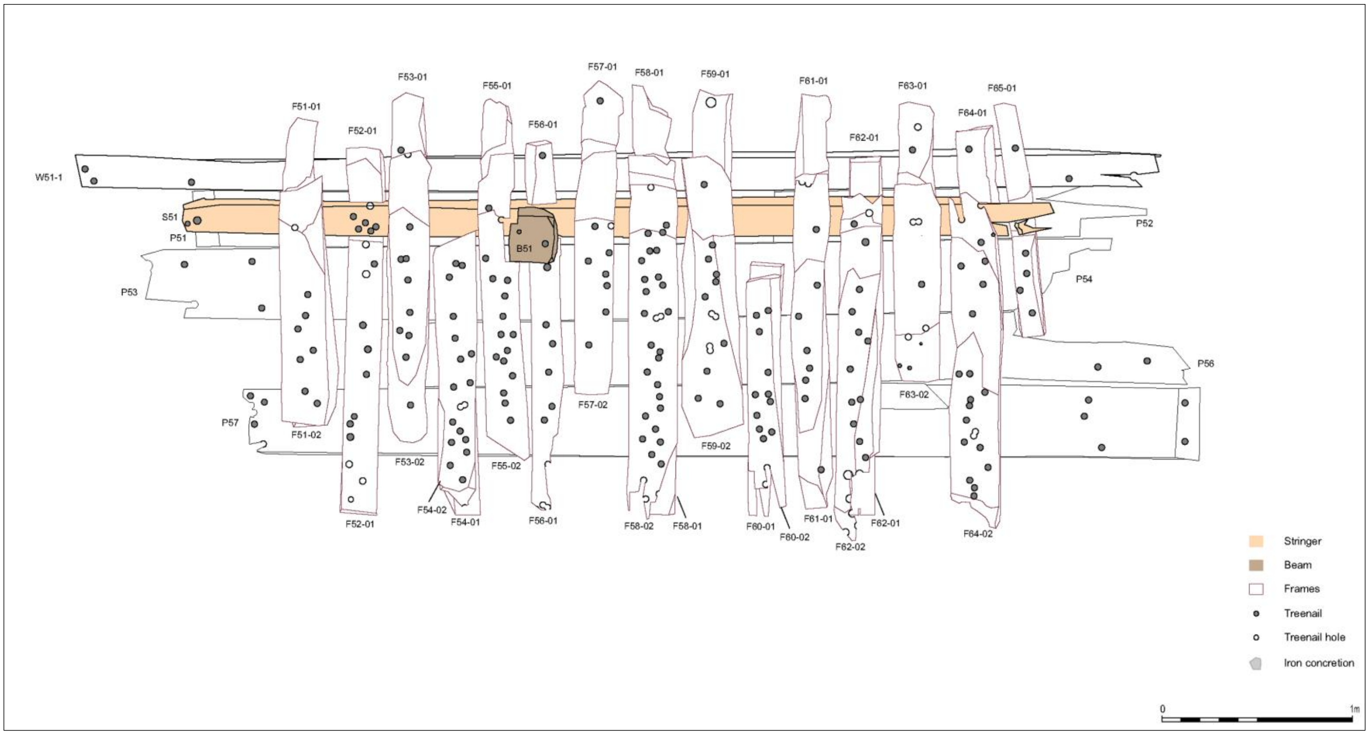

Figure 3-4: inside view of wreck piece 2.

Piece 2 had been located above piece 1 towards the stem; they connected by the two highest strakes of piece 1 and the two lowest of piece 2. The overall dimension of the piece is 6,11m x 2,29m. Extensive framing is preserved including futtocks, filling frames and furring frames. Approximately 4,46m of the wale that was sandwiched between the original frames and the furring timbers was still in situ. Four strakes of the planking are preserved and above these is the lowest wale. A short piece of a cross beam was preserved in a beam shelf cut out in the futtocks.

3.2.3 Piece 3a

Figure 3-5:inside view of wreck piece 3a.

Piece 3a is the lowest remaining part of the hull side. It is 8,2m long and 2,23m wide. Seven fragments of floor timbers are preserved and they all join to futtocks. In all, eleven futtocks are on still in their original position. The joint between floor timbers and futtocks is covered by two ceiling planks of which the lowest is only preserved in half its width. Five broad strakes are preserved and the lowest two are from the bottom of the ship. The strakes are curved in the end towards the bow and shows that the piece is located few meters from the bow.

3.2.4 Piece 3b

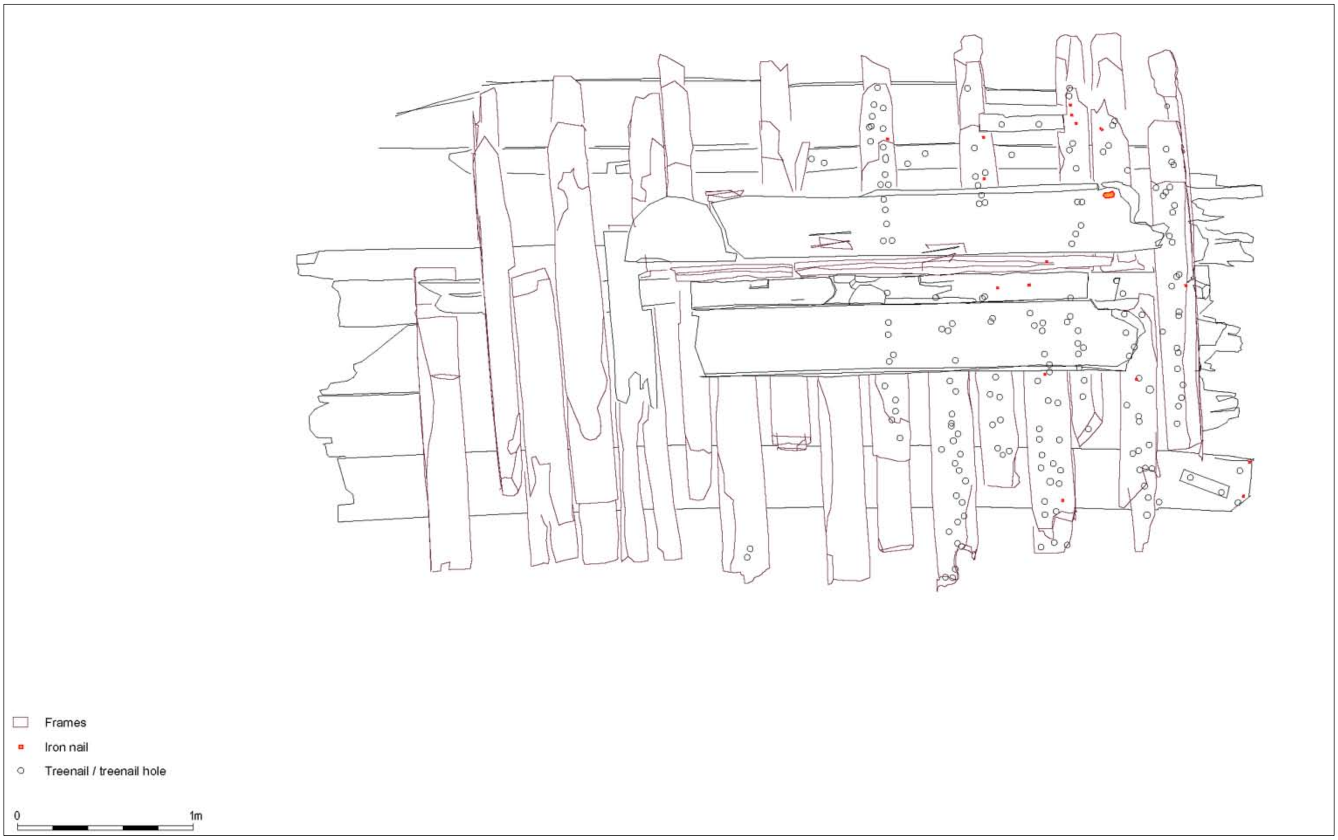

Figure 3-6: inside view of wreck piece 3b.

This piece was a massive coherent part of the side, forming around the sandwiched wale. Before lifting, piece 3a and 3b were joined together, piece 3b above 3a. The piece measures 6,3m x 3m and reaches from just above the turn of the bilge to the lover edge of the gun port. The framing extends approximate 40cm above the planking. One complete underside of a gun port is preserved near the forward end of the piece and the remains of a second gun port can be recognized towards the aft limit of the piece. Two beam shelves are located at the height of the sandwiched wale, just below the lower wale on the outside. The distance between the beams is equal to that of the gun ports but they are displaced with one frame width. The framing of this piece is almost completely intact with only a few futtocks missing from it. Were the futtocks are missing a wedge shaped piece of wood is revealed between the original frames and the furring; the wedge was not present between every futtock and framing timber. The moulded shape of the furring frames indicates a pronounced tumblehome. Seven strakes are preserved and two outer wales are also in situ. The wales are located only one strake apart and make a bend towards the bow which indicates the close position to the stem. Fragments of the orlop deck construction and cross beams are also preserved on piece 3b below the gun ports.

3.2.5 Piece 4

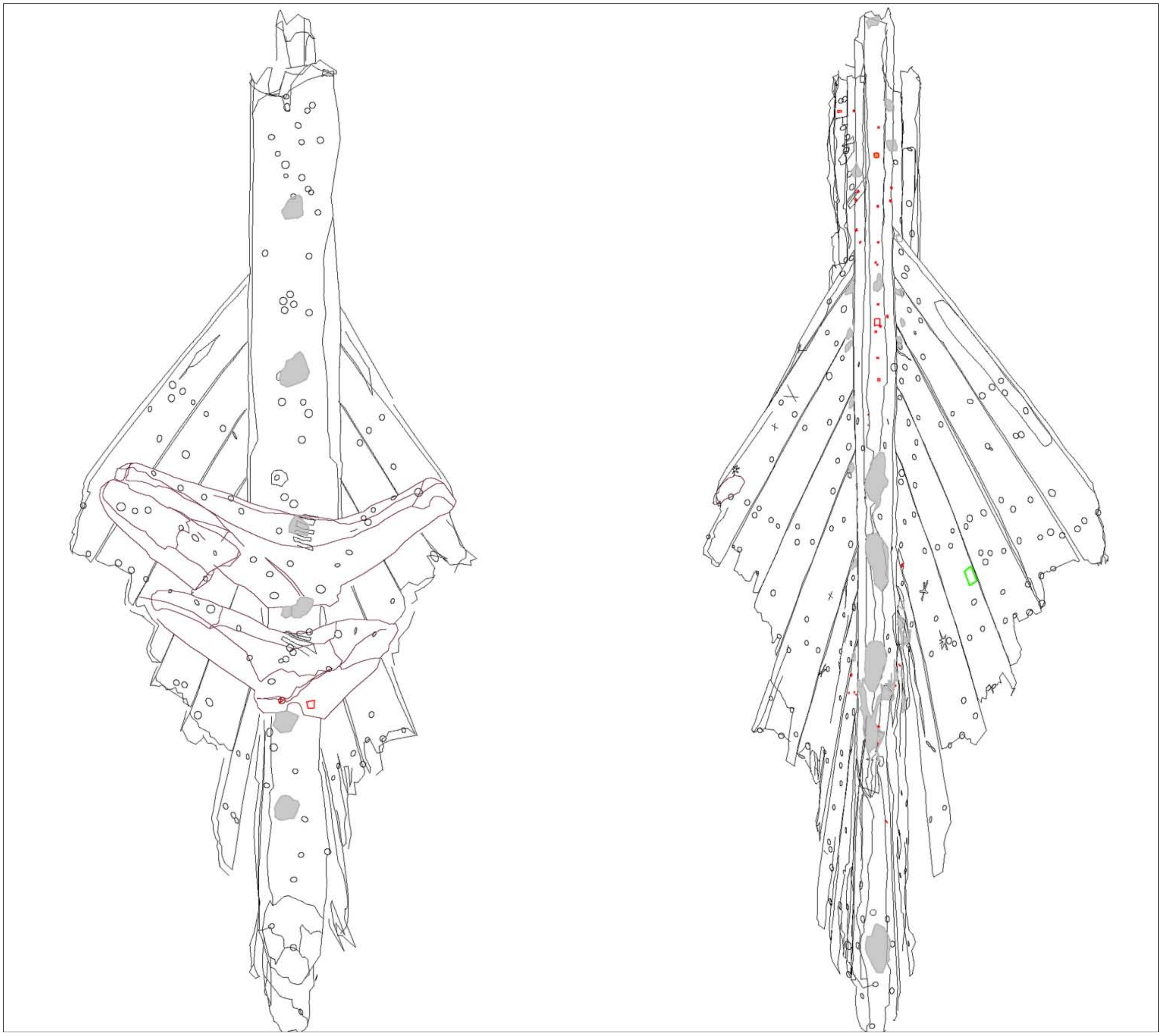

Figure 3-7: inside and outside view of wreck piece 4.

This is the preserved lower part of bow of the ship. Its extreme measures are 4,9m from the brake of the keel to the end of the stempost and 2,2m across of the planking. It consists of a fragment of the keel joined to the stempost, and has six hood ends of the strakes of the starboard side and seven preserved on the port side. On the inside a massive timber called the apron or stemson is preserved in situ and attached to this timber are two raised V-shaped floor timbers that have been nailed with iron and treenails to the apron. The floor timbers were also fastened to the planking but only with treenails. The apron and stemson were initially thought to be two individual pieces but this was later changed to the stemson and apron being the same piece of timber which also functioned as a stem knee. The apron was bolted to the stempost with iron bolts. A single fragment of a futtock was still in situ on the planking when the piece was raised and broken treenails and treenail holes showed where other floor timbers and futtocks had been located. The hood ends of the planks were resting in a rabbet in the stempost and fastened to this with treenails and additional iron nails. The planks were tapering towards the stempost from a width about 30-35cm approximately 2m from the stempost to about 22-25cm where it ended in the rabbet. Above the preserved planking on the stempost a triangular piece of wood was visible. The function was to smooth the transition for the planks between the apron and the stempost rabbet.

3.3 Structural components

3.3.1 The keel

The keel was only fragmentarily preserved as a 1,82m long piece. The fragment was still joined with a flat vertical scarf to the stempost and held together by large iron bolts. The keel was equipped with a 9cm high and 6-6,5cm deep rabbet to receive the garboard strake. The moulded dimension appears to be approximately 25-30cm and the sided around 30cm near the brake of the keel. The garboard strake had been fastened to the keel with treenails.

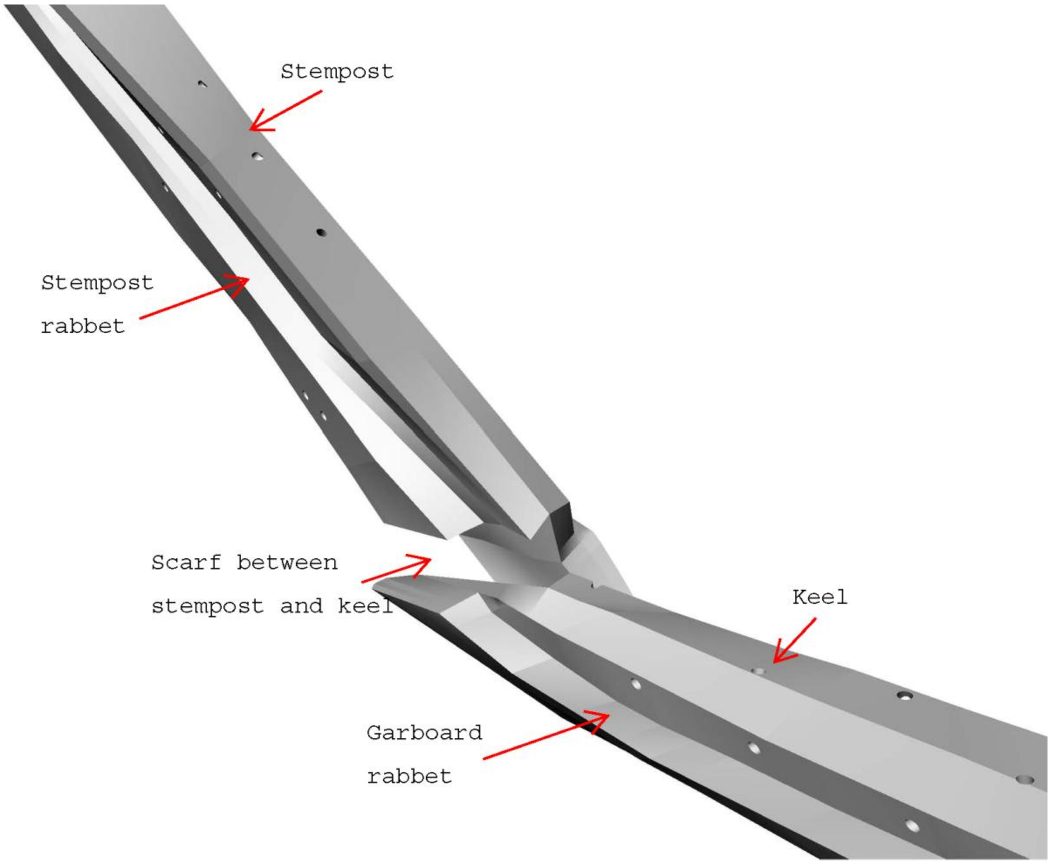

Figure 3-8: exploded view of the digitally reconstructed scarf between the stempost and the keel.

3.3.2 Stempost

The stempost, as preserved, is 4,86m long from the scarf of the keel to the upper brake. The curve of the stem is a sweep of a circle with a diameter of approximately 10,28m or 33,7feet. The moulded dimension is in average 30cm and the sided dimension is 20-25cm on the outside of the planking and 25-35cm on the inside. The rabbet from the keel continues on the stempost and has an angle of 36º. The angle between the keel and the stempost was measured to approximately 32º.

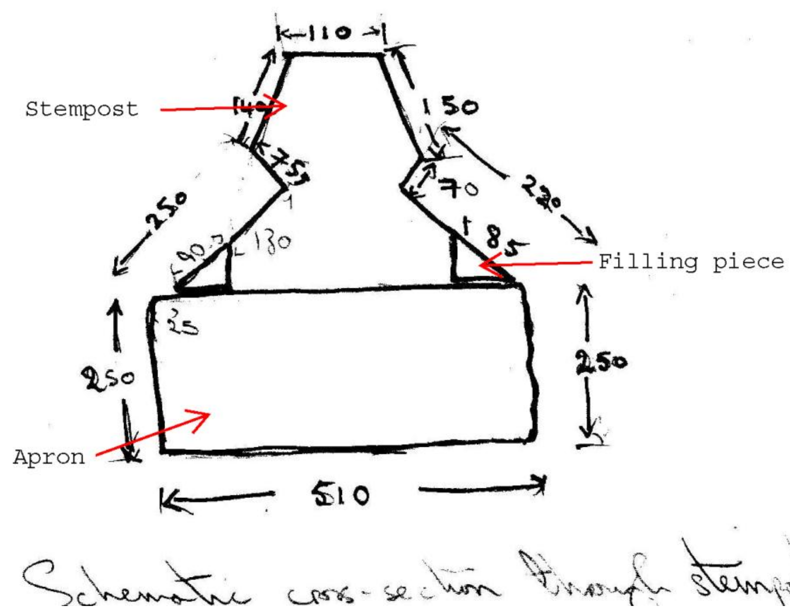

Figure 3-9: measured sketch of cross section of the apron and stempost.

Tool marks and cut treenails below the planking clearly indicated that the angle of the planks had changed during the rebuilding of the hull. Several treenail were registered on the outside of the stempost, the function of these remains unknown, probably they have to do with the construction of the ship.

Concretions on the front side of the stempost shows that the large bolts that were used to fasten the apron also protruded all the way through the stempost.

3.3.3 Planking

The planks vary in length from 2-6m and are all sawn of oak. The general width is between 30-46cm and with the widest planks at the bottom of the hull. The thickness varies from 5 to 7cm. The planks are joined in the ends by vertical diagonal scarf joints with flat ends and fastened to the framing by treenails. The joints are in addition to treenails also secured with square shafted iron nails. A V-shaped groove has been cut in the lower edge of the planking in which three spun threads of animal hair and tar was placed to ensure a waterproof hull.

Figure 3-10: the planking and the wales (right) of wreck piece 3b.

3.3.4 Orlop deck construction

Only fragments of the lowest deck have survived to reveal information about the internal construction. A single fragment of a crossbeam has been preserved in situ. The beam fragment is on piece 2, only 19cm long and with dimensions of 22 x 22cm. Three of the original locations of the cross beams are still visible at the height of the sandwiched wale, two on piece 3b and one on piece 2. Another beam would have been located where the brake is between piece 2 and 3b. Underneath the beam mortises in the futtocks a beam shelf plank is preserved on 3b. A half beam clamp with mortises cut for the half beams was preserved between the two cross beam positions. On top of the half beam clamp there was a fragment of heavily degraded L-shaped waterway carved from one piece of wood.

