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Front page figure: the bow of the physical model (figure by author).

Digitizing a Physical model of a Dutch warship from the 18th Century: the potential of 3D models as archaeological sources in maritime archaeology.

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TABLE OF CONTENTS.

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CHAPTER 1. INTRODUCTION

1.1) **OVERVIEW**

In his book on sailing ship models, Morton Nance emphasizes the importance of the ship as a source of information and a form of art. In the same way ship models can enlighten us about a society's approach towards the construction of ships which, until the invention of plane, were considered to be the most complex structure of man-made technology (Nance 2000, 9). In other words, ship models inform the maritime historians and the archaeologists about the perspectives and the notions of a society which produced and manufactured those items (Williams 2015, 242). Moreover, Roach recognizes the importance of ship models, starting from prehistoric times, as essential sources of archaeological maritime information (Roach 2007,313). He also agrees that, until now, the function of ship models as sources has been neglected by the scientific community (Roach 2007, 331).

This thesis will use a physical ship model, acquired from the deposit of the Maritime Museum in Amsterdam, to construct a 3D replica. The model in question represents a Dutch warship from the 1720-1750 period and its creator is unknown. The main aim of the Thesis is to examine to what extent the 3D replica can be used as a source of archaeological inquiry about Dutch warships and shipbuilding in the aforementioned period. In addition, the methodological advantages and limitations of digitizing cultural items such as a ship model will be explored.

1.2) MOTIVATIONS FOR THE PROJECT.

Firstly, the scarcity of archaeological sources concerning 18th century Dutch warships was the main motivation for starting this research project. Few examples of this type of shipwrecks exist in the Dutch archaeological record from the period between 1720-1750. Secondly the issues connected with the preservation of shipwrecks was another reason to highlight the importance of the 3D replica of the physical model as a source. In the case of wooden shipwrecks, among them the VOC ones, environmental factors cause significant deterioration in situ. Parts of the rigging or decorative features might be lost or partly preserved. The reconstructed 3D replica provides a digital repository for any archaeologist who would like to examine these missing features.

Furthermore, I made a conscious decision to use a physical ship model from the 1720-1750 period, as this was an era of profound innovation in Dutch shipbuilding. During those years' British shipwrights, the most prolific of them being Charles Bentham, were called to the Netherlands in order to assist local shipmasters in the construction of their warships (Peters, 2013, 83). This exchange gave rise to experimentation and warships from this period reflect the combination of and conflicts between the two different traditions of warship-building. The 3D replica of the Thesis will provide an additional source for a period which has received comparatively little attention.

Additionally, a ship model, as a physical object, is characterized by a complex non-linear shape. Hence, taking measurements by hand would require a large amount of time making 3D technology particularly suitable to document such items. The construction of the 3D replica will enable me to acquire measurements which cannot be acquired from the physical model (i.e., the hull, rigging, etc.) thus the fragility of the second. Depending on the information which will be extracted by these measurements the comparative value of the 3D replica can be analyzed in contrast to other sources such as the archaeological record (shipwrecks) or the naval plans from the studied period.

Apart from those two issues the successful rendering of the geometry and texture of complex museum items is one of the most challenging matters in the field of digital archaeology. Radu Comes, Buna Zslot and Badiu Ionut highly stress that the creation of realistic 3d models requires an advanced knowledge of digitization techniques and it is truly a demanding task (Comes et al 2014,51). As the physical ship model, of the Thesis, is characterized by a complex geometry the digitization process suggests a complex task. Due to this fact the Thesis will comment on the challenges which will arise during the process of digitization especially in terms of geometry and texture.

Finally, even though a significant number of digital projects, with boats as specimens, exist in the museum context few have used ship models as the basis for their research. Moreover, most of them combine more than one digital recording methods such as laser scanning together with photogrammetry. The creation of the Thesis 3D replica was based entirely on photogrammetry thus it differs from similar projects.