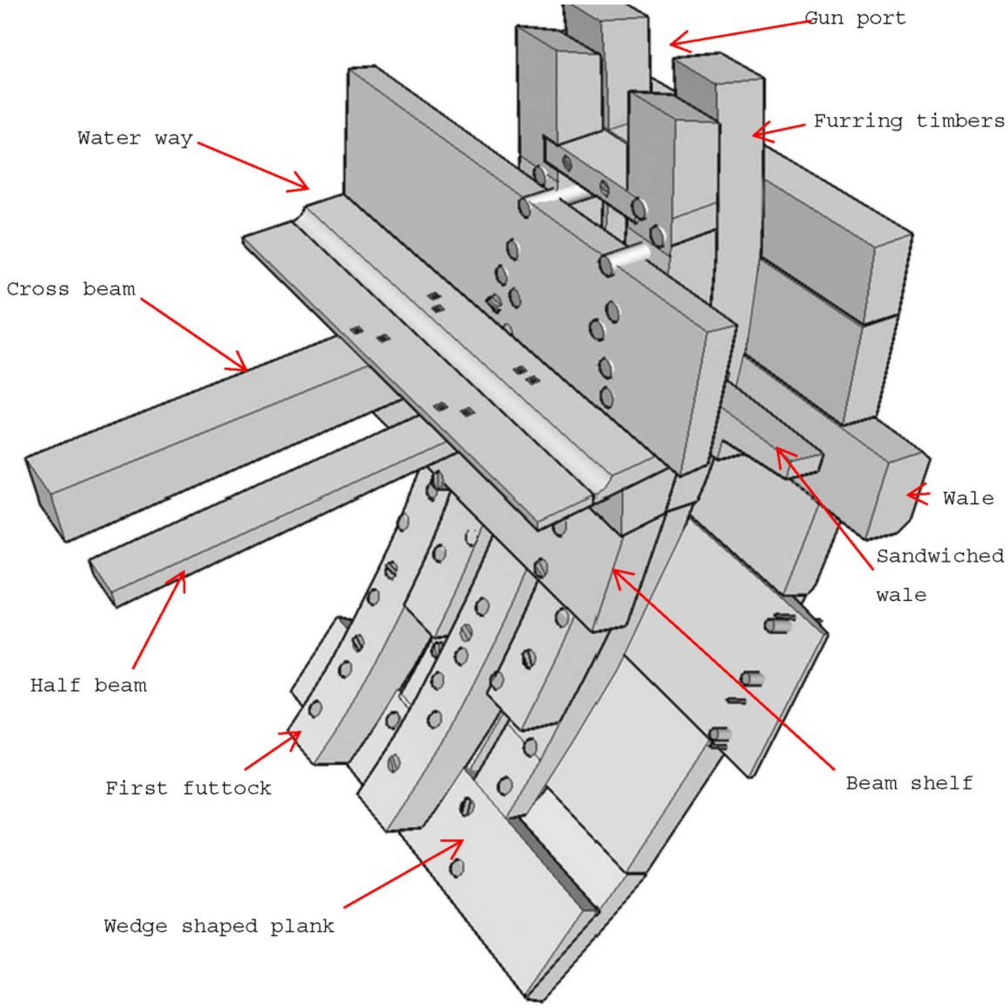

Figure 3-11: illustration of the deck construction.

3.3.5 Framing and furring

The preserved framing consists of five different elements; floor timbers, first futtocks, second futtocks, filling frames and furring timbers. The futtocks are joined on the aft side of the floor timbers with double dovetail joints some are trapezoidal and others are not. Between every pair of first futtocks and floor timbers there is a narrow filling piece and the distance from one side of a floor timber to the same side of the next floor timber is 55-60cm. The moulded and sided dimensions of the floor timbers and futtocks are in average 15-25cm while the filling pieces vary from 10-15cm in sided dimension.

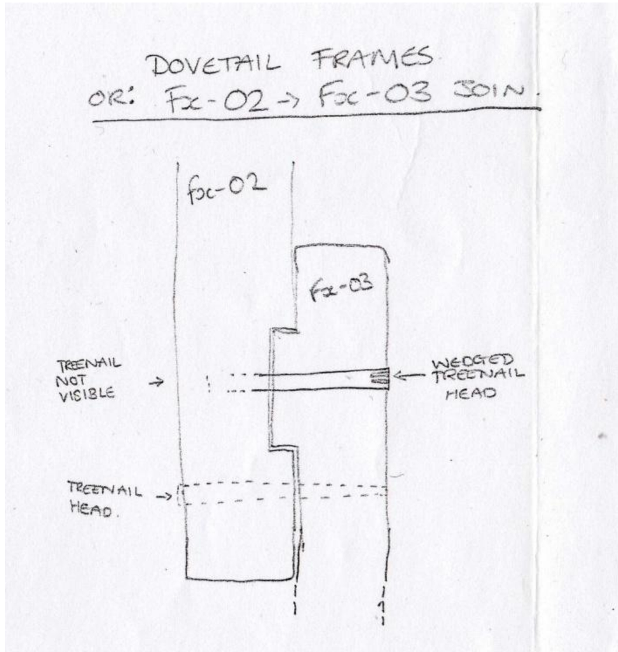

Figure 3-12: sketch of dovetail joint locked with horizontal wedged treenail.

The floor timbers in the bow are made from asymmetrical crooked timbers and are only roughly shaped. Rounded limber holes are positioned in the middle of the lower edge. A close resemble to the floor timbers in the bow is found in the ship from Red Bay.

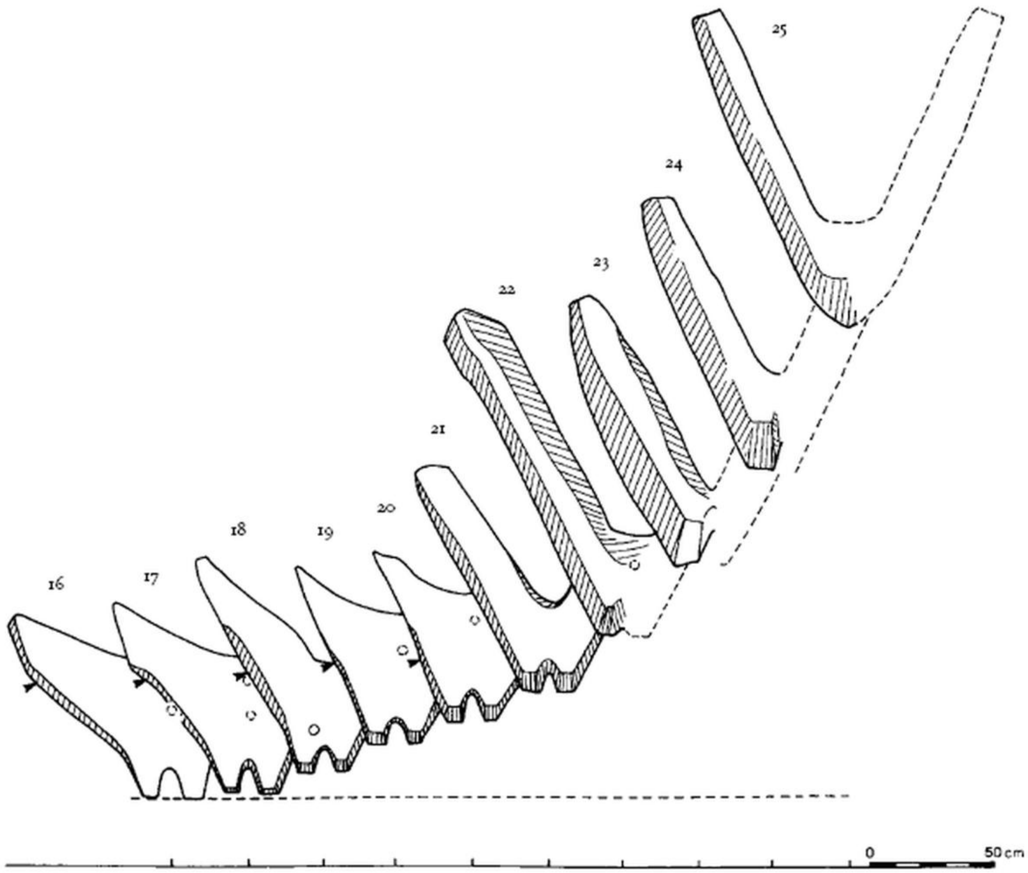

Figure 3-13: frames from the bow of the Basque whaler from red Bay Labrador.(Grenier 1998, p.280)

In the aftermost part of the hull there is a change in the pattern of the floor timbers and futtocks. The preservation state of this area is particular poor but it appears that floor timbers and first futtocks are no longer connected by dovetail joints. This detail is also seen at the B&W 7 wreck dating from 1577 to around 1590 and build of wood from north-western Europe.(Lemée 2006, p.277)

The first futtocks reach all the way from the joining with the floor timbers to the height of the gun ports where they have been broken off. The second futtocks are preserved on piece 2 and 3b but they are not connected or joined to the first futtocks in any way. Between the original framing system and the hull planking are the furring frames located.

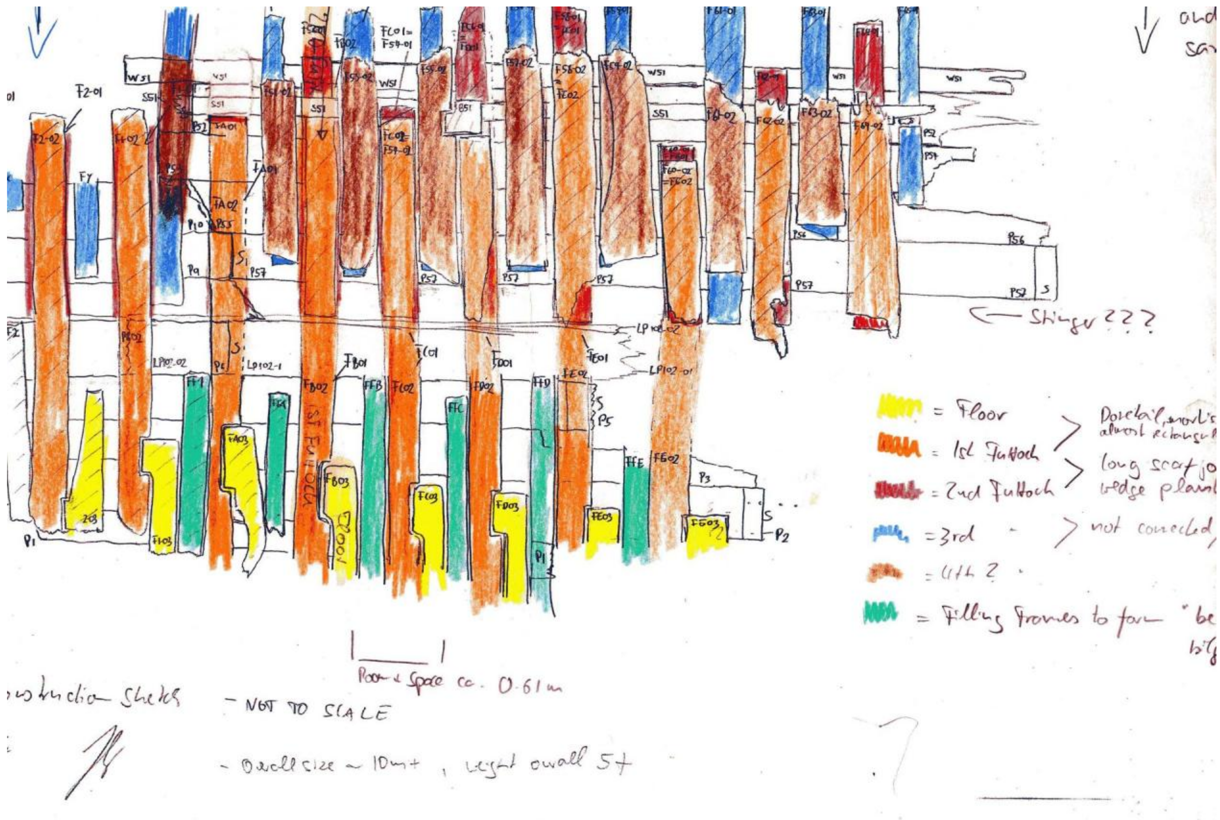

Figure 3-14: schematic sketch of framing. The legend on the drawing is confusing the furring timbers with concealed futtocks. It should be: yellow= floor timbers, orange= first futtocks, green= filling pieces, brown= second futtocks, red and blue= furring frames.

The furring frames reach from the turn of the bilge upwards to the highest preserved parts of the hull. Between the futtocks and the furring a wale that was part of the original shell of the hull has been left in place. Sections of wood in the furring timbers were cut away around the wale to make the timbers fit. The furring tapers from around 5cm in moulded dimension to a maximum of 25-30cm just above the sandwiched wale. Below the furring timbers a wedge shaped plank is located to smoothen the transition between the furring and the futtocks. All timbers of the framing and the furring are made from oak.

3.3.6 Fastenings

The main method of fastening the hull planking to the framing was with the use of treenails. The general diameter of the treenails is 30mm and the majority was split to receive caulking. Iron nails were, as mentioned used at hood ends of the planks and in the planks joints. The nails were counter sunk and the holes plugged with a mixture of tar and caulking material. Larger bolts were used for securing the apron to the stempost and to hold together the stempost and keel scarf.

3.3.7 Gun ports

The remains of two gun ports are preserved both located at the upper edge of piece 3b. The forward most gun port is preserved in its full width that measures 40cm. Because of the state of preservation it was not possible to measure the height. The internal construction of the underside of the gun port was preserved and consisted of two horizontal boards for which mortises were cut in the futtocks and furring timbers. The two boards were fixed to each other by treenails and the gun ports are positioned 70cm above the orlop deck construction. 2,5m aft of the preserved gun port construction the remains of a second gun ports were detectable. Nothing is left of its construction but an edge of the mortise cut for the shelf in a futtock indicates it position. If gun ports were evenly distributed along the side of the ship it is not unreasonable to assume that a total of 6-8 guns were located on along each side of the orlop deck.

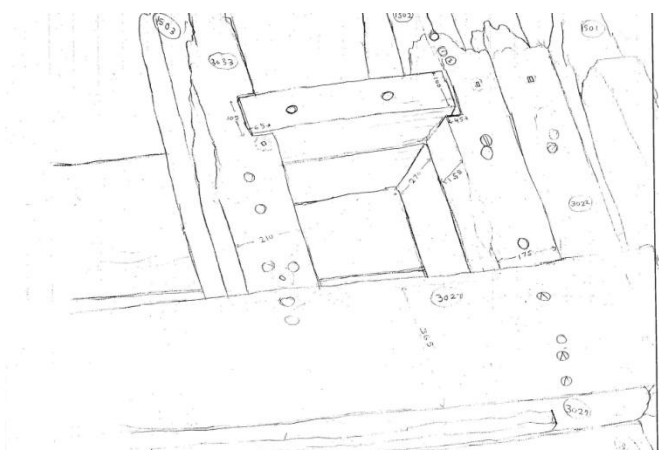

Figure 3-15: sketch of gun port.

3.4 Dating and origin of the timbers

12 dendro samples were cut from the timbers of the ship, all of them with sufficient number of growth rings to come up with a felling date. A single sample, including bark gave the last felling date of 1574. The best match to a regional curve was from Eastern England particularly East Anglia and Essex.(Wessex Archaeology 2004) From the sample it was not possible to distinguish between different phases of the ship. The stocking of wood can be a confusing factor the dating of the ship. For example one of the samples that included the bark ring, showed a felling date of 1514. If the ship was build after 1574 which is the latest dating acquired, the timber was either stocked for 60 years or it was a reused timber from a dismantled structure. Nothing can be said of for how long the ship was in service before it was wrecked. The 1574 date from the dendro sampling is a post quem dating of the construction time and an ante quem dating for the wreckage of the ship.

Figure 3-16: dendro samples wrapped in film displayed on the futtocks.

3.5 Technology and tradition of construction

The level of technology available for constructing a ship is a limitation for the complexity of the structure. By technology is meant the actual tools that were used in the process of preparing timbers and metals to become components in a ship. Tool marks and constructional solutions reveal what kind of technology was used.(Adams 2003, p.27) No comprehensive analysis of the tool marks has yet been made for the Princes Channel ship, but some conclusions can be drawn from an immediate investigation.

The planks of the ship are cut with some sort of large scale timber saw, most likely a pit saw. Tool marks on the planking show that the faces have been smoothened with adzes and maybe also with broad axes. The framing timbers were shaped using different kinds of working axes. Chisels were used for making mortises, dovetail joints and other scarves and rabbets and for hammering caulking material in to the treenails. Standard sized drills were used for drilling for holes for the many treenails. A range of hammers and mauls were used for hammering in the treenails and nails as well as for adjusting the position of the heavy framing timbers. In addition to these tools a wide selection of clamps, pliers, knives and planes were used in building the ship.

The Princes Channel ship belongs to multicultural period of European shipbuilding where many traditions of shipbuilding are practiced on the European continent. Traditions are melting together and implements are borrowed and adopted between shipwrights across national borders. This also complicates the answer of an unambiguous definition of tradition.

The Princes Channel ship is a carvel built ship which is often mentioned in contrast to the clinker tradition. The clinker tradition had been the dominant technique of shipbuilding in England since the Saxon period. But changes in demands for the ships to carry greater weight and heavy ordnance necessitated new designs and construction methods and as a result of this the carvel technique was adopted to the English navy in large scale by Henry VIII in the early 16th century. (Adams 2003, p.48-

50) An archaeological example of the transition from clinker to carvel construction is visible in the case of the Woolwich ship that has been rebuilt from a clinker ship to a carvel planked ship in 1509.

At this point in history carvel built ships were common on the European Atlantic coast as part of a tradition originating from the Mediterranean. The idea of carvel built hulls was probably gradually transferred to the mainstream shipbuilding of the medium and smaller shipyards for merchant vessels to which the Princes Channel ship must be subscribed.

In the 16th and 17th century texts on shipbuilding there is being distinguished between two main branches of constructional traditions namely as mentioned the English treatises and the treatises of the south-western Iberia and Venice.(Marsden 2009, p.34) Because of this branching of the text there is a natural tendency of looking for indicators of the written traditions in the archaeological material.

The ship from the Princes Channel is built in England of eastern English timber and therefore it would be obvious to assume that the ship is of some sort of English tradition even though influenced by foreign traditions. As the Hull analysis will show, the ship was obviously built after a concept of predetermined design, but the question is whether the design was a part of an established tradition or if it was part of the development of a tradition in change. The furring timbers and the redesign of the hull suggest the second option.

3.6 Sequence of construction

The construction sequence of the Princes Channel ship can be determined by analyzing the timbers and their constructional features.

The first timber to be laid out was the keel probably composed of two or three timbers joint together. After the keel the stem and sternpost were raised and fastened to the keel. Semi preassembled control frames including the master frame, consisting of floor timbers and first futtocks were fixed transversal on the keel, probably bolted to it with iron bolts. The frames could not have been completely preassembled since there were no connections between first and second futtocks. First futtocks and floor timbers were joined with a variation of dovetail joints and fixed with horizontal treenails. The position of the treenails shows that floor timbers and futtocks must have been assembled before erected because the narrow space between the framing would not have allowed for drilling and hammering the treenails after placing the floor timbers on the keel. As mentioned only a single fragment of the keel has been preserved that did not reveal much as to the assembly of keel and floors. After the partially preassembled frames had been placed on selected stations, ribbands or battens could have been attached to the framing for guidance of placing the rest of the frames after which a keelson was probably bolted on top of the floors.

Before frames were added in the stem the massive apron was installed. The apron also forms a stem knee that strengthens the connection between keel and stempost. At this stage the planking was applied from the keel and up to the end of the first futtocks and filling pieces could then be attached to the planking between the frames. After fastening the filling pieces, internal stringers and ceiling planks of the lower hull were fastened mainly to floor timbers and filling pieces. Most likely the cross beams at the master frame and the other controlling frames were installed before the internal stringers and ceiling planks. As the planking proceeded up the hull side it was possible to install the second futtocks and thereby build up the planking on these.

Above the tumblehome nothing has been preserved of the hull structure and the building from here could have proceeded in several different ways, but most likely third and maybe firth futtocks were added as floating futtocks to support the higher planking.

The furring can be regarded as a second phase or round of the ships construction. As explained in the section on furring, the planks were stripped from the hull and the furring timbers attached to the futtocks after which the planking was reattached. In this connection the frames from the bow section must have been changed as part of the rebuild otherwise they would not be able to support the planking running to the stempost in a new angle.

The conclusion of the sequence of construction is that the shape of the hull to the tumblehome was controlled by predesigned frames and from above the first futtocks the planking and the higher parts of the framing was build up together. The principles of the construction sequence for the Princes Channel ship is different in central aspects compared to the interpretation of both the Mary Rose and the Sea Venture.(Marsden 2009, p.50) (Adams 2003, p.72) The morphology of the floor timber and futtock joints on Mary Rose suggests that the frames were made as individually installed frames rather than a series of strictly designed frames. It has not been finally determined if all the frames or only the master frames were preassembled before placed on the keel, but the latest analysis suggests that they were not. Also the Sea Venture had its floor timbers and futtocks installed separately. In this aspect the Princes Channel ship is more similar to the ships of the Iberian tradition that is partially determined by the dovetail joints between floors and futtocks. The ship from Studland Bay is different in many details but the assembly form of the semi preassembled frames is noticeable.(Thomsen 2000, pp.72-73)

4 Archaeological method and methods of reconstruction

4.1 The archaeological recording of the ship from Princes Channel

The archaeological recording of the Princes Channel ship was divided in two main phases, an underwater recording and a recording on land, after the wreck pieces had been raised.

This chapter will describe the methods used in the recording processes of the Princes Channel ship. It will mainly be based on the information available from the summary archaeological report.(Wessex Archaeology 2004) The recording of a ship wreck is essential to the process of reconstructing it in the post processing of the archaeological data; therefore a short presentation of the methods used is relevant in context of reconstructing the ship.

4.1.1 Underwater recording

The underwater recording was carried out by a dive team and the aim was to have two divers in the water at a time. The diving was done using surface supplied equipment and with a river tug as the diving platform.

The environmental conditions such as wind currents and swells, made the diving operations difficult. Also visibility on the wreck location in the Thames estuary was very low which made the underwater recording cumbersome and slow. Video recording and underwater photographing was impossible because of the often zero visibility and therefore visual recordings of the wreck are not available.

Strong currents constantly ripped away tape measures and made it impossible to establish a reliable grid system around the wreck. Instead it was chosen to use the timber structures as a datum system with only a few extra control points around the wreck that made it possible to link the loose finds on the sea bed to the wreck site.

All timbers that could be distinguished by feeling of hand were labelled with yellow plastic labels containing a unique number to identify the timbers. From the datum system established on the wreck pieces a trilateration drawing in 1:20 of the wreck site was made. The measurements were communicated from the diver to the surface where they were written down to be plotted on the site drawing afterwards.

Figure 4-1: diver going in.

4.1.2 Land recording

When finally all the wreck pieces were recovered and brought on land, the more detailed recording of the ships structural remains could begin. Loose finds and separated timbers were brought to the surface, photographed and timber sheets with measurements and descriptions were produced for each timber and included in an electronic database.

The main recording method chosen for the wreck pieces was the use of a total station. The reason for this method was because it is a relatively fast way to record complicated standing structures. The total station has a high accuracy and the data produced easier to handle and store than the traditional 1:1 or 1:10 manual drawings.

The total station is able to establish the exact distance from its position to the target. This is done via a laser beam shot from the total station aiming to the point of recording and the time of reflection is then calculated to the distance. The total station stores the recorded points in 3d space and thereby forms a cloud of 3d points that can be accessed on a computer.

Figure 4-2: recording with the total station.

Each wreck piece was recorded as an assembled structure component, and therefore it was only possible to record what could be seen from the outside. While recording the wreck pieces an individual layer of recording for each timber was made. Also treenails, iron nails, concretions and other features were divided in separate layers. This made it possible to look at each layer separately when post-processing the data.

In supplement to the total station recording, measured sketches and scaled drawings were made of chosen components and loose timbers. As part of the recording an archive of digital photographs was made with detail pictures from all the wreck pieces as well as overview photos from both inside and outside. The archive also contains working pictures documenting the whole project.

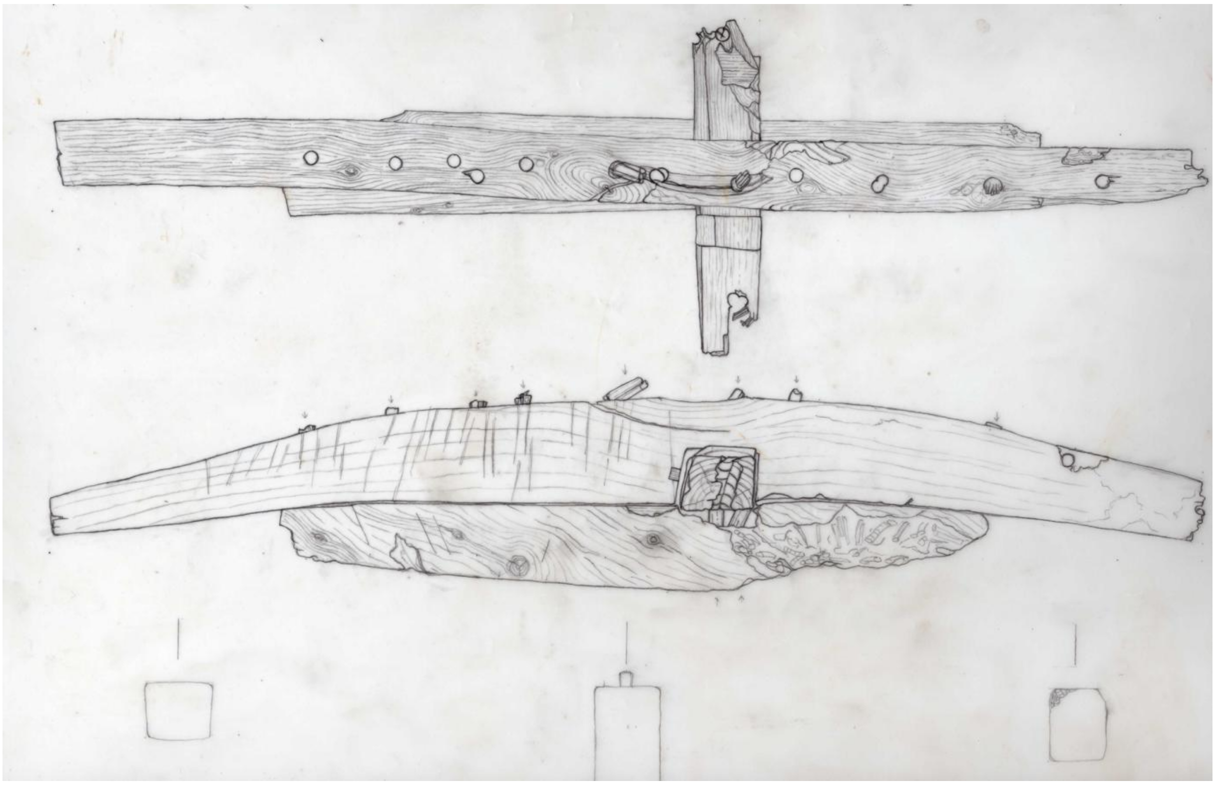

Figure 4-3: drawing of futtock with furring timber.

4.2 Approaching the reconstruction

Basically there are three different methods of reconstructing ships; graphical, three dimensional and physical or full sized reconstructions.(Steffy 1994, p.214) The graphical method is a two dimensional presentation of the reconstruction. This includes tabular and mathematical data, archival information, pictures, drawings, computer generated graphical presentations and text. The three dimensional reconstruction is a way of increasing the potential of understanding the ship as a physical structure, and it answers questions never thought of, using only the graphical method. The three dimensional reconstruction can be made of physical materials like wood and cardboard but there is also the possibility of creating the model as a digital 3d model. Compared to the graphical method, the third dimension adds the physical limitations and control of the material that is not present in two-dimensional or digital reconstruction. The full scale physical reconstruction is by far the most complex and demanding method. It is very expensive and time consuming procedure, mainly limited to what is thought to be historically important and well preserved wrecks.(Steffy 1994, p.215) Building the full scale replica will necessarily include both the graphical and the three-dimensional method as important steps in the process.

There can be many reasons for building a scaled model of an archaeological wreck and the methods used varies with the final aim of the process. The full reconstruction will contain the highest obtainable relevant information on construction, design, technology, cargo and artifacts, economics and people.(Steffy 1994, p.193)

The scaled reconstruction model is built with a variety of purposes sometimes with the full scale replica in mind, but also “just” to answer questions on overall hull shape, constructional details, building sequence, design and technology. No matter how technically advanced the ship research might become, using digital recording methods and 3D modelling, ship reconstruction is not an exact science in the positivistic meaning. The interpretation that is necessary to work with archaeological material always keeps the window open for relativistic criticism, but the research must aim for keeping as close as possible to the source. There are hundreds of issues that will need the interpretation of the ship archaeologist and a lot will be based on qualified guessing, more or less supported. The goal must therefore be to present the material as honestly and fully as possible giving the reader the opportunity to re-evaluate the archaeologist’s choice. In the end, ship reconstruction is a tool to understand the people behind a material culture. The ship is part of the material culture and everything we can learn from studying it will reflect back on the society that it was serving; it reveals aspects of society both in terms of the people on board, the cargo of trade and also of the wider society.(Adams 2003, p.25)

The work of creating a model from the recorded remains of a wreck has to be accurately executed and carefully planned, otherwise the chance of the result being misguiding and not representing the original material is considerable. No matter how thorough the process might be, there will always be the need for interpretation. Several of the interpretations made are at the best, qualified guesses.(Bischoff et al., p.5) The process of reconstructing a wreck from the archaeological remains has been called “reverse naval architecture”.(Lemée 2006, p.97) The Alpha and Omega for a successful and reliable result is the quality of the archaeological recording. If the recordings are unfulfilling and inaccurate the reconstruction will answer in the same terms.

To gain the best understanding from working with reconstruction of archaeological ship wrecks, a multidisciplinary approach is the way forward. A broad variety of different skills and experts is necessary if the process has to be taken from the discovery of the wreck to a possible full size reconstruction. All depending on the conditions, there would be need of people with diving skills, archaeological recording and excavation skills, knowledge of 3d registration and computer processing, engineering on different levels, model builders, wood experts and boat builders, not to mention historically able boat riggers, rope makers and sail makers and many more.(Crumlin-Pedersen 1995, p.303) It is a demanding, time consuming and expensive process, not possible to be contained by a single discipline and much less by a single person, and such projects will only succeed in corporation of a multitude of disciplines.

4.3 Methods of reconstructing the Princes Channel ship

The reconstruction of the Princes Channel ship contains different approaches combined. The 3d recording of the wreck gives the possibility to work with the model in wood and cardboard as well as the selective laser sintering for rebuilding the hull. The two different approaches will be explained in detail in the chapter on building the model.

There are three basic methods of reconstruction. All the methods are interlinked in a way that they contribute to each other. A complete reconstruction of a ship will necessarily consist of all three methods made in their full extend. None of them can as a single method fulfil or answer all the questions that will appear in the process. So to speak they build upon each other. It is unimaginable to make a serious full scale replica without making both an extensive desk-based graphical reconstruction and a scaled model reconstruction. In this case of reconstructing the Princes Channel ship, the model reconstruction is going to be a necessity to make fulfilling graphical reconstruction. In that way the methods are closely interlinked or maybe more accurately they are all components in the full reconstruction research.

Inspiration on how to actually work with a reconstruction was gained from projects with different approaches. But it was in no way possible to transfer a single method that could be used in this project. The work that is carried out in the research department of the Viking Ship Museum in Roskilde had a series of approaches that were taken in consideration, but narrow focus on the Nordic clinker constructed vessels left several dilemmas unsolved. The clinker built vessels are usually reconstructed in similar way as they were originally built namely shell-first. This means that cardboard reconstructions of the planking are attached in their original clinker fastenings which re-establish the shape of the hull. Since the Princes Channel is a carvel built ship, this was not a suitable approach. In this aspect Christian Lemée's work with the B&W was a more useful approach. The B&W ships were mostly carvel built and they were recorded using a total station. Different to the Princes Channel ship it was recorded in a flat top view with additional hand drawings of the moulded dimensions of timbers. Also all the wrecks were recorded in situ which meant a fairly limited distortion of the remains and several of the ships were extensively preserved which stands in contrast to the Princes Channel ship. But the choice of building material and the approach of the model as a research tool was chosen as the main inspiration for building the reconstruction.

The reconstruction work of the Newport ship shows the possibilities in the digital recording and reproduction and served as inspiration to use the selective laser sintering. This was chosen to gain the maximum level of accuracy in the bow section where the chances of misshaping was greatest. It was not possible to use it as a complete method of reconstruction because of the recording method that had been used, the labour intensive preparing of data and also due to budget limitations.

It had been tried several times to align the total station recordings of the wreck pieces digitally but all attempts had failed. If it had succeeded to align the pieces digitally, the reconstruction model could theoretically have been completed as a digital 3d object, but the understanding and interpretation of the physical model could hardly have been obtained by a digital model alone.

Because of the broken state of the Princes Channel ship and the lack of coherence between the ships side and the keel, the best option was to make a fragment model of the hull. This method is particularly benefitting for ships that has been broken in pieces after wreckage. (Steffy 1994, p.221) Since only the large coherent pieces of the wreck had been recorded systematically it was not possible or desirable to reconstruct every loose fragment that had been recovered from the sea floor. Therefore only the major pieces were reconstructed.

The individual wreck pieces were used to establish the most likely shape of the hull by joining them with long flexible battens that could be fastened to the stem and stern post and in that way indicate the curving of the hull lines. It was chosen only to reconstruct the port side of the ship since all the wreck pieces came from this side. The method was therefore to create a 1:10 half model of the ship that could be used for developing line drawings of the shape.

5 Building the model

The following chapter will explain how the model of the wreck pieces was produced in a 1:10 scaled model. This concerns the different methods that were used, speculations and interpretations leading to choices that affected the outcome of the model.

There are two aspects in building the model. The selective laser sintered plastic model and the part made of wood and cardboard. Both methods were primarily built from the digital total station recordings of each of the salvaged wreck pieces. Before it was possible to start building the physical model, preparing the digital recording was fundamentally important.

5.1 Preparing the data

The recording of the remains of the ship from the Princes Channel left an extensive post processing of the 3d data to be done. All the digital 3d data were processed in the software package R

What initially needed to be done was to finish the outline of all timbers that had only been partially recorded by the total station. In practice it meant revising every single component of the wreck pieces and finishing it to be a complete timber that would fit back in the rebuild structure. The preparing of the data needed to be done at two levels, one for the wooden reconstruction and one for the selective laser sintering. Creating solid 3d files will be explained in the section on selective laser sintering later in this chapter. Preparing the data for the parts that was going to be reconstructed in wood and cardboard did not need the same amount of precision as the ones going to be manufactured in plastic. For the wood and cardboard reconstruction it was enough to have a more rough outline of the timbers and it was not mandatory that there were no breaks or bends on the line. For these parts the important issues were to make the outline and the shape of the timber as clear as possible so that confusion of the shape while manufacturing the pieces could be minimized.

For making the digital reconstruction it was important to understand how every component was indicating the shape of the timber that it would partially cover. By gradually solving the lines of one timber it came to define the shape of the timber beneath or next to it. This way of reconstruction naturally has a problem of accuracy but the combined shape of the complete wreck piece would still be accurate to an acceptable level.

Most of the work consisted of cleaning the recording from brakes and kinks on lines and to sort out confusing areas. It was important to make the material easily readable and each timber piece clearly distinguishable. Lot of the recorded points had to be deleted and lines re-established in the effort to make the recording clear enough to work as the basis for the reconstruction. As such the preparing of the data was a simplification of the recording that was absolutely necessary for the further work.

It was essential to digitally flatten out the warped planks before creating them as models. In the Norwegian Barcode project a solution to the problem of printing a 3d figure to a 2d plane was developed. A polysurface was made from a number of cross sections of the plank. This surface was then unrolled to the 2d plane where the curves, nails and other details were flowed along the surface. In this way the model got the right 2d shape and it could then be bend to shape with the other planks. Only the most distorted planks and curved faces of the framing needed to be straightened. The unrolling of the 3d object to the flat surface are standard functions of the software program.

After the necessary digital reconstruction, a system of control-lines was applied to the timbers. The control line is a coherent polyline that reaches from the bottom of a frame on one side, over the top face and down the other side. The lines are placed so that they mark the places where the strakes are crossing the frame. Every timber was saved to a separate file that would only contain information of that particular component. A timber file ready for printing would contain the complete outline of the shape, all recorded treenail holes and nail holes, significant brakes of the wood and control-lines. Other details such as joints, concretions and repairs would also be shown in the file.

5.2 Wood and Cardboard

The main part of the Princes Channel wreck was reconstructed manually from wood and cardboard. This is a well established method of reconstruction and it is a fairly simple procedure with a minimum of requirements to workshop facilities and economical expenses. The work requires a good working space with proper lighting and a large table. Some mandatory tools are needed; cutting and carving tools for wood and cardboard, mini-drilling machine, pencil, glue, a selection of screws and screw drivers, small hammer, pliers and other basic tools. The most important tool for shaping the frames is a small band saw. I used a hobby saw with a 180 watts electrical engine and a narrow blade. The small saw and narrow blade gives the best accuracy in controlling curves when sawing out the frames and other timbers. The wood for the frames was fir cut from construction timber and floor planks.

The progress of the work would be fairly similar whether working with traditional hand drawn recordings of the timbers or as in this case with digital recordings. Every frame was printed in the scale 1:10 in three different views, two sides and a top view. Every view was printed out double so there was one in reserve if one view needed to be cut away. The most important shape for getting the reconstructed hull shape right was the moulded shape shown on the side views.

A piece of wood with an appropriate dimension was prepared for making a frame. One of the side views were glued to the wood and the inside curve of the frame was cut out. The top view was then glued to the newly cut surface so that the control lines on top corresponds to the control lines on the side.

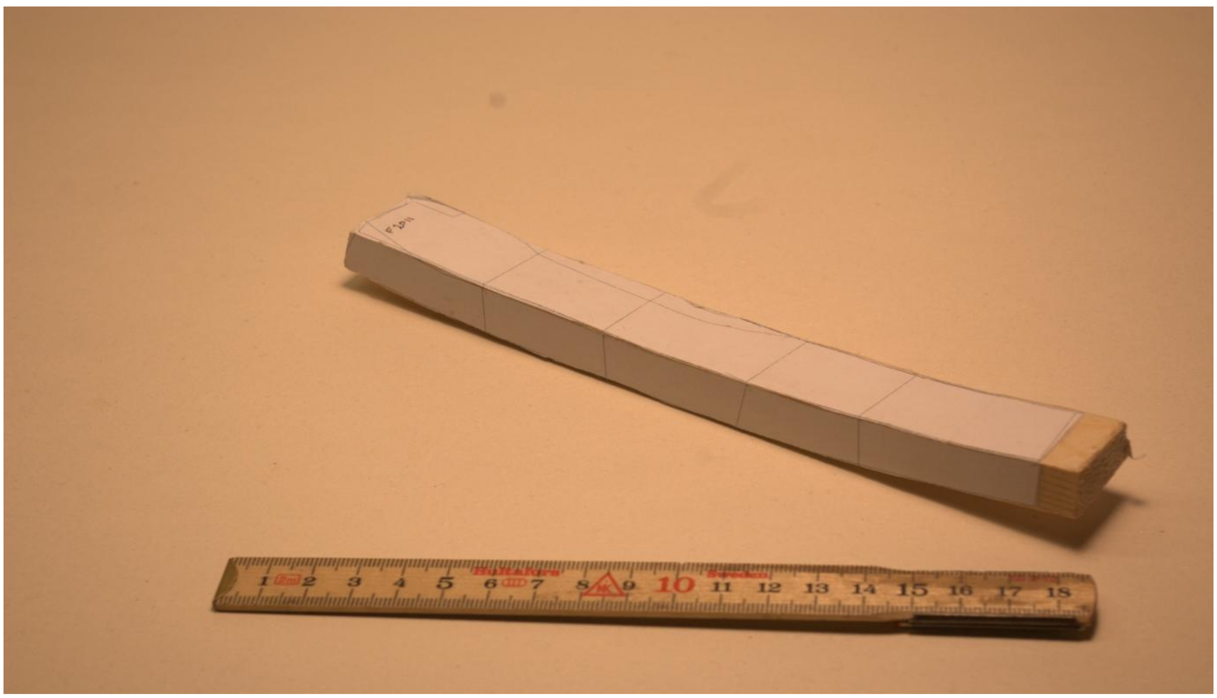

Figure 5-1: frame with the control-lines indicates where the side view and the top view fits together.

If the frame is straight and regular it is enough to cut one side of the frame to get the right sided dimension, but usually both sides needed to be adjusted to get the right shape. When both the sided dimension and the inside curve of the frame was correct, the frame would be completed by cutting the outside face of the frame and thereby finishing the moulded dimension. The control lines are important because they ensure that the views are connected in their correct individual positions. The frames were rarely rectangular in cross-section and therefore the cut often had to go diagonally through the wood to make sure that the outline of the frame was followed.

If it had been necessary to cut away some of the glued print-outs from the frame, the reserve print-out could be applied afterwards. Where the sufficient precision could not be obtained with the band saw, small wood carving chisels and carving knives were very helpful.

In this way the product will become a fairly accurate reconstruction or outline of the shape of the recorded timber. The print-out views of the piece will show all registered details such as nails and treenails, repairs, markings placed in their mutual correct positions.

It was found that the most efficient way forward was to organize the work as a serial production where one wreck fragment at the time was produced in the sequence of their numbers given during the recording.

Figure 5-2: picture showing the newly produced frame elements in the right order placed on the cardboard planking.