Taking that remark into consideration an extra motive of the Thesis is to establish a new workflow for digitizing ship models in maritime museums. Marcos Llobera acknowledges the fact that the combination of computer systems (such as 3D modelling software) and archaeology has not been valued as it should be. According to the same author, this combination can lead to innovative discoveries and also the emergence of a separate discipline within digital archaeology (Llobera 2011,217). For that through the creation of the Dutch ship model's 3d replica a standard workflow can be established. The issue of a standard workflow within the museum has been also commented by Hess and Robson who acknowledge the need for applicable standards in the creation and evaluation of museum's cultural items (Hess and Robson 2012,103).

1.3) AIMS AND RESEARCH QUESTIONS.

During the recent decades a number of archaeological museums embrace digital practices for the documentation and preservation of their collections. Within the context of digitization, a number of theoretical issues have been aroused in relation to the methodological standards for a 3D replica to be successful. For example, one of the debated issues is that of objectivity. Sara Younan and Cathy Tredway agree that all 3D products of cultural heritage contain an amount of objectivity (Younan and Tredway 2015,240). The same authors suggest that, even though 3D models might appear real, they can be considered as a hypothetical reconstruction of the original item. Furthermore, they strongly support that the 3D models of the original artefacts sustain a dualistic relationship as human action participates in both the real and the virtual world (Younan and Treadway 2015,241). On the other hand, some scholars disagree with the use of 3D models in the museum context. More specifically they stress on the fact that those models do not include all the necessary information which can help the archaeologists comprehend the nature of the object. According to them the sense of touch or smell is one of the elements that cannot be found in a 3D model (Di Franco 2014,2). In other words, once the original objects are digitized they lose their "aura "(Di Franco *et al* 2018, 2). That loss highlights the issue of authenticity in 3D models which will be commented also in my Thesis together with the matter of objectivity. More specifically I will try to state if the 3D replica of the physical model can be characterized as authentic or not. The same complies for the objectivity matter exploring more particularly if the 3D replica actually is objective in regard to the physical ship model.

The fundamental aim of this Thesis is to examine the feasibility of the 3D replica of the ship model as an additional source of archaeological information. After proving to the reader that the specific 3D model is capable of meeting a number of methodological requirements, necessary for functioning as a source, I will proceed to the analysis of the information which the 3D replica produced. In relation to the type of information that can be extracted by the 3D replica volumetric ones are most valuable. According to Marcos Llobera archaeologists rarely attempt to use scientific forms of visualization such as volumetric (Llobera 2011,203). In the same frame Hermon Soni and Joanna Nikodem strongly emphasize that few 3D modeling projects focus on the use of the 3D models as a research tool (Hermon and Nikodem 2007,1). If the 3D replicas of the Thesis prove to be successful, then they can be characterized as a strong form of scientific visualization for Dutch warships between 1720-1750 and enhance the notion of using those 3D models as a research tool for ship models.

Secondly with the availability of digital cameras and a variety of image-based modeling software many projects, within the museum context, focus on the comparison of different software for the creation of accurate and reliable 3D models of their artefacts. Their size varies from small to medium artefacts (Katsichti et al 2019,157). To my perspective the ship model of the Thesis suggests an excellent choice for comparing the performance of the image software I used with that of similar projects in the museum context. Depending on the quality of the final 3D model the accuracy and reliability of the selected software will be commented.

Based on the pre-mentioned aims the research questions which this Thesis attempts to answer are the following:

- What are the methodological requirements a 3D model of a Dutch warship from the 18th century should meet in order to be considered a valid source of archeological information for the nature of Dutch warships in the 18th century?

- Did the use of photogrammetry, as a digital method, prove to be effective for an item such as a ship model compared to similar projects?
- Did the developed 3D models provide archaeologists with novel information about Dutch warships between 1720-1750?

Regarding the first question I will connect these requirements to the London Charter and the Seville Principles. More specifically I will examine if the final 3D models cover these principles.

1.4) THESIS OVERVIEW

This thesis consists of 7 chapters:

Chapter 1: This introductory chapter includes an overview oft he Thesis subject. Secondly a separate section with the reasons for initiating this project follow together with the aims and the research questions of the Thesis. Moreover the Thesis overwiew is the next section. This chapter concludes with a brief presentation of the research method.

Chapter 2: In this chapter the physical ship model will be described within the historical context of Dutch shipbuilding between 1720-1750. A separate section will follow analyzing selective features of the physical model.