On each reproduced frame the timber number from the registration was written with a black pen, preferably at a place where it could be seen also after the pieces were assembled. Being relatively systematic in the production of the frames was important to keep track of the different components. The furring timbers were attached to the futtocks continuously as they were produced. In this way it was fairly simple to line up all the components ready for planking.

Futtocks and furring were connected by imitating the original treenail fastenings. As the print-outs showed exactly where the original fasteners had been on the timber it was natural to use the same places for fastening the reconstructed components. With a mini-drilling machine and a 2mm drill, holes were drilled where they were indicated from the registration. Not every single treenail fastening was drilled but only sufficient for connecting the pieces properly. The 2mm drill corresponded exactly to the diameter of ordinary round toothpicks which were used as treenail substitutes. It is obvious that the fastening with a 33mm oak treenail in a massive 7cm oak plank cannot be compared to fastening cardboard planks with a toothpick, but it was rather surprising to feel the combined strength of even such minor toothpick fastenings that one can imagine the original strength of the fastenings.

Figure 5-3: picture shows the cardboard planking fastened with toothpicks.

The toothpick treenails had the advantage of being a reversible method of holding the constructional elements together. Despite the relative strong fastening it was possible to draw the components from each other without damaging the pieces. Where much strain was put on the structure from the curving of the planking and frames it was necessary to use small screws to make sure that components would not come apart.

Like the frames the planks were printed from the Rhinoceros program in 1:10. It was often not possible get a prober view of the inside of the planking since the internal timbers were blocking the view during recording. Where a reasonable view was available and in the areas with sparse preserved framing, the inside face of the planking was printed. Each side of the plank prints were glued to 3mm thick cardboard and cut out.

Figure 5-4: making the cardboard planking.

The two sides where then glued together with wood glue and held together with clamps until dry. With the 6mm cardboard planks the 1:10 planking was corresponding the average thickness of the original planking. All the planks had also been supplied with control lines that showed the placement of the frames. In this way it was easy to fit the planks and frames together to their original positions.

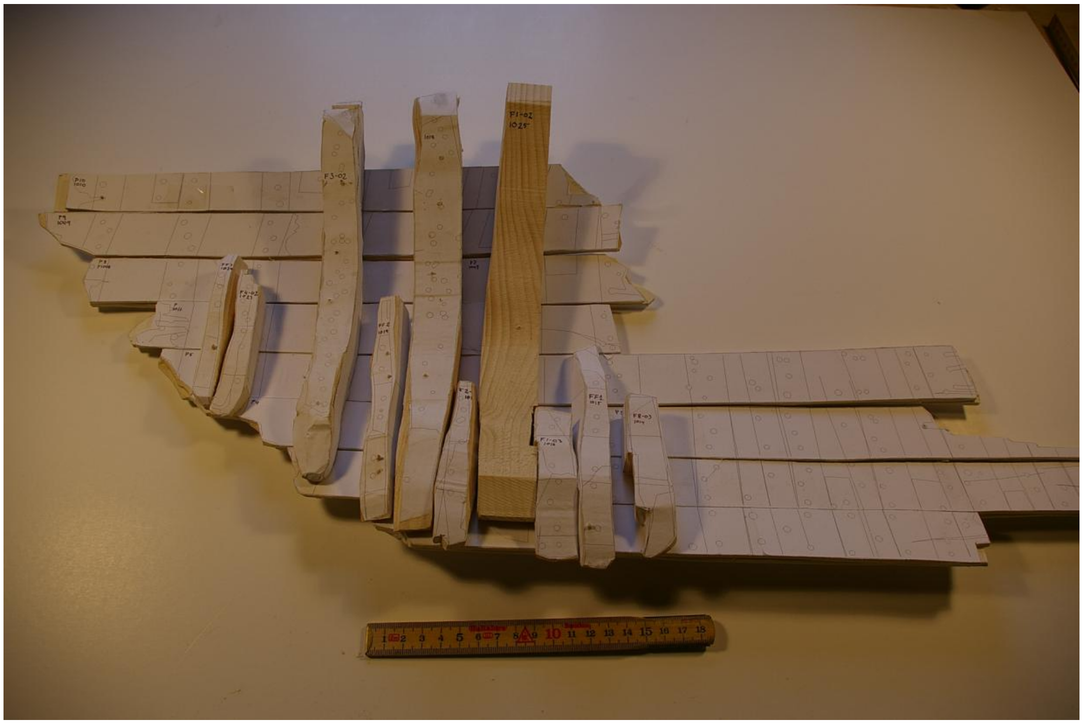

Figure 5-5: reconstructed piece 1.

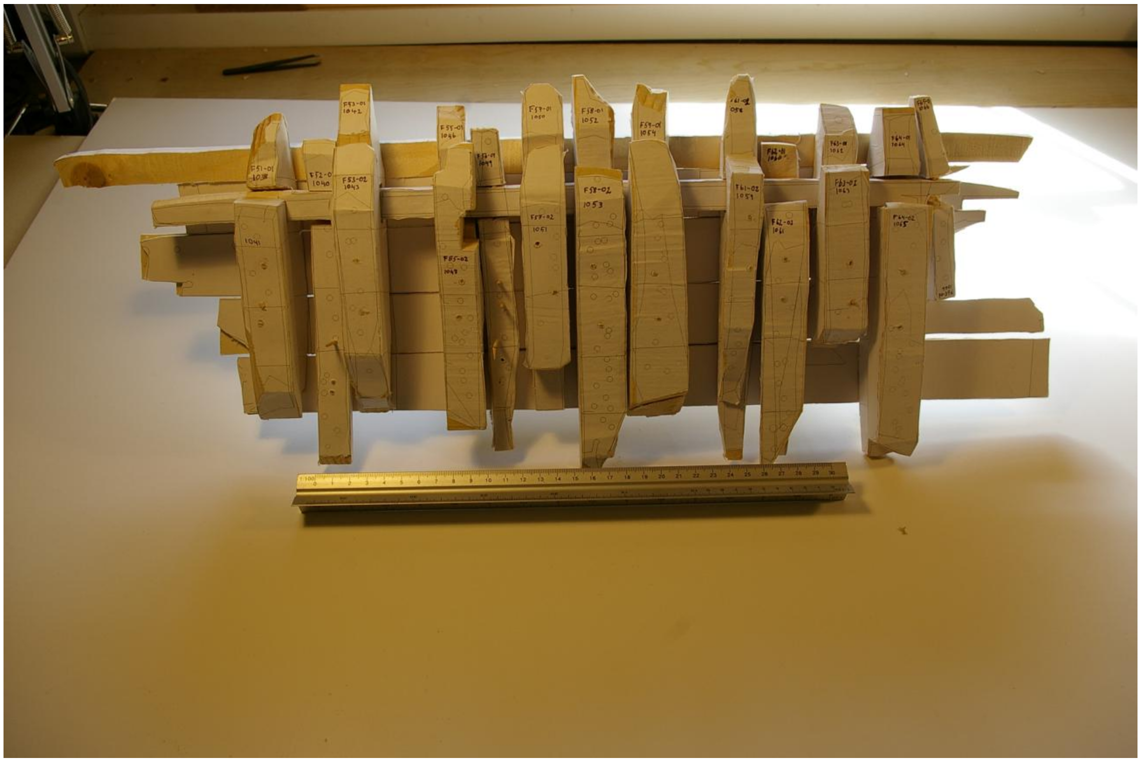

Figure 5-6: reconstructed piece 2.

Figure 5-7: reconstructed piece 3b.

5.3 Selective Laser Sintering (sls)

As mentioned sls is a method that is rapidly entering the field of ship archaeology as a method of reconstruction and producing scaled models of ships. The method is dependent on certain standards of recording and is therefore develops with the spreading of digital recording methods.

To create a SLS model of polyamide nylon dust was chosen as the best solution for the wreck piece of the bow section. In this way the most accurate reconstruction for this part was ensured. The bow section is particular important for the reliability of the model because the run of the strakes start here and indicates run of the strakes and therefore the positioning of the wreck pieces on the ship's side.

After preparing the recorded data as explained above, each individual timber had to be made in to what is called a digital solid. In practice this meant exporting each timber to create a separate file that could be worked upon as a component independent of the rest of the structure. Creating digital solids from the total station recording was a process of simplification of the data to an extent that allowed a smooth digital web to be drawn over the surface of the timber shape. If the shape of the timber recording was too complicated and had too many incorrect and complicated shapes it became difficult to make a completely closed surface that covered the whole piece and further simplification was necessary. The main issue in creating successful surfaces for the solid models was to make the shape simple. This does not mean compromising the shape as such but an effort should be taken to use as few points and curves for making the shape as possible.

Figure 5-8: digital reconstruction of a plank with a complete surface. From this view it is possible to get an impression of the twist of the plank.

All the recorded treenails were also created in the solid file. These were made as cylinders with diameter of 2,6cm. The cylinders were subtracted from the digital solid by the program, leaving holes in the timber models exactly where the treenails were originally placed. The recording, however, did not include details on the angle of the treenails, so this had to be based on the recorded marking which would in many cases not correspond to the original angle. The markings of the treenails were transferred to the files of all the timber pieces that it realistically could have penetrated and this helped linking the pieces back together in the right positions.

The processing of the recorded data to the finished digital solid was a time consuming process. This was mainly due to the quality of the recording since many concealed areas had to be rebuilt completely before creating the solids was possible. In cases with a better recording strategy this work would be much faster.

The most problematic areas of reconstruction were the parts of the bow section that were extensively covered by other timbers and planking. This was in particular the inner face of the stempost that was completely hidden by the massive stemson. Also the scarf between stempost and keel had to be partially reconstructed since only the outside part was visible. The forward most preserved frame of the bow section covered for a closer inspection of the stemson. After considerations and no evidence of a scarf the stemknee and the stemson were reconstructed as a single timber. During the rebuilding of these areas hand drawings and detail sketches along with photographs were crucial for a reliable reconstruction.

When a separate file had been created for every timber of the bow section and the digital models had been made to solids, the model needed to be scaled to 1:10. The 1:10 timber model file was saved as a stereolithography or STL file. The STL file had to be opened in the display program MiniMagics in order to check the quality of the file. This program would approve the file as ready for manufacturing or if corrupted areas existed that needed to be rebuilt.

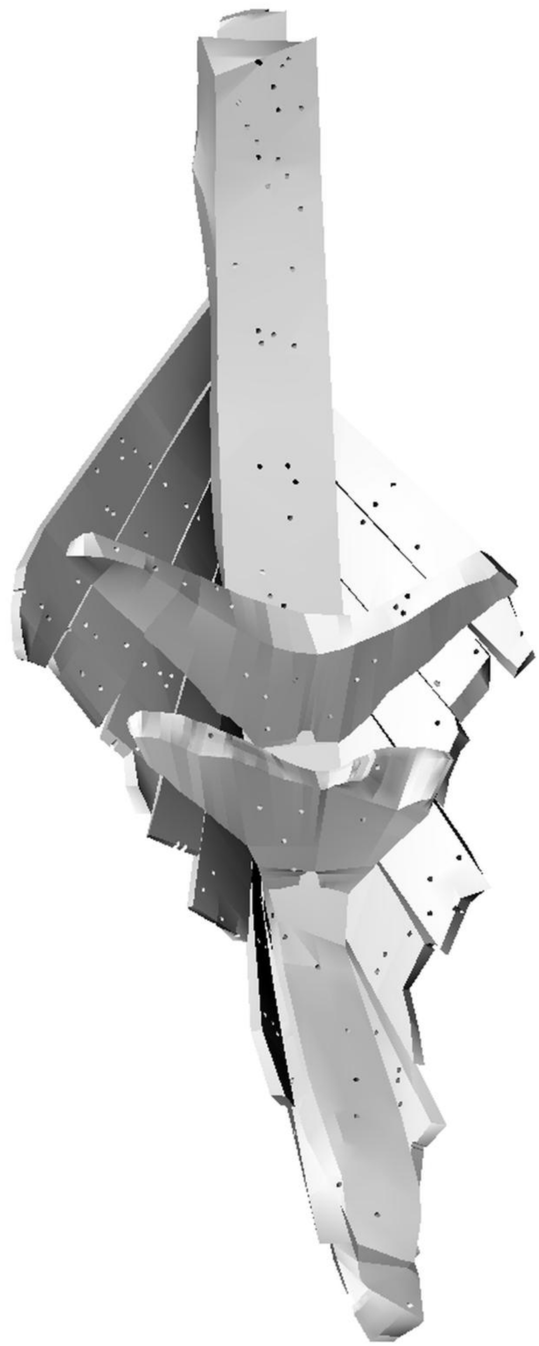

Figure 5-9: the digital solid bow section

Every step of the process was saved as different files that ensured the possibility to move one step back in the process to rectify corrupted areas without having to begin from scratch. When a 1:10 STL file had been made for every timber, they were mailed to the sls company for manufacturing.

After receiving the plastic models of the timbers they were assembled with small 2,7 x 16mm brass screws. The diameter was just right to bite into the plastic making a strong fastening and still they could easily be screwed in with a manual screwdriver. The size of the screws should be considered already in the digital processing phase and a size that lies as close as possible to the original fastening should be chosen. Pan headed screws are preferable since these can be screwed further in to the plastic and make a tighter connection.

The shape of the reconstructed areas might not represent the exact true shape of the original timbers where these were concealed, but the absolute benefit of this method and why it was chosen for the bow section is the fact that the model has come as close as possible to the recorded shape. The planks have the correct curvature and importantly the twists that they make towards the stempost.

The method of reconstructing a ship using selective laser sintering is an option that should be considered in many cases of ship reconstructing. As with any other reconstruction method the result will be best if the wreck is more extensively preserved. Very fragmented wrecks might not benefit in particular from this method. However the SLS method requires certain standards of recording of shipwrecks to be cost efficient. If the process of recording is systematized like it is on the Newport ship reconstruction project the SLS method must be a method to consider. The modelling of the bow section of the Princes Channel ship shows that SLS is also a possibility for projects of much smaller budgets than the Newport project. The manufacturing cost is at a level that makes it feasible for smaller projects to choose this method of reconstruction.

The recording strategy of the Princes Channel ship was not optimal for producing an SLS model, since the amount of work for preparing the data was simply too extensive to make it a realistic method of reconstructing the whole ship.

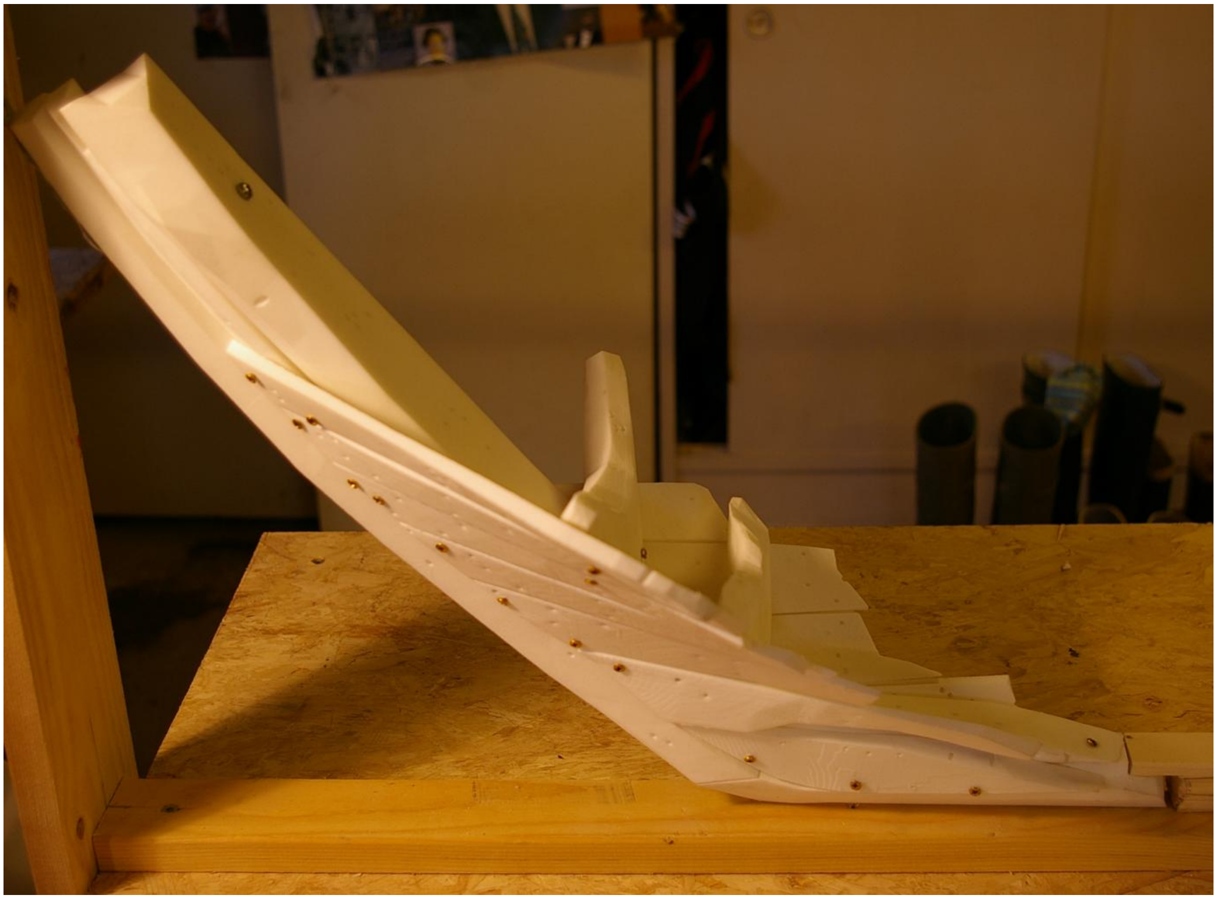

Figure 5-10: the assembled sintered model of the bow section.

5.4 Modelling problem areas

Modelling problem areas of the hull is a closely interlinked process between the digital reconstruction while preparing the data, and the actual physical scaled reproduction of the components. It is a floating process that makes it impossible to distinguish exactly when it is a matter of straight forward data processing and when it is reconstruction led by the interpretation. Therefore the modelling of problem areas is part of preparing the data but is divided in two paragraphs for the sake of clarity.

Piece 3a was the most distorted section of the remains. The main explanation is that the wreck piece had lost the tension that was present while connected in the ends and to the keel. The piece was so misshaped that the inside recording and the outside recording did not fit together. The distortion of the piece was partially from the lifting with the grab but also because it was not properly supported while being recorded.

Figure 5-11: screen shot of the inside recording of piece 3a.

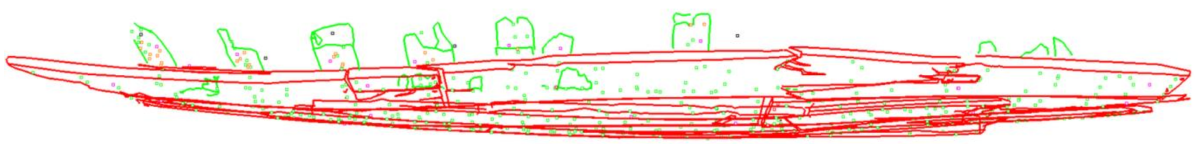

Figure 5-12: screen shot of outside recording of piece 3a. Notice the difference of the shape of the planking.

The uppermost planks on the piece made an inward bend that needed straightening. It was not possible to see if the frames had been damaged and the angle between floor timbers and futtocks had changed significantly or if they actually still represented the original shape only out of place. The only way to make the interpretation was to recreate the frames in the recorded form and see what shape the planking would take when attached to the frames. The model showed a slight distortion as a hollowing inward bend of the planking appeared after fastening. Since the original shape was unknown the best solution was preliminarily to accept the distortion to be evaluated in connection with the other pieces. To keep the model piece as flexible as possible the ceiling planks were not attached to the inside of the framing. The ceiling planks would as such not contribute to the shape of the piece and only require more force to be put on it when trying to bend it to shape.

Figure 5-13: note the distortion of the piece 3a as lifted by the crane. This distortion was partially present in the model.

The ceiling planks on piece 3a were covering the area above the joints between floor timbers and first futtocks and these joints were therefore not recorded. Examination had confirmed that they were connected with dovetail joints but the reconstruction of these joints was simplified because of the lack of recording and in the model they were represented by simple overlapping scarves.

One hull plank from piece 3a was broken around the middle and therefore distorted. The print-out was therefore cut out in two pieces, separated in the break. When glued on the cardboard the two pieces were connected so that the distinctive edges of the break were aligning and in that way it was possible to eliminate most of the recorded distortion.

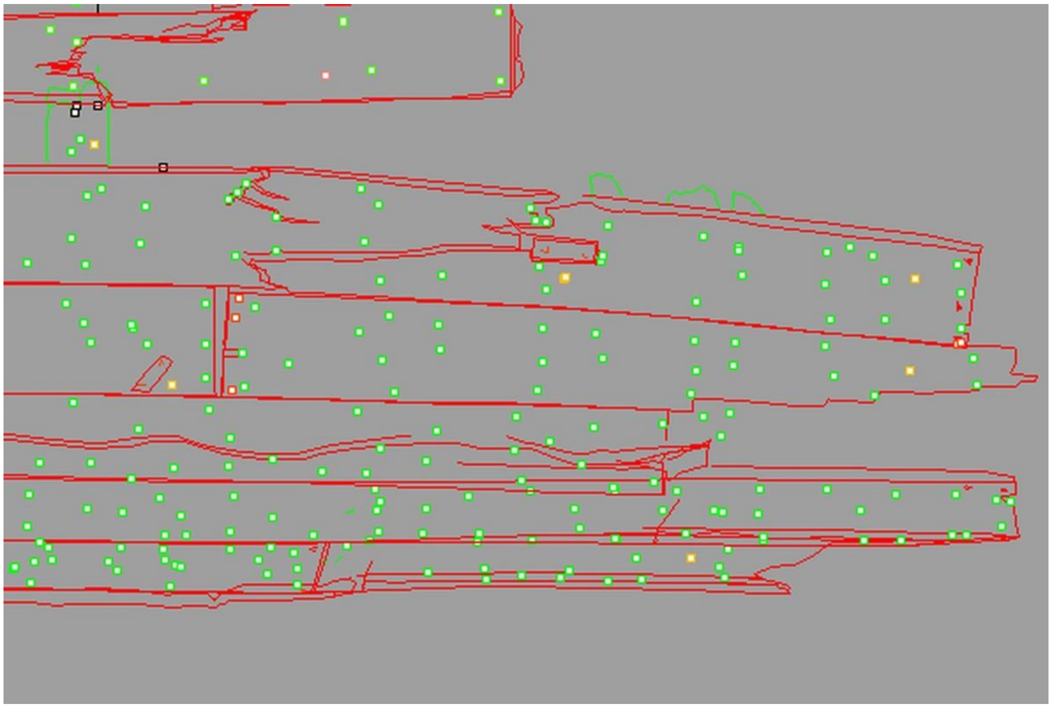

Figure 5-14: screen shot of the 3d recording showing the broken planks that needed to be put back together.

Piece 3b is a large coherent piece and the highest and the uppermost preserved part of the ship. It includes two wales and a gun port and the furring are also intact.

In contrast to piece 3a it was possible to merge the inside and the outside recording of the piece. It was clear though that the shape of the piece had changed as it was turned around to be recorded on the other side. The merged recording files were important for understanding the coherent piece, but the distortion was a disadvantage while trying to reconstruct the framing timbers. Therefore it was chosen to reconstruct the partially recorded timbers from the inside recording only and not use the merged file.

Because of the double layer of timbers on piece 3b it was particularly problematic to reconstruct the framing from this part of the wreck. Several lines and shapes for each timber had to be improvised and timbers that had been almost completely covered by other timbers during the recording had to be reconstructed almost completely from artificial lines. To rebuild the timbers in the 3d program was like making a puzzle of lines. Each timber had to be recreated so that it would fit with all the other lines. In the middle of the wreck piece only a few lines were available so the method was to move inwards to the centre of the piece using the lines recorded with the total station to guide the artificial lines. This process was done carefully since there was a risk of multiplying a mistake if the interpretation of the previous lines was wrong. Therefore even fragments of timbers recorded in the centre of the structure were important to the reconstruction.

A major problem with all the pieces was that the strakes were separated from their original fastening points in the stem and stern and therefore the longitudinal curvature of each piece was problematic and a matter of interpretation.

5.5 Alignment of the pieces

After finishing the models of the five wreck pieces it was time to align the pieces in the frame constructed for the purpose. The first piece placed in the frame was the bow section. The idea was to place the other wreck parts in relation to the bow section since the run of the planks would be helpful when moving the pieces around to make them fit. Several attempts were made before the setup was satisfying and the work made it clear that a range of solutions were possible. In the following it shall be described how the alignment of the pieces was a shifting process based on considerations and interpretations.

Placing the keel was the first step in setting up the fragment model. The keel was reconstructed simply as a prolonging of the surviving keel piece attached to the bow section. This means that it had the same cross section extending from stem to stern. It is possible that the keel originally was flattened and broadened towards the mid section of the ship and then again to be higher and more narrow towards the stern. Partially for practical reasons the keel on the Princes Channel ship model was made with the same cross section from stem to stern. This allowed for most flexibility when reconstructing the rest of the ship. Since the length of the keel was still unknown it was not possible to make it with a changing cross section. Therefore it was made as simple as possible in order not to make a presumption of the keel length before other indicators were in place.

Figure 5-15: the keel on the frame.

After the keel had been placed in the frame the bow section was assembled and placed at the end of the keel. The stempost was fastened with screws and a metal batten to vertical board at the end of the frame, while the sls part of the keel was screwed to the sub-keel timber on the frame.

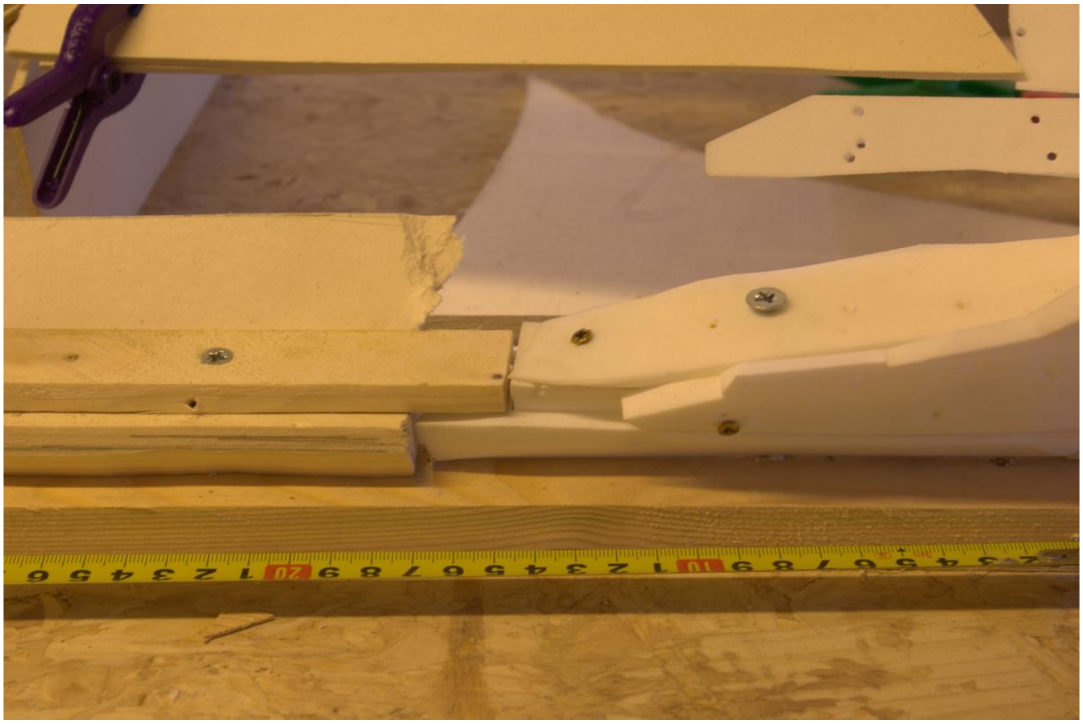

Figure 5-16: the sls produced keel connected to the wood keel and fixed on the frame.

With the bow section fixed in place the first challenge was to find the right distance to piece 3a. The distance between these two pieces was one of the main keys for reconstructing the hull shape since this was the only missing connection between the fragments. If this distance could be established to some degree of certainty the rest of the wreck pieces would also be linked to the bow.

When the wreck pieces were investigated on the sea floor there was an approximate distance of 2 meters between the end of the keel fragment on piece 4 and the nearest frame on piece 3a. This distance was not any certain measurement of the original distance between the two points on the hull, but given the impression of the site and the fact that the pieces were greatly covered by sediments and that both pieces were heavy and solid it is unlikely that they have been shifting around compared to their original positioning. The reason for the gap between the two pieces is most likely caused by the grab used by the harbour authorities when the wreck was discovered. Because of the in situ observation it was not unreasonable to apply the same distance between the two pieces on the model. The distance also fitted well with a gradual tapering of the planks from piece 3a towards the bow. If the piece was moved closer to the bow the tapering of the planks would have been remarkably steep and also the twisting of the garboard strake and the second strake would have been very sharp. These things would not have been impossible features but were good indicators that the chosen distance between the pieces was close to the original. A couple cardboard planks were used to indicate the run of the strakes in the gap between piece 4 and piece 3a. Prolonging the cardboard planks helped ensuring that a natural run of the strakes was possible between the two pieces.

In the preliminary setup the model pieces were fixed using clamps that held the pieces together. The frame was equipped with metal bands that the model piece could be clamped to.

Figure 5-17: preliminary alignment of the pieces clamped to metal battens attached to the frame. This solution of the model frame was untenable and the method of holding the pieces in the frame was changed several times.

The second unknown factor that had to be determined before proceeding with the set-up was the distance from the keel to the lowest preserved plank of piece 3a. Different solutions were tried out and were possible options.

The run of the strakes matched so that the third plank from the keel of piece 4 corresponded to the first preserved strake of piece 3a. This left room for the garboard strake and the second strake as the only missing planking between the wreck piece and the keel. There was no direct evidence that indicated the right distance but what was important to ensure was that the lower edge of the lowest preserved plank of piece 3a was running parallel to the keel. Looking at the Sea Venture as a parallel for the floor timbers indicated that the distance from the centre of the keel to the start of the wrong head sweep was the same as the overlap between the first futtock and the floor timbers. If the same rule had applied to the Princes Channel ship the distance from the centre of the keel to the lower edge of the preserved plank would be 100cm. The distance from the garboard rabbet to the plank edge would then be 90cm corresponding exactly to the width of two planks with the same breadth as the ones preserved. This solution seemed reasonable and was chosen as the basis for aligning the rest of the wreck pieces.

Figure 5-18: the distance from the keel to the lower edge of the third strake.

The third wreck piece that was placed in the frame was piece 1. Piece 3a an piece 1 shared four strakes where only one plank had been broken and the rest had separated in overlapping planking scarves. This meant that a good fit between the pieces could be obtained relatively easy.

Figure 5-19: the fit between piece 1 and 3a.

The futtocks and floor timbers of piece 1 was clearly much steeper than the floor timbers of piece 3a. This indicated clearly that the narrowing of the breadth towards stern had begun and therefore the piece was past the middle of the ship. The angle of the floor timbers and the rising of overlapping scarves between floors and futtocks was an indication of the rising line towards the sternpost.

Piece 2 was located above piece 1, displaced towards the bow. The pieces could easily be aligned since the connection was indicated by two factors. The wreck parts were sharing two strakes where one plank had been broken and the other strake was separated in a scarf. The sandwiched wale that was still present on piece 2 aligned with the upper brake of the futtocks and the furring of piece 1 where the wale would have run through the furring. The cut-out in the furring timbers that allowed the sandwiched wale to run through and had been the weaker point coursing the brake exactly here.

Figure 5-20: connection between piece 1 and 2.

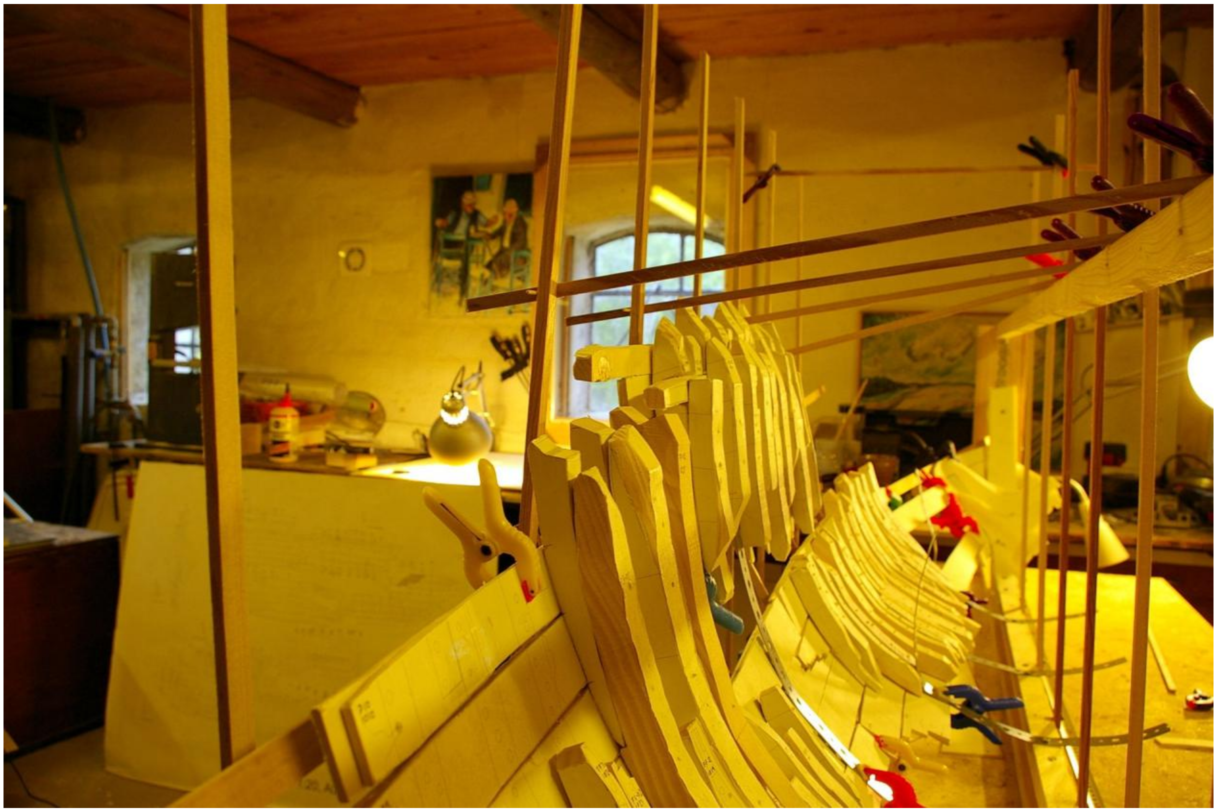

Figure 5-21: the furring timbers and the futtocks had broken of where the sandwiched wale ran through the furring.

Between piece 2 and 3a there was a gap where two strakes were missing and the frames had been broken off. Both piece 3a and 2 were connected directly to piece 1. In the first alignment of the pieces the space between piece 2 and 3a was getting narrower towards the bow. This was evidently an error in the setup that had to be corrected. By pressing in the stern end of piece 1 and at the same time lifting it a few centimetres the run of the strakes straightened up and the gap became evenly wide in both ends leaving room for the two missing strakes. This also resulted in a more convincing arch of the missing floor timbers.

Figure 5-22: the picture shows the narrowing space between piece 2 and 3a.

The last piece to be included in the model was 3b. The wreck piece had originally joined on top of 3a but the piece came apart which resulted in broken futtocks just below the furring timbers. Eight futtocks had connected the two pieces and the recording made clear which ones were originally connected. It was therefore possible to place 3b on top of 3a with certainty of the pieces not being mutually displaced. At this point the distortion of piece 3a was very evident because the awkward inward bend of the planking was contrasting the relatively fair curve of the planking of 3b.

Piece 3b and 2 shared four strakes and the lower wale as well as the sandwiched wale between the futtocks and the furring timbers. Three of the planks and the lower wale had been broken by force and fragments of the planking were missing. One strake was separated in the plank scarf which indicated that the pieces had been directly connected.

Now, with all the wreck components placed in the frame a careful adjustment of the pieces was necessary to ensure that the run of the strakes was reliable before the pieces were fixed in relation to each other.

In the first setup the gunport of piece 3b had an upward angle which seemed unrealistic and the shape of the hull was very rounded and had a significant tumblehome. The angle of the gunport indicated that the shape was wrong and changing this meant folding out the side of the ship. Naturally the hull shape changed a lot in the process and the result was a shape with a very flat curve from the bottom of the ship to the lower wale.

After adjusting the model parts, long flexible wooden lists or battens were screwed on the outside of the model, running parallel to the strakes. The lists continued past the extend of the wreck pieces all the way to the stem and stern. In the aft they were kept extra long since the placement of the sternpost had yet not been found. On the inside of these lists a double layer of cardboard was attached so that it had the same thickness as the rest of the planking. In this way the surface of the model was extended to areas were nothing of the ship had been preserved. On the inside of the extended planking, vertical flexible battens were clamped to ensure that the inside of the planking was following the same curve. The battens were in fact functioning as the internal framing but instead of stiff moulds in substitute for the framing, the battens would allow for continuous adjustments. In this way the planking was actually defining itself in natural curves. The double cardboard layer on the inside of the battens would ensure that the right distance was kept to the frame and thereby also that the outer surface of the planking was even and smooth when recorded.

Figure 5-23: the wreck pieces aligned and fixed in the frame by the battens running along the strakes.

With all the wreck pieces finally aligned it was possible to determine a feasible length of the keel. The length remains an estimate and it is debatable if it could be a meter longer or shorter than the estimate on which the reconstruction is based.

The main argument for the chosen length was the run of the strakes in the aftermost preserved parts of the hull. By adjusting the curvature of the battens fastened on the outside of the planking. The most likely shape was found with the heel of the sternpost placed 19m from the stempost scarf. This estimate was a matter of judging the lines of the hull and is no scientific proof. A supporting argument for this placement of the sternpost was found after it had been placed and fixed to the keel with a 20º rake, it turned out that with an even spacing, exactly three crossbeams would fit between the aftermost preserved location of a crossbeam and the transom of the stern. To clarify, the transom was located four times the distance between beams aft of the last preserved beam fitting.

In the bow section the battens were connected to the sls model so that the prolonged cardboard plank's hood ends, fitted in the rabbet of the stempost. Above the preserved part the stempost a curved piece of wood was fabricated to continue the arch of the stem, the prolonged planks and battens could then be fixed to this.

Figure 5-24: the bow section with the prolonged stempost.

5.5.1 Locating the master frame

The length of the keel for this reconstruction was decided to be 19m based on the archaeological material represented by the model. This goes back to what looks as the fairest lines of the run of the strakes and the assumption that the keel was not lengthened during the rebuilding of the hull when it was furred. Therefore the length is determined as a product of the reconstructed model rather than on the basis of the shipbuilding manuscripts, but it is worth investigating if there is some measure of correspondence.

According to the Treatise on Shipbuilding the master frame or the midship frame is not placed exactly midship. The broadest mould is placed 1/3 of the keel length from the fore edge of the keel. 1/3 of 19m equals 6,3m from the fore end. This corresponds very well to the model setup that shows the largest breadth of the hull just around 6m from the keel and stempost scarf. The master frame could then be appointed to be the frame registered as floor timber 1177 that is linked to futtock 2006. The two timbers are joined together most likely by a dovetail joint but the place where the two timbers joined were still covered by ceiling planks and the exact composition of the scarf was therefore not accessible when the ship was recorded. Since the dovetail joints were recorded on other transitions between floor timbers and futtocks this can reasonably be assumed.

Unfortunately the upper part of the framing in this area was missing from the wreck so the framing needed to be reconstructed from the inside of the hull planking and the surrounding surviving frames. The argument to move the master frame one frame towards the aft is that this would corresponds with the assumed placing of the central crossbeam. The master frame is then most likely the floor timber 1139 joined to futtock 1179. This places the master frame 7m from the stempost scarf. As mentioned nothing was left of the upper framing in this area and therefore there is no actual evidence of the master frame crossbeam, but it is located exactly between the aftermost beam fitting of piece 3a and the only preserved beam fitting on piece 2.

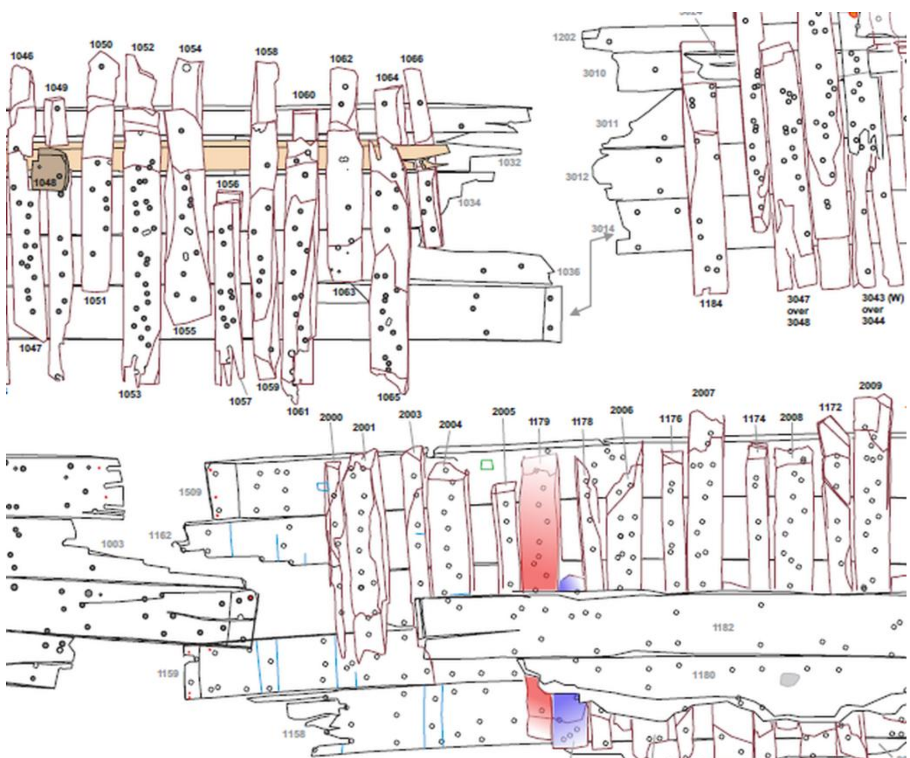

Figure 5-25: the floor timber marked with blue and the futtock marked with red constitute the master frame.

5.6 Developing the model frame.

The model frame was constructed as a rectangular platform of 200x65cm. Along the centreline of the frame a piece of wood was attached on which the keel of the ship was later placed. In each end at the centre a vertical board screwed to the base was holding a list running parallel to the keel support, 45cm above this. Important about the frame was that the basic structure was fairly simple, this allowed alterations as the model construction evolved. It is essential that the system is flexible and it should be possible to extend the frame by different means if it appears that the frame is too limited.

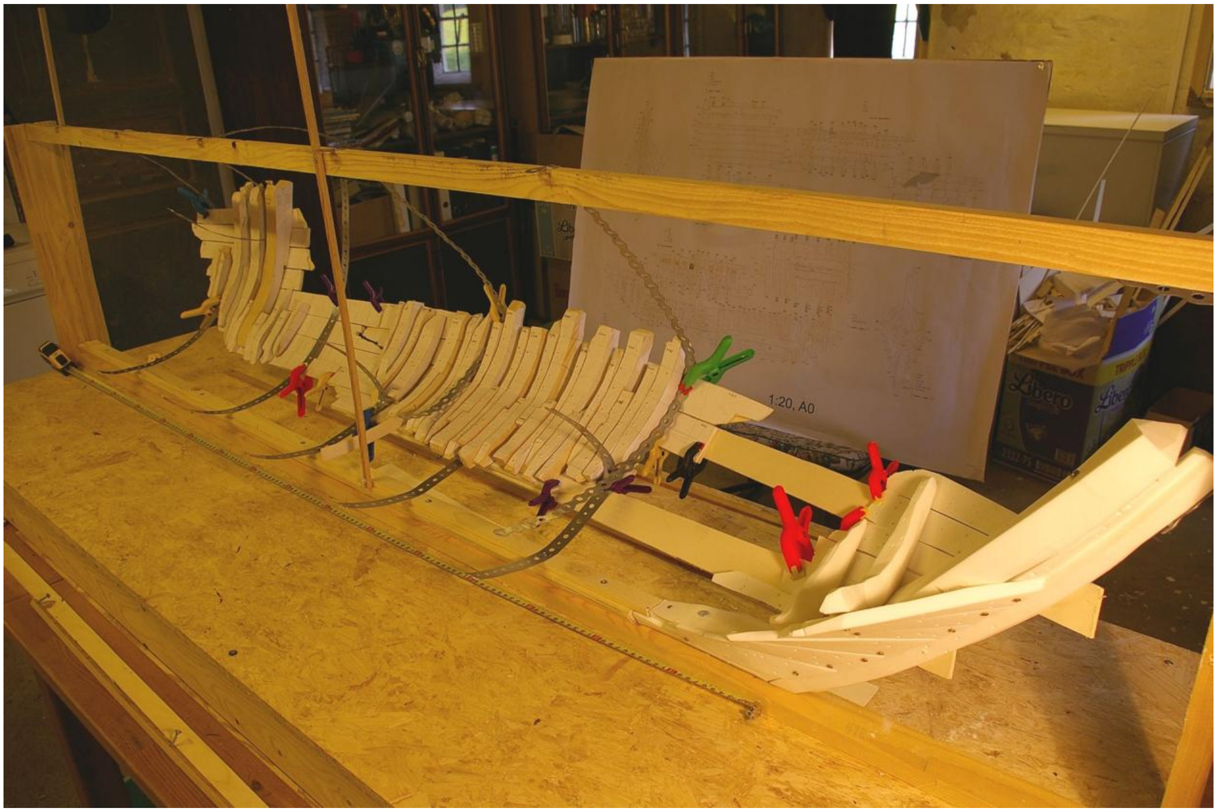

Figure 5-26: shows the simple "raw" model frame with three of the wreck pieces preliminarily installed.

As the alignment of the model pieces was developing it became clear that a more extensive system of scaffolding around the model had to be put in place. The initial metal battens that were used to hold the pieces were either too stiff or too soft and therefore difficult to control. The metal battens were removed with an exception of four that were attached to the keel acting like flexible floortimbers supporting the structure.

Vertical lists were attached on the left side of the frame with 20cm individual distance. A parallel number of lists were attached on the starboard side of the keel reaching to the longitudinal piece of wood running parallel to the keel 40cm above this. A system of additional lists could then be placed across the frame to secure the individual model pieces in their right positions. The scaffolding had several advantages in flexibility when it came to sliding and rotating the sections in position, but it also gave a much better visual impression as it was possible to remove several of the clamps from the model to the scaffolding.

Figure 5-27: picture showing the scaffolding controlled by clamps.

As the scaffold developed while the pieces were put in place it was possible to remove the last supporting metal battens from the frame and the model was then only supported by the scaffolding.

At some point the scaffolding holding the wreck pieces became too cumbersome to work with and several times I found myself running out of hands while trying to hold the pieces in position and supporting them with the scaffolding and clamps. To work around this problem a simple system of strings was rigged to a series of vertical lists on the side of the frame. The whole shipside that was held together by the wooden battens could then be placed in the lines and by adjusting the tightness of them the model could be lowered or raised to the right position. The whole shipside was supported by a few cardboard moulds and spacers that could be slid beneath the structure to adjust the height of it (see figure 5-24).

The frame that had been built for the model reconstruction turned out to be too short to contain the full ship. It was possible, though, to extend the run of the battens beyond the limits of the frame and therefore it was not prioritized to build a new frame. Also the vertical boards in the fore end and aft was replaced with smaller piece of wood that allowed for extending the stempost upwards and the keel could be prolonged further aft. Several of these alterations could have been avoided had the model frame been big enough from the beginning.

5.7 Recording the model

The recording of the model was done by using a total station. The 3d recording was going to be the basis for developing a prober lines plan of the hull. A manual approach of measuring the stations along the hull side could also have been chosen but the opportunity of recording the model with the total station would also result in a 3d digital model that otherwise would not have been directly obtainable. Because of the extensive framing it was not possible to gain a clear view of the inside of the planking and therefore it was chosen to record the outside shape of the planking

The first line to be recorded was the coherent running line of the stempost, keel and stern and after this the transom was measured. A series of the strakes were also recorded with their curving runs. A section at the master frame was recorded as section 0 and for every two meters for named F1, F2 etc and aft of this a section 0 they were named A1, A2 etc. This resulted in six sections aft of 0 and four sections from the for-ship.

Four waterlines were recorded with one meter of individual distance and the lowest waterline was one meter above the bottom of the keel. With these lines recorded in digital 3d form the whole model could be aligned to a coordinate system that allowed for exact top, side and front views. The model was then scaled to 20% which means 2% of the original size. The different views were converted to pdf files and printed on paper. From these prints a set of 1:50 lines drawings of the ship were produced. The process of making the drawing from the prints is explained in the chapter on the results of the model.

6 Results of the reconstruction

The most obvious result of the reconstruction model is a concept of the basic dimensions of the Princes Channel ship. Naturally the results must be seen in the perspectives of a number of uncertainties linked to the reconstruction, as explained in the discussion of the model. There are different kinds of results that can be deducted from the reconstruction. The basic dimensions such as length, breadth and depth are simply measured from the model, but there are other indirect outcomes that are depending on debated definitions such as the issue of tonnage where several different results can be found depending on what criteria used. Therefore presenting the outcome as results is not to be understood in the meaning of facts, but a possible way of interpreting the work of the reconstruction model. The detailed considerations of how the results were reached are explained and debated in chapter 5 on building the model and discussed in chapter 7. The immediate results are actually only part conclusions that should be included in a larger research strategy.

6.1 The basic dimensions

One of the central dimensions gained from the reconstruction is the length of the keel. Initially it was expected to be 14-15 meter of length based on the impression of the dimensions from the wreck pieces. As the reconstruction evolved and the modelled wreck pieces were placed in the frame it became clear that the expected length was a clear underestimate. Based on different considerations the length was set to 19m between the scarf of keel and stempost and the fitting of the sternpost. The rake of the sternpost was decided to be 20º from horizontal, based on archaeological comparisons and general rules from the contemporary manuscripts concerning shipbuilding. The position of the rake of the sternpost also determined the length of the ship at the level of the orlop deck to be 24,5m.

The breadth of the ship at the master frame, measured on the inside of the planking was found to be 7,4m of the furred hull and approximately 7m of the original hull.

6.2 Tonnage

The measurement of tonnage is a subject to much debate of the scholars dealing with the subject. A debate that is too extensive to present in detail in this context. A more extensive presentation of the subject can be found in W. Salisbury article on early tonnage measurement in England.(Salisbury 1966)

The tonnage of a ship is the measurement of the amount of cargo that a vessel is capable of carrying. The tonnage might not be the actual capacity of the ship, but it is used as a means to compare ships in size and to calculate the rate of port charges and taxes.(Steffy 1994, p.144) The development of tonnage as a measurement for ships was related to the development of the merchant fleet rather than for military purposes where the capacity of guns and men would be better measure for the ship.

In England from late fourteenth century and early fifteenth century the standards of tonnage was calculated from the standard of the Bordeaux wine casket. The estimated tons burden of a ship was based on the number of *tons* that could be stowed in the hold of the ship.(Salisbury 1966, p.43) It is mentioned by Salisbury that previous authors has stated that the cargo capacity could actually change after repairing or rebuilding of a ship, this should be kept in mind since extensive rebuilding actually happened to the Princes Channel ship. The casket or ton weighed 2240 lbs or 1016kg. In volume the ton was 57 cubic ft or 1,6 m^3.

There were several ways and reasons for calculating the tonnage of a ship. Except from the taxation perspective the shipwright also had a reason to do the calculation since he was paid after this measurement. In this way there were several reasons for either underestimating or overestimating the tonnage of a ship and therefore it is not a neutral technical value for a ship.(Friel 1983, p.54) In *Deans Doctrine of Naval Architecture* from 1670 it is mentioned that the rule for measuring the tonnage for any ship is a custom rather than the truth. And he argues that in reality ships of different design but the same general proportions could have very different tonnage capacity.(Lavery 1981, p.48)

The general rule for tonnage calculation that is closest to the Princes Channel ship both in time and place is stated by Matthew Baker in *Fragments*. Actually Baker uses two different formulas, one a bit more advanced than the other. In the following K is keel length, B is maximum breadth and D is depth of hold. The first formula is:

$$\frac{K \times B \times D}{K + B + D}$$

The formula most frequently used by Baker in his calculations is:

$$\frac{K \times B \times D}{100}$$

The second formula was adopted as standard in England in 1582, only shortly after the building of the Princes Channel ship, and it remained the general standard with modifications until late in the 17th century.

To be able to calculate the tonnage of the Princes Channel ship we must first convert the different dimensions to feet which are the original unit of measure. 1m is 3,28 times the length of a foot. The converted measures are as follows K= 62,32' B= 24,27' and D= 10,63'.

The dimensions inserted in the first equation gives a tonnage of 165,3 tons and inserted in the second equation the tonnage is 160,77 tons. Assuming that the shipwright aimed to build a 160 tonnage ship the calculation using the second equation comes fairly close. The combined weight of 160,77 tons would be 163.3 metric tons. The breadth used for this example was taken from the furred hull. If we calculate the tonnage with the second formula using the original intended breadth the tonnage is 152,10 tons.

6.3 The lines plan

A set of basic views of the recorded model was printed out in scale 1:50 and from these a lines drawing was produced by tracing the cross sections and water lines to sheets of tracing paper by hand. This procedure also included faring the lines from the staccato impression that was the result of the total station recording. Corrections of the sections was also done so that the spacing was exact and the lines straight and fair. Since only port side of the ship had been reconstructed it had to be mirrored to the starboard side as well. The mirrored side was sticking directly to the port side which was incorrect and on the manual drawing the breadth of the keel was restored by cutting the print-out of half- breadth view along the centreline and in that way made the two sides run parallel.

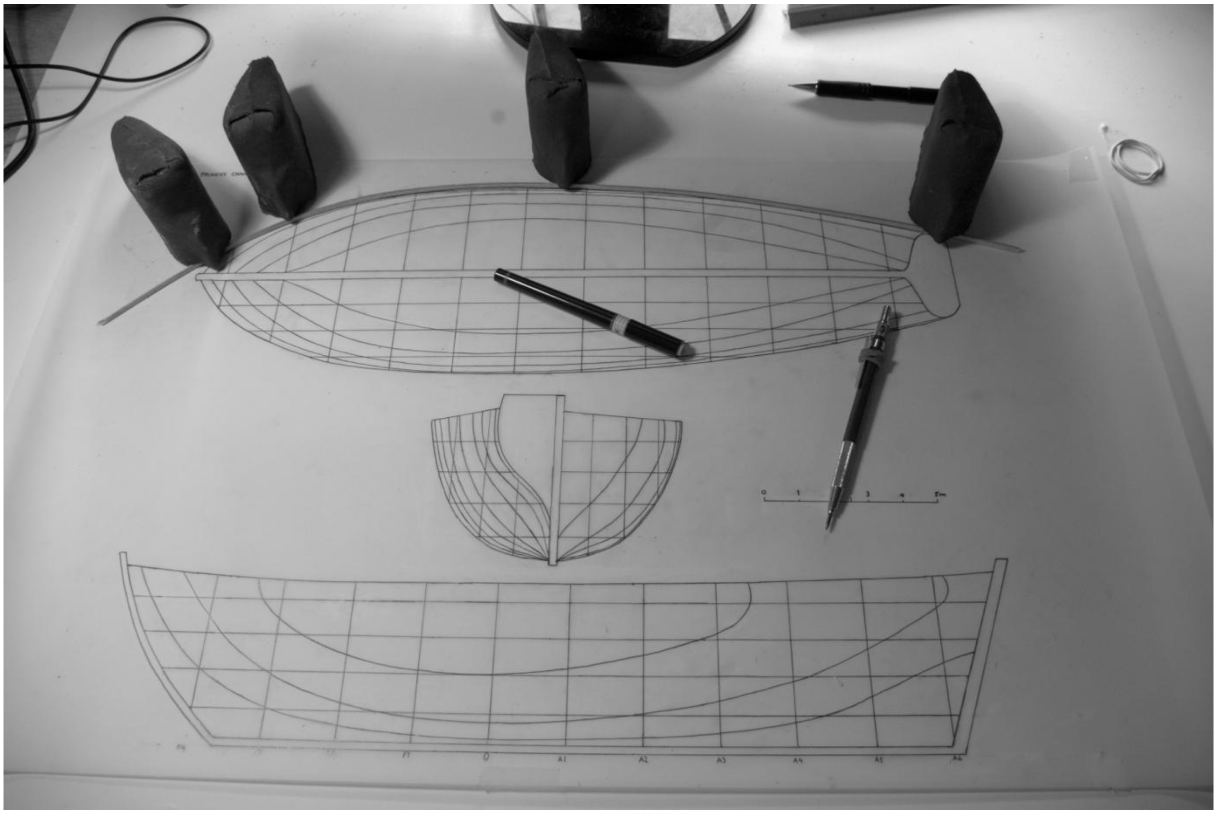

Figure 6-1: inking the lines on the tracing paper.

The lines plan consists of a top view or a breadth plan that shows the shape of the four waterlines and the extreme breadth of the hull at every station. The body plan shows an aft view (left) including the transom and a front view (right) combined. The body-plan reveals the shape of all the sections spaced with 2m between each. The sheer plan shows the shape of the buttock lines that are spaced for every 1m from the keel. All the lines are shown on each view but only one of the drawings reveals its curved shape.

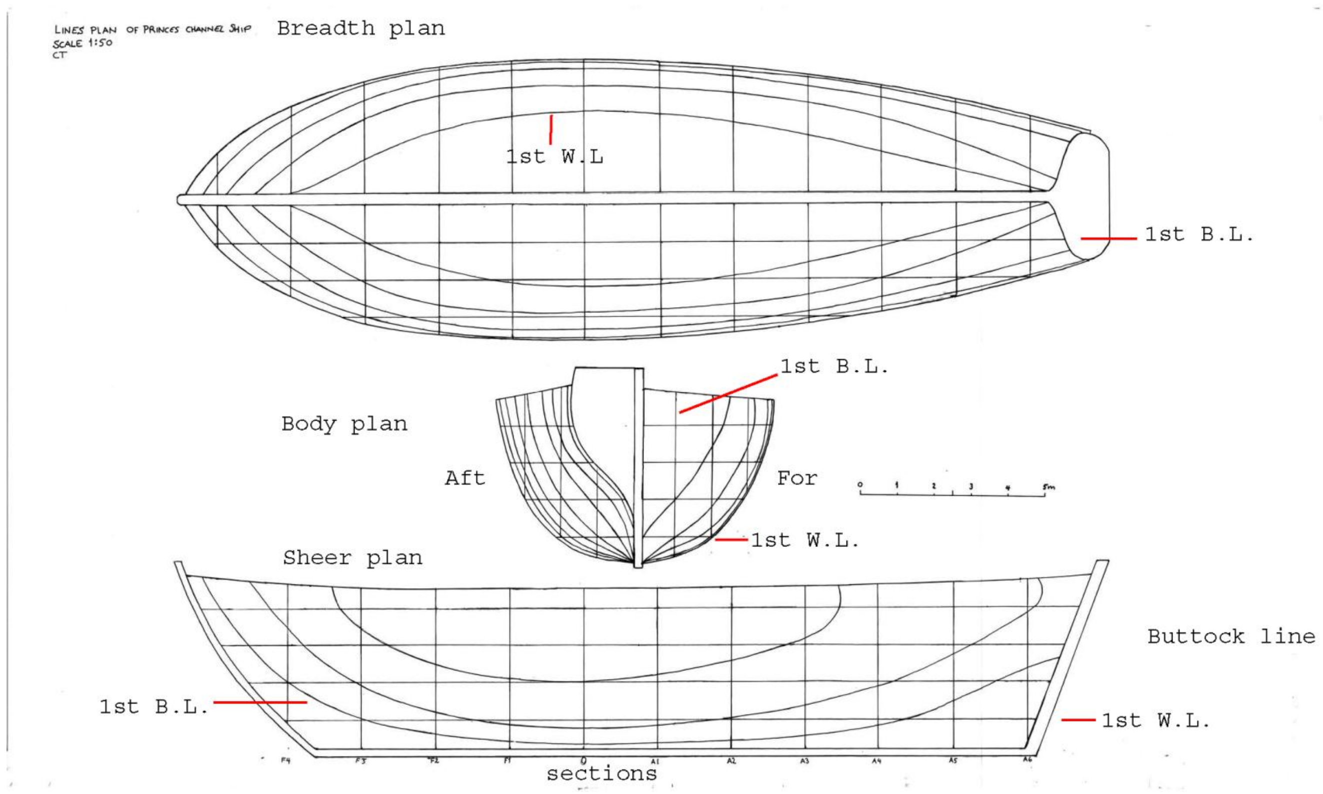

Figure 6-2: the lines plan, not to scale. B.L. = Buttock line, W.L. = Water line.

The 1:50 lines plan is included to this document as an appendix.

6.4 3d digital hull

As the direct outcome of the method used to record the model a 3d digital shape of the hull was produced. The wreck pieces were recorded as individual layers to illustrate their mutual positioning in the hull. As mentioned, the 3d shape was the basis for the lines drawing but it also includes a series of perspectives for further research such as digital hull performance simulations.

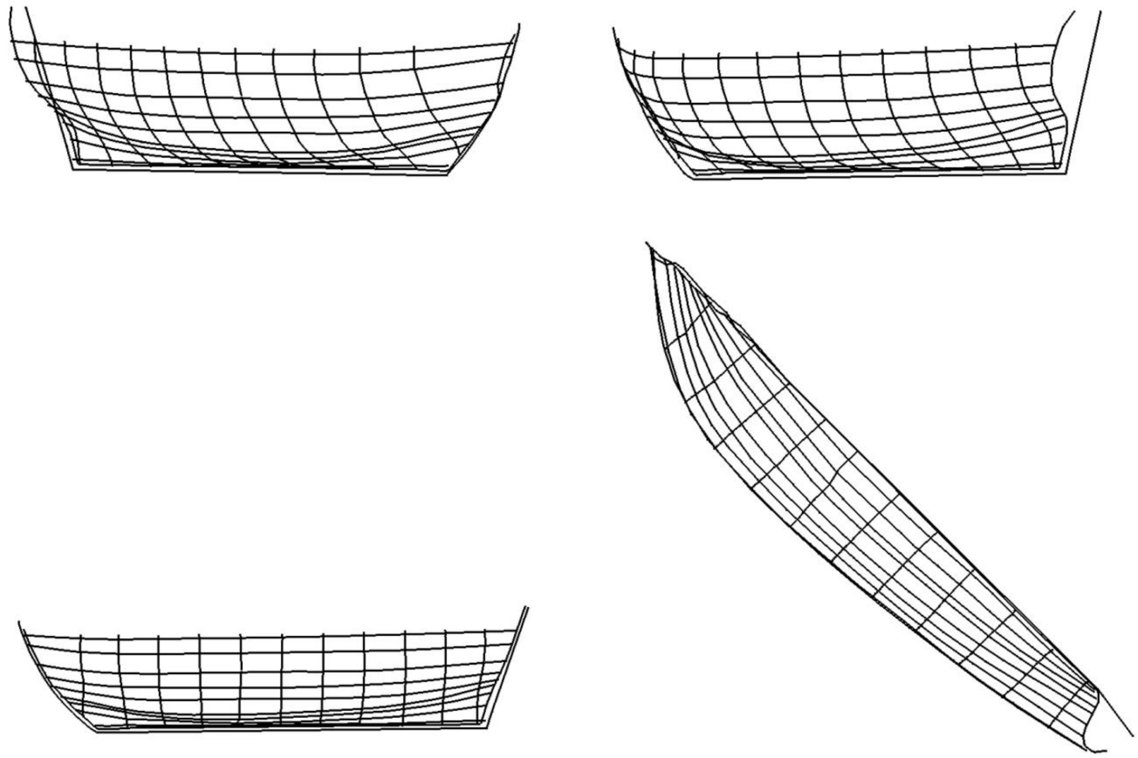

Figure 6-3: four views of the 3d digital model of the Princes Channel ship.

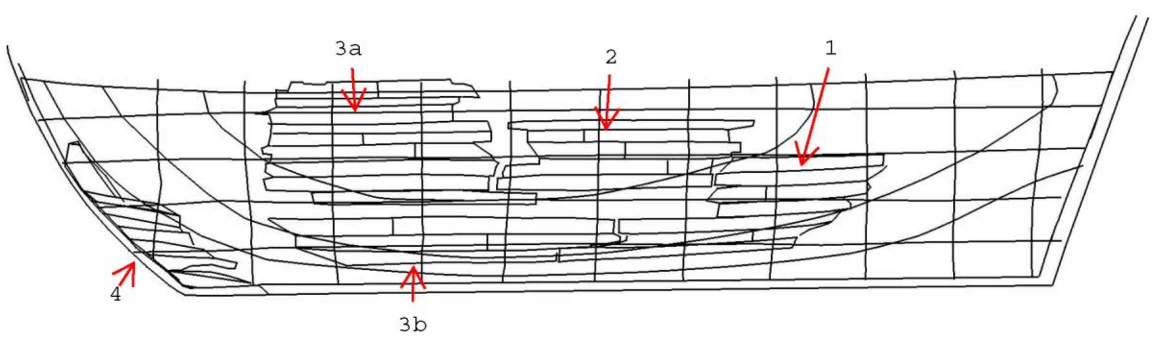

Figure 6-4: locations of the wreck pieces in the reconstructed hull.

7 Discussions

7.1 Discussing the model

The discussion of the model is closely linked to the description of the modelling process, but here some more details of the considerations behind the model shall be explained. The amount of unknown variables of the reconstruction model of the Princes Channel wreck makes the result open for discussing several central aspects of the outcome. Every single angle of the pieces of the model could be changed more or less and the outcome would be different from this present reconstruction. The issue is that the reconstruction is aiming for a general shape and size of the Princes Channel ship and the overall impression of these aspects are not changed by minor adjustments.

With this reconstruction it was tried to keep speculations of design and shape that is out of reach of the archaeological evidence to a minimum, and therefore the ship was only reconstructed to the height of the gun ports while everything above this area was left out.

The relational proportions of the ship are all calculated after the reconstruction model was built and recorded and are therefore extruded from the archaeological remains. By doing it this way the risk of ring conclusions transmitted from secondary sources are minimized.

7.1.1 The bow and stern

Luckily a unique persevered piece of the lower bow of the Princes Channel ship had survived for more than four centuries on the bottom of the Thames estuary. This piece was of central value to reconstruct the lower parts of the hull from bow to stern. A central issue that was to debate from the beginning of the reconstruction was the distance between the bow section and the heavily distorted piece 3a. This is brought up in the discussion because it is a key aspect in the shape of the ship. There is a possibility that the distance was originally shorter than concluded in the present reconstruction. If it is actually so, that the stem had been much closer it would have a considerable influence on the shape of the ship, and it would indicate a shorter but wider hull. A gradual rising of the head of the floor timbers shows that the last preserved floors are placed on a gradual rising line and therefore not far from the bow. There are no archaeological comparable cases to support this area. I am convinced, however, that the positioning is not far from the original. The supporting argument is the fact that the tapering of the planks would be very steep and have a sharp angle on the planks towards the hood end. A shape like that seems very unlikely when looking at the plank remains from the bow. Also the twist of the garboard and the second strake would by quite extreme in the transition between the bow section and piece 3a.

The upper part of the bow however is much more uncertain in its reconstructed shape. The solution that was chosen was a fairly straight run from the preserved planks toward the stem. The run was indicated by the shape of the wale that makes a bend just before the brake. It is likely that the bow at deck level was fuller in shape and this is definitely a place in the reconstruction that is open for an alternative solution.

As the aligning of the wreck pieces took shape it was necessary to extent the height of the stem post. The prolonging was done by copying the tangent of a circle that shaped the stem post and cut it out in a piece of wood. Extending the stem post by continuing the arch is supported by the illustrations of Matthew Baker's manuscript and also a *Treatise on shipbuilding* explains the construction of the stem as "*one or more compass timber scarfed and bolted together, swept out by a circle whose radius is the strake forward on."* (Salisbury & Anderson 1958, p.7)

Archaeologically it is rare to have an extensive preservation of the stem post like the case of Princes Channel and therefore it is at the moment not possible to present closely related archaeological comparable finds. The closest is probably the Mary Rose which has the stem post construction preserved and it shows the same concept of the stem post being a sweep of an arch.

The Swedish royal warship Vasa from 1628 that is almost completely preserved also has a stem post that was made from the sweep of an arch. The Vasa and the Mary Rose are in age and size not comparable to the Princes Channel ship but the evidence of the stem post shows that the method was used in different contexts of shipbuilding.

The preserved part of the stem post of the Princes Channel is approximately half of its original length but it shows that it was constructed as sweep of a circle with a radius of approximately 10m. This radius is measured on the outside of the stem post. In comparison the radius of the Mary Rose stem post is roughly 27m.(Marsden 2009, p.86) By prolonging the stem post with the continuous sweep the hood end of the strake battens could be attached to it. In this way it was possible to establish the complete run of the strakes towards the bow.

A geometrical rule of thumb in the *Treatise on Shipbuilding* says that the radius must never precede the whole breadth of the ship and the optimal relation is ¾ of the ship breadth. In the case of Princes Channel but especially the Mary Rose the radius is far bigger than the breadth of the hull. In fact there seems to be a major difference between these dimensions. In the commented publication of a *Treatise on Shipbuilding* W. Salisbury notes the inconsistency of the dimensioning and believes that an error most have occurred during transcription.(Salisbury & Anderson 1958, p.40) Based on the remains of the stem post and secondary textual and archaeological evidence, it is fairly safe to assume that the reconstruction of the stem post is trustworthy.

If the guide line for the stem post as mentioned in the *Treatise* was applied anyway, the calculations could be as follows. The optimal proportion according to the manuscript is the same as 7,125´ of 9´ this is equivalent to 79,1%.(Salisbury & Anderson 1958, p.23) It should not be forgotten that especially in the case of the Princes Channel ship there are certain problems concerning the breadth of the ship. Not only the absence of floor timbers that could connect the shipside with the keel, but also the fact that the ship has been furred to increase its breadth.

The outer line of the Princes Channel ship stem post forms a section of a circle with a radius of 10,28m. If constructed after the principles in *A Treatise on Shipbuilding* the radius should make up between 75-100% of the breadth of the ship with the optimal being 79,1%. Because of the furring of the ship we must assume that something in designing the original hull shape had to be corrected and was a least partly rectified after it was furred. If 100% of the breadth is the absolute maximum we can assume that the ship was originally closer to the 75% maybe less since it had to be made broader. After the furring it is reasonable to assume that the breadth was between 75-85% of the stem post sweep radius, which means somewhere between 7,69m and 8.73m. The reconstruction suggests an intended width of the original hull of 7m which is approximately 2 feet narrower than the lowest value calculated from the stem post. It was more or less this breadth that was added to the ship by the later furring.

In the other end of the ship a great deal of uncertainty is involved in the reconstruction. There has been reconstruction attempts of other much less preserved wrecks like for example the theoretical reconstruction of the Alderney ship were only the rudder was preserved or the purely hypothetical reconstruction attempts of the *Mayflower* or the *Susan Constant*. For these reconstructions the only basis was the early manuscripts on shipbuilding and their geometrical rules with generally a great deal of leverage in the designing possibilities. It would have been possible to use similar rules to try and re-establish a design for the transom, but using the treatises for the purpose would hardly be a more true solution since the design method or the geometrical rule-set used has not been positively identified.

Figure 7-1: the sternpost of the reconstruction model.

The rake of the sternpost is a matter of choice and qualified guess rather than direct evidence. The closest example on archaeological evidence of a stern rake is probably the remains of a ship from Alderney. Actually the only thing preserved of this ship is the rudder. From analyzing the angle of the rudder the rake of the stern is calculated to be 16º from vertical. (Roberts 1998, p.33) This is a bit steeper than recommended in the Treatise on Shipbuilding, where it says that the rake of the stern post should never be more than 22º or less than 18º from vertical, (Salisbury & Anderson 1958, p.23) similar guidelines are given by Baker.

A ship of different origin but largely contemporary with Princes Channel is the Basque whaler found in Red Bay in Labrador. The ship was extensively preserved including the complete stern structure and transom. At this ship the rake was 21 º from vertical and thereby within the recommendations in the Treatise on Shipbuilding. The Iberian-Atlantic vessel found in British waters in the Studland Bay has a fragment of the aftermost part of the keel been preserved and from this the rake is known to be 20 º from vertical.(Thomsen 2000, p.72) Since there are some constructional features, such as the dovetail joints that relates the Princes Channel ship to the Atlantic-Iberian tradition, it is possible that the Princes Channel ship had a sternpost construction similar to these ships. Since the rake recommended in the Treatise on Shipbuilding also corresponds to what is found in Studland and Red Bay it would not be controversial to propose a rake of 20º for the sternpost of the Princes Channel and since the evidence for the Alderney ship is sparse it was chosen to reconstruct the ship with this rake of the sternpost.

7.2 Adjusting the midship

As the lines from the model were forming into the basis for the lines plan it became clear that some parts of the hull were not quite trustworthy. The midship bend seemed to be slightly narrower than the section F1. The model setup had to be re-evaluated to see if better results could be gained. The whole structure was twisted by force so that the rear end came out a bit while the bow was pressed slightly further in towards the centre. This made the area just behind section 0 straighter and longer before it started the narrowing towards the stern. The twist affected section 0 so that the midship bend was widened by a few centimetres and became slightly broader than F1.

7.2.1 Proportional relations of the basic dimensions

Discussing proportional relations of the basic dimensions of the ship might be helpful as an initial investigation and comparison to the contemporary treatises on shipbuilding as well as to other ships. The relations of the dimensions are simply shown by dividing the one dimension with the other. In the literature the calculations are not always done in the exact same way and therefore the one result will show how many times the larger is divided in the smaller dimension while the second will show the percentage of the lesser value compared to the greater. If for example the a keel of 21m is divided by the breadth of 7 the relation is 1:3 and if the breadth is divided by the length the result is 0.33 or 33%.

The breadth measured on the inside of the planking at deck level is 7,4m while the breadth of the original hull was closer to 7m. The depth from deck level to the upper side of the keel is 3,24m. In proportion the furred breadth is 2,28 times the depth of the hull. The best proportion between these two dimensions is according to the Treatise on Shipbuilding, 7 to 3 or in decimals the breadth is 2.33 times the depth.(Salisbury & Anderson 1958, p.15) Compared to the Princes Channel ship the proportional relation is fairly close to what is recommended by the treatise and definitely within the range of allowed variation

With the master frame placed 7m from the stem post scarf it is tempting to conclude that the keel should be 21m since the recommended placement is 1/3 of the keel length from the stem post. Like in the example above the keel length of 21m on a ship only 7m wide would have a length/breadth ratio of 1:3 or 33%. In the reconstruction of the Susan Constant, Brian Lavery mentions a list of small to medium sized merchant ships around 200 tons. The average breadth of length is 39,2% for the larger and 41,6% for the smaller ships. This list is dated around 1625 but the proportions seem to have been fairly constant from the 1580s to the 1620s. (Lavery 1988, p.10) Compared to the average of the ship list presented by Lavery, the original breadth compared to the 19m keel is slightly below average with 36,8%. If the furred hull breadth of 7.4m is compared to the 19m keel it would be 38,9% and thereby very close to the average length breadth ratio of the listed ships from 1625.

The length/breadth/depth ratio of the hull with 19m long keel and the furred breadth would be 1: 38,9% : 17%. The *Treatise on Shipbuilding* recommends a proportional relation of 1: 40%: 16.6% while Matthew Baker suggests the relation to be around 1: 40%: 20%.(Lavery 1988, p.10) With these proportions as comparison the Princes Channel ship must be characterized as a fairly common of proportions and close to the recommendations of the *Treatise*. One could argue that the Princes Channel ship is closer to the *Treatise* than Matthew Bakers *Fragments*, but the uncertainty of the reconstruction and the relatively small difference between the manuscripts would be a very fragile foundation for such a statement.

Another principal proportion of the 16th and 17th century manuscripts and treatises is the relation between the main breadth and the flat of the floor timber. (Adams 2003, p.133) The reconstructed master frame shows a flat of the floor timber of 1,1m which is 14,8% of the main breadth (7,4m). In his work on the Sea Venture, Jonathan Adams has recorded the different recommended proportions of the flat of floor in relationship to main breadth, from treatises and manuscripts ranging from 1545 to 1670.(Adams 2003, p.137) This work clearly shows a development from a narrow flat of the hull around 14% in the earliest manuscript while the relation increases to 20% around 1600 and in the latest source Deans Doctrine from 1670 the flat of the floor timber has reached 33,33% of the main breadth. The material that was included in Adams work were mainly concerning large merchant ships and warships but the Princes Channel ship seems to chronological fit the statement of ships of the earlier part of the period by having a narrower flat of floor than later on.

It is noticeable that the depth of the hull is almost exactly the same as half the breadth of the original breadth as it is recommended to be in *Fragments of Ancient English Shipbuilding*.

7.2.2 Design of the master frame

The design of the master frame is a central but also a problematic issue. The first question is exactly which design we are trying to reconstruct by this reversal engineering, and is it at all possible to reach a final definition of the ideas and concept behind the design? What is clear from the initial investigation of the reconstructed master frame is that it is designed from a series of sweeps of arches. It is clearly evident that three main arches are the basis for the master frame and this counts for both the original hull and the furred ship. The problem is however that it can be difficult to determine exactly where one sweep ends and the next one takes over. The transition between the sweeps is fluid and it is therefore possible to dislocate the sweeps of the frame and thereby also dislocating the design. This issue also makes it problematic to try and establish geometrical rules on how the master frame was designed. The radius of the circle of which only an arch is known can be calculated by the formula:

$$\frac{Rise^2 + (\text{span} \div 2)^2}{2 \times Rise}$$

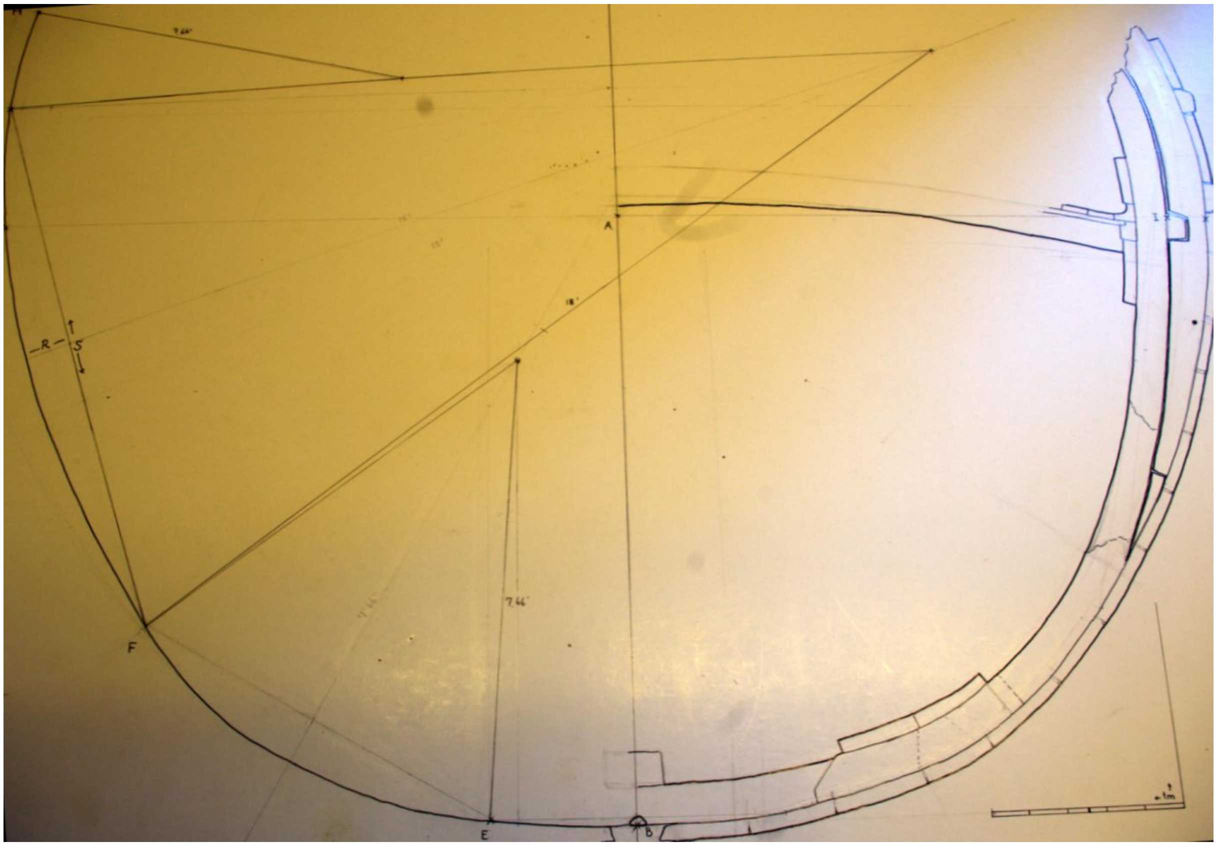

Figure 7-2: the master frame with the three sweeps of arches. *R*= rise, *S*= span. Not to scale.

The three main sweeps are the wrong-head sweep, the futtock sweep and the upper sweep. The wrong-head sweep begins about 70cm from the centre of the keel and consists of an arch with a radius of approximately 205cm. The radius of the futtock sweep is the largest with a radius of 554cm for the furred hull. The sweep for the original hull is more uncertain because the curve of the futtocks might have been altered during the rebuilding but judging from the steep futtocks it was probably a bit larger than the radius of the furring timbers. If the radius was actually as big as the recorded timbers indicate without knowing whether or not they were altered, the radius is 30-35m but this is hardly the case. The upper sweep of the furring also represents the tumblehome of the hull and the radius of this sweep seems to be similar or close to the futtock sweep. The measures of the circles are only approximations and might change depending on exactly where they were taken. The problem by taking the relation between the sweeps and deduct a set of design rules is enforced by the fact that the Princes Channel ship was designed in two different tempi. It would be possible to deduct a full set of rules that would apply to the reconstructed master frame, but the result would be highly speculative.

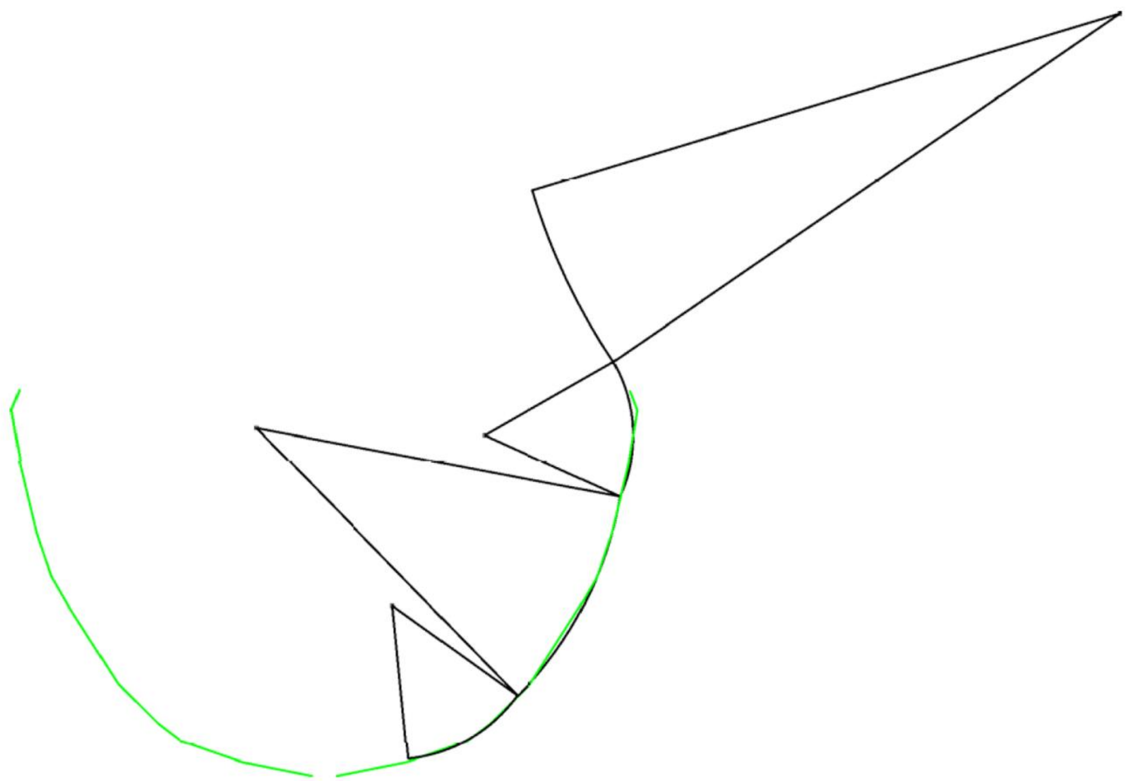

Figure 7-3: shows the midship bend with superimposed sweeps of arches following the geometrical rules of Folio 91 in *Fragments of Ancient English Shipwrightry*.(Adams 2003, p.134).

The sweeps of arches superimposed the midship bend on the figure above are deducted from geometrical rules from one of the folios in Matthew Bakers *Fragments*.(Adams 2003, p.134) The Folio 91 was most likely produced by John Wells who was the second author of the work and he inherited it after Bakers death in 1613. The geometrical rules that have been applied above do not fit with the reconstruction of the Princes Channel ship and also it has not been adjusted for the fact that the rules are referring to the outside moulded dimension of the frame while the midship bend that it is compared to here is from the outside of the planking. The intention of the figure is simply to show a possible approach to find the fitting rules for the design of the ship.

What is maybe more central than the exact rules of geometry is the fact that the ship was definitely predesigned from a concept of arches of circles forming the midship bend. This statement is obviously more vague, but establishing the exact method of design is beyond the extend of this thesis.

7.3 The lines plan

The lines plan was the intended main product of the model building. It was made from recording the model with the total station and is in that sense very precise. The lines plan is of course never more precise than the reconstruction and the reconstruction is never more accurate than the recording. The lines plan is not a detailed plan but an imitation of the hull shape. The digital wire-frame of the hull was altered slightly in problem areas, mainly of the upper bow where nothing was preserved. These alterations happened directly in the digital form by consulting the model and trying different solutions for the run of the planking.

The common way to draw the lines is of the moulded shape of the hull. This means that the inside face of the planking is defining the lines because the thickness of planking often vary above and under the waterline and also wales are much thicker than rest of the planking. Therefore it is often difficult to get smooth even lines of the outside face of a wooden carvel hull. In cases like this reconstruction of the Princes Channel ship the problem was rather to get a clear view of the inside planking since this was largely covered by the framing. Because of this it was decided to record the outside of the hull to use as the basis for a lines drawing. The difference between the results of the two methods would in practice only be the thickness o the planking and since the planking in this case is a standard size of 6mm the variation of planking thickness is not a major issue. The original way of copying the lines of a ship hull was also by measuring the outside of the planking at stations along the ship, since recording the inside of the planking would often be practically impossible.

The lines drawing has not been subjected hydrostatic analysis but the initial impression of the hull shape is a relatively sharply defined bottom of the ship, with a slender aft part of the hull. The transition between the bottom and the sides of the ship is also very distinguished, whereas the shape above the bottom to the lower wale is formed by a noticeable flat curve. The impression is that the ship was a relatively fast sailor and not distinctively merchant like in shape.

7.4 The archaeological recording

Preparing the data of the digital recording of the Princes Channel was half the work of making the model. The main part of the work was to clean the files for disturbing and unnecessary information. This was necessary just to get an overview and a clean outline of the timbers. Especially around breaks in the timbers the recording could be very confusing to interpret and these areas had to be extensively modified and simplified. The wreck pieces were left assembled during the recording and this decision led to frustrating moments during the digital reconstruction and preparing of data. The amount of interpretation could have been drastically reduced had only selected elements been removed to allow recording of the hidden construction. Especially in this case with the Princes Channel ship this would have been rewarding because of the double frame layer. If maybe every second original futtock had been removed together with a few of the furring timbers, the quality of the recording would have been extensively improved. This would have given the opportunity for a much more precise reconstruction of not only the concealed framing elements but also the inside of the framing. The preparing of data was naturally much easier of wreck pieces with only sparsely preserved framing.

Another aspect that disturbed the quality of the recording was, to be able to shoot both the inside and the outside of the wreck pieces with the total station, the wreck pieces had to be flipped over when one side had been recorded. The own weight of the wreck pieces caused them to change the shape when moved around. This was a problem when the two recordings of a piece had to be merged to one coherent file, and then the two shapes would not correspond entirely to each other. A solution of this problem could have been to ensure a better stabilization of the pieces and their position so that only a minimum of moving them around would have been necessary. A strategy where the total station was moved around instead of moving the pieces would have ensured a better correspondence of the inside and outside faces in the final file.

From a reconstructional point of view the recording could have been optimized drastically if a more carefully planned recording strategy had been chosen. Unfortunately this was not possible due to political decisions, severe time pressure during recording and the experience with the method of recording at a pioneering state. The optimal solution for the total station recording of ship timbers would be to combine the recording of the coherent pieces and gradually removing timbers to be individually recorded. With an additional detailed recording of individual timbers a more fulfilling dataset would be created of the wreck and the work of reconstruction would be much more natural and a straightforward proceeding of processing the data. If the timbers had been individually recorded it would have been possible to determine the angle of fastenings penetrating the timber and preparing them for reproduction would also have been much less troublesome.

The recording should also be simplified, not meaning a less amount of detail but by increasing the accuracy of the recording and making a detailed strategy of shooting. Before beginning to record, markings of areas, details and edges that are to be recorded is crucial for the quality of the outcome. The staff should be able to recognize relevant features that need detailed recording from areas of more irrelevant nature. In that way attention should be given to ensure that scarves and other constructional features are recorded to full extend and that eroded and broken areas are made recognizable but also that the amount of detail should not confuse more important constructional features.

Another step that could be implemented in the recording would be to make a system of cross sections on the timbers. In the Princes Channel recording the outline of missing frames on the inside of the planking was a great help for aligning the planks properly after reconstruction. If possible two or preferable more cross sections should be made of each timber and these would also function as control lines when a possible model is built.

When this has been said about the total station recording of the Princes Channel ship it should be recognized that aspects of the recording were very functional and helpful when working with the recording files. The basic layout of every timber being recorded in its own layer was absolutely indispensable when preparing the data for physical reconstruction be that in wood, cardboard or plastic. Also fastenings of different kinds, concretions and other details were distributed in individual layers that could be turned on or off as wished. This sorting of data and the Rhinoceros 3d software was a very flexible working platform that offered good possibilities for working with the, to some extend problematic dataset.

A total station recording of wrecks in the future is definitely a possibility that should be considered in many cases. The method cannot be used underwater but is effective for fast accurate recording either of salvaged wrecks like Princes Channel or in dry excavations the total station recording has a large potential. The nature of 3d recording makes it very suitable for registration large and complicated objects that can be difficult to register satisfyingly by traditional methods. The method works as a primary recording facility but hand sketches and measured drawings are important supplemental recordings that should be highly prioritized. An extensive photographical recording is also essential for the quality of the holistic wreck recording.

When it comes to archaeological projects it is often the case that there is no complete strategy from the beginning of an excavation to the final display or publication, especially with rescue archaeology this is a major problem. A project like the Princes Channel ship is carried out in stages that rely on individual funding. This means that it was not possible to make a complete solution for the wreck and its destiny was relying on a series on temporary solutions that is now resulting in a rapid dissolving of the timbers and a possible complete loss of the archaeological remains. This kind of rescue archaeology that is actually only delaying the destruction of the excavated material, demands an extra high quality of recording since it will in many cases not be possible to go back to the material to clarify questions that have been left unanswered.

Digital recording methods are getting more and more common and are now often the norm compared to traditional manual recording. The complete digital reconstruction of a ship wreck is definitely a possibility and is under rapid development but the physical model is none the less an important part of all the research projects summarized here.(Bischoff et al., p.14) The cardboard and wood approach is a preferred method in many cases because it gives a manual feeling for the construction and an understanding of details that otherwise is difficult to reach, but it is definitely also a question of tradition.

The Newport method shows the way forward in creating a physical ship model directly from the digital recording, a method that contains great possibilities also for future reconstruction projects. With new methods new problems appear in the wake. Questions about filing and saving the information for the future is a real problem that needs discussion and attention by the archaeologist using digital recording methods.

No matter how well every step in the reconstruction process is carried out, the finished model or full scale reconstruction will in many aspects remain a hypothesis but so will our understanding of history.

What ship is being reconstructed? Is it the ship as it was thought of by the shipwright, is it the ship as it actually came to be when finished and ready to be launched or is it the ship as it was while performing in service? A ship wreck contains the potential of many shapes and the task of reconstruction is to find those that represent ideas, practical solutions and wear of use.

There are no international standards for archaeological recording, be that land or maritime archaeology. Often the planned processes of the archaeological work are altered during excavation and improvisation to solve unforeseen problems is unavoidable. New systems of excavation methods and recording tools are constantly being developed to counter the problems arisen from environmental and archaeological conditions. In this way different traditions and methods have evolved as part of institutions working with the matter.

Maritime archaeology is probably the most technically advanced discipline within the field of archaeology when it comes to recording large complicated shapes. The environmental conditions call for excavations that need technical and specialized equipment but nonetheless it is still archaeology and the aim is to learn about the societies of the past that tells the stories of our time.

8 Conclusion

The main aim of this thesis was to produce a lines plan of the ship that sank in Princes Channel in the late 16th century. The available material was the recordings of the salvaged ship wreck that was lifted from the sea floor in 2004. The aim was reached through a 1:10 reconstruction model of the wreck, built from the 3d total station recording of the salvaged parts. The construction process was to a high degree an experimenting process which in this case was not possible to plan in every step. There was a general plan of the procedure but problems of different kinds appeared and often it was necessary to improvise to reach a solution. Part of this definitely came down to personal inexperience of ship reconstruction through modelling.

From a reconstruction perspective the recording method proved to have several problems linked to it, but most of the issues were overcome and for most cases reached with satisfying results. The construction of the wreck parts as scaled models proved fairly accurate and a reliable hull shape was gained as the wreck parts were aligned to form port side of the ship. Combining two different methods of modelling were used while reconstructing the archaeological material and both approaches proved successful.

The preparing of the data for both the selective laser sintering and the wooden model was a labour heavy process that had some uncertainty involved while reconstructing poorly recorded parts. The finished shapes of the wreck pieces were however convincing in their outcome, even though heavily distorted areas were in the case of piece 3a partially transferred to the model.

Except from producing a lines plan of the ship the reconstruction revealed that the ship had definitely been designed before the building process started. The dovetail joints and the fore and aft oriented horizontal treenails between the floor timbers and the futtocks indicated this. With the reconstruction it became clearly visible that the midship bend was designed from three arches intersecting each other. It was also evident that the master frame was not a complete pre-erected structure like it is the case of the Iberian building tradition. Only the floor timbers and first futtocks were raised together while the structure from above the first futtocks must have been built by a frame-led method rather than a frame based.

By comparing the basic dimensions of the Princes Channel ship it becomes clear that it represents an average size of ship for its time. The length of the keel compared to breadth and depth is actually remarkably close to the recommendations of both the *Treatise on Shipbuilding* from 1620 but also the older *Fragments on Ancient English Shipbuilding*. Even though the shipwright clearly was following a set of geometrical thumb rules when designing the ship, something went wrong in the process. It is not clear whether his design was wrong from the beginning or his plans were not accurately followed in the shipyard. Anyway the ship must have proven to be unseaworthy since an extensive rebuilding was necessary. Whether or not the furring of the hull was a redesign or merely a rebuild is not certain, but the furring timbers are clearly shaped by the principals of sweeps of circles and therefore an actual redesign is very plausible.

Recording the shape of the model with a total-station was a reliable method of getting the shape of the reconstruction. With the shape once again in digital form it was unproblematic to prepare the data for making a set of lines plans. The rough data of the ship lines were printed to paper and traced manually. It would have been perfectly possible to create the lines plan in a fully digital version, but the manual tracing, I would argue, has a more appealing finish.

The initial conclusion of the ship's shape, based on the lines plan, is a fairly sharp bow section that turns into a bottom with a slight rounded deadrise at the midship bend, and with a slender aft body. The ship is not a plump merchant vessel but has the shape of a relatively fast sailor. Since no hydrostatic analysis has yet been made it is not possible to say anything specific about the performance of the hull.

The physical modelling as a research tool is evidently unavoidable for attaining basic information about hull dimensions of a ship in the preservation state like the Princes Channel ship. The modelling is an interpretation of the archaeological material but placing the recordings in 3d context, like a reconstruction model, enhances the possibilities of the interpretation to a higher level.

The initial setups showed different hull shapes than the final model. It was necessary to dismantle the pieces several times and try out new possibilities until the best fitting solution was reached. It would have been possible to look for solutions in for example Baker's manuscript for indications on dimensions and proportions but the effort was put into letting the archaeological material and the model develop itself. Eventually this process will lead to many questions where interpretation becomes the shaping factor.

Part conclusions and measurements are really difficult to obtain and should be avoided until every element is in place and fitting. Adjustments of one part can force changes in the whole setup. Therefore it is important to consider several different options and try them out before reaching conclusions.

Loss of data: for each interpretation there is a data loss. This happens during recording the wreck, digital reconstruction, copying to wood and cardboard and shaping the components. This is a simplification of the data that enables the researcher to work with the material and reach some sort of conclusion. Without this simplification there can be no interpretation and without interpretation there can be no conclusion. This does not mean that the data-loss never has a negative effect on the research. In this case every interpretation level holds uncertainties and therefore probably includes some errors in the reconstruction of the ship.

The time needed for making a reliable model reconstruction is easily underestimated. I spent several days with the model-setup only making minor adjustments and just observing it. This often resulted in frustrating feelings of not moving forward with the research. However the time used on observation resulted several times in radical changes to the model that proved elementary for the result.

The reconstruction model and the creation of the lines plan is forming the basis for further investigation of the Princes Channel ship as a potential pool of knowledge of the common English ship of the 16th century.

Summary

In 2003 a wreck was discovered by the Port of London Authorities in Princes Channel in the estuary of the Thames. It was initially thought to be the remains of a barge from modern times and without further historical importance. During the salvaging different items along with a cannon appeared in the mechanical grab and the cultural heritage authorities were notified. An underwater excavation was carried out and five major wreck pieces were lifted from the sea bed for further investigation.

The wreck showed a remarkable constructional feature which has no archaeological comparison. In a few historical documents, references to the particular feature were found and the term "furring" was applied. The furring was an extensive rebuilding of the hull of a ship. The planking was stripped from the side of the ship and the original frames were supplied with additional furring timbers to make the hull wider.

The ship carried a cargo of iron and metal bars and was therefore thought to be a merchantman of medium size. The dating of the ship was determined by dendrochronological analysis to shortly after 1574 and thereby falls into a period from which the archaeological knowledge of the English merchant fleet is very limited. Except from being the only excavated wreck of an average sized merchant ship from the early renaissance its date of construction is very close to the earliest manuscripts on English shipbuilding.

The first chapter is a short introduction to the material of investigation along with the aims and objectives of this thesis, followed by a review of approaches to modelling and reconstruction of ship wrecks. The aim was to produce a set of lines drawings of the ship based on a 1:10 reconstruction of the model and while doing this also to establish basic dimensions of the ship.

The second chapter summarizes secondary sources of early manuscripts and treatises on shipbuilding in England in the 16th -17th century. Secondary archaeological sources are also summarized and the background chapter introduces different regional shipbuilding methods from the same period as the Princes Channel ship. The Atlantic-Iberian tradition is incarnated in the wreck of a Basque whaler from Red Bay in Labrador as it holds all the features that are generally characterizing this tradition. The

tradition is based on a frame-first construction method where the framing is predesigned and preassembled before it is placed on the keel. The link between the Atlantic-Iberian tradition and the Princes Channel ship is the characteristic dovetail-joints between the floor timbers and the futtocks. The main Dutch shipbuilding traditions were bottom-based or frame-led construction methods.

The English method of ship construction is not a strictly defined method, probably because it was not homogeneous, but also because of lack of archaeological evidence. Anyway a general outline of the English method is possible to reach and it seems as if the technique was somewhere between the Dutch and the Iberian-Atlantic method where the frames were preerected to the height of the first futtock.

The third chapter is a description of the wreck parts from the Princes Channel. It describes each individual wreck piece in size and components, and it also includes a more detailed description of central structural components, the furring and the building sequence of the ship.

Chapter four is a presentation of the archaeological methods used to record the wreck on the sea floor and the total station recording of the wreck pieces on land. The underwater excavation was done by a team of divers but recording was problematic due to environmental conditions of strong currents and very low or even zero visibility. On land the pieces were recorded as individual pieces with a total station as the main recording method.

Approaches to reconstruction are considered in three levels: the graphical reconstruction is a 2d presentation of a ship, including tables and illustrations. The physical reconstruction is divided in a scaled model reconstruction and a full size rebuilding of the ship. The three levels of reconstruction are highly dependent on each other and results from one level of reconstruction influence the others.

In chapter five the process of building the reconstruction model is explained, including the work of preparing the data for the two different methods of modelling used. The first method consists of plastic components produced by selective laser sintering that directly reflects the digital reconstruction, while the second method is a manual production of the scaled timbers in wood and cardboard. Further the chapter explains the process of aligning the wreck pieces and how the model frame needed to be developed as the model took shape.

The results of the model are presented and summarized in chapter six. Both the main product of the lines plan and the basic information of the ships dimensions are shown here. The estimated tonnage of the ship calculated from the formula of contemporary standards is presented. The question of tonnage is a much debated subject and the measurement is not an objective calculation of the ships size, but a value that changes with the reason of why it is demanded.

Chapter seven is bringing up different subjects to be discussed. It concerns the modelling process and the reason why certain issues were solved as was the case. Further it brings up some thoughts about the design of the master frame. The issue of design is only superficially discussed and no definitive results are sought for here. It is mainly discussed what methods could be used to establish results in further investigations. As a last but central issue some aspects of the main recording method used on the Princes Channel ship is being discussed. There were certain problems with the recording material that should be sought solved if the same basic method is to be used for recording in comparable cases.

10 Outlook

The Princes Channel ship needs to be placed in a larger historical context of common merchant shipping in Europe at its time. The ship was not a specialized cargo carrier, which is clearly indicated by the lines plan. It was a fairly slender and probably a fast sailing vessel armed with artillery for aggressive defence. The wreck from Princes Channel is an interesting and unique chance of investigating the dual role of the merchant fleet of the Elizabethan England.

The specific design method of the ship also needs further investigation in order to narrow down the geometrical rules that had been used. Since the wreck from Princes Channel contains two different ships in its hull and it would be necessary to extract the two ships from each other to learn about the differences and the reasons for the extensive rebuilding of ship hulls.

In the present thesis the Princes Channel ship was only reconstructed to the height of the gun ports. But with further investigation of the design methods from the period it would be possible to create a theoretical reconstruction of the hull above the preserved remains. An extended reconstruction could be made in fully digital form and by using appropriate naval architectural software a technical analysis of the hull could be carried out. There is also the possibility to produce the hull as a solid scaled model by using selective laser sintering. In that perspective tank-testing of the two hulls would be a possible method to establish the performance abilities and capacity of the ship.

The Princes Channels ship is a unique chance to enhance our knowledge of ship design in the period of the earliest surviving English manuscripts of ship building, but from the perspectives of the common merchant vessel. This is an area that so far has been widely neglected compared to the studies of the much more prestigious war ships. Nonetheless it is of central value in understanding the private shipping and the nongovernmental ship building industry of the late medieval and early renaissance England. This subject is still a dark spot in the maritime history of Europe.

It is my opinion that the work of this thesis opened up a range of questions that are left unanswered and which would be relevant to investigate further as a possible PhD project. The issues are relevant to create a better understanding of the coherent shipping and ship design in northern and western Europe in the 16^{th} and 17^{th} century.

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