Chapter 3: In this chapter I will highlight the importance of creating a 3D model based on the physical ship model. That will justify the significance of the 3D model as a source of archaeological infromation. A separate section will follow with the presentation of the rest of the sources in relation to Dutch warships between 1720-1750 (such as naval plans and writing sources).

Chapter 4: This chapter will be devoted totally tot he archaeological record of the Dutch shipwrecks between 1720-1750.

Chapter 5: This chapter will be devoted to similar digital projects in the museum context. I will focus, especially, on the methodological challenges which these programmes encountered. A separate section will present the London Charter together with the Seville Principles.

Chapter 6: In this chapter I will present the digitisation process for the Thesis physical ship model. Much of this chapter will demonstrate the calculations that I conducted on the photogrammetric models. A discussion oft he results will be included in the end of the chapter.

Chapter 7: In this chapter the overall conclusions, in relation to the research questions, will be presented.

1.5) RESEARCH METHOD

In essence archaeology can be defined as a "visual" science. Starting from the 15th century archaeologists used drawings and sketches in order to record structures and cultural items. Until today still archaeological illustrations remain an essential part of the process (Piccoli 2018,49). The issue which arises through the traditional type of documentation is the difficulty to record the depth value of the archaeological entity. Also, as Fabrizio Galleazi states, digital pictures are not considered the ideal mean to as to interpret the details of an object or artefact (Galleazi et al 2015,15).

An equally important issue is the following: by seeing the artefacts, archaeologists comprehend their shape, texture and size. However, in some cases the information extracted by these features may be insufficient or vague not only for the archaeologists but also for the public wishing to understand the artefact. A systematic and quantitative method is needed as to lead in more precise conclusions concerning the nature and the characteristics of the artefacts worldwide (Barcelo 2014,16).

As a tool 3D modelling is capable of confronting those issues. A 3D model is defined as a "mathematical representation of a concrete or abstract entity in which its features are displayed according to the geometry of their real volume "(Piccoli 2018, 49). Practically this definition means that a 3d model can be viewed from multiple angles providing a large number of information which could hot be apprehended based on the archaeological drawings/illustrations. For example, 3D models can be used for morphological comparisons or even for fitting fragments of the original model together (Lambers and Remondino 2007,30). That is the primary advantage of a 3D model thus the perception of a site or an artefact from various views and angles. Secondly a 3d model can be updated and the data derived from it can be processed further. That ability provides a dynamic perspective instead of a static one as in traditional archaeological illustrations (Piccoli 2018,49). The dynamic perspective is connected also with the ideas of movement in a 3 space. Within this space an object can acquire 6 movements of freedom which are translated to coordinates. The first three define the position of the center of the object's mass while the three other set the rotation around the object. Based on that notion it is clear that a 3d model of an artefact offers a variety of views thus different interpretations not only for the archaeologists but also for the public.

With the evolution of digital technologies, a number of optical sensors are now used in archaeology for the documentation of heritage sites and cultural heritage items in the museum context. Four major advantages are being connected with those sensors which are the following:

1) **Application in a large variety of scales.**

2) **Ensuring the preservation of the original artefacts since the acquisition of measurements is performed without physical contact with the item**.

3) **In the case of an excavation archaeologists can process the data while continuing the fieldwork tasks**.

4) **Within the years and due to the technological developments the availability of multiple sensors is increasing.**

Secondly a basic distinction is made between the active and passive sensors. The principle behind the second is based on their ability to transform 2D images to 3D data through mathematical formulas (Remondino 2011,1106). One of the most relevant passive techniques, in order to capture the shape of the objects, is that of photogrammetry. Through the literature various definitions have been provided. For example, photogrammetry, as a method, is usually defined as the procedure of producing high quality digital replicas of objects using a series of overlapping photo-images. A more scientific definition describes photogrammetry as the scientific method of extracting quantitative and qualitative measurements of objects from images (Remondino and El Hakim 2006, 66). Another similar definition emphasizes on the ability of photogrammetry to extract reliable information in relation to the object's surface and properties without the requirement of physical contact (Schenk 2005,2).

Taking into consideration the previous definitions photogrammetry suggests a suitable choice for estimating the size, shape or volume of the object (Luhman and Robson 2013, 3). For that I decided to use close-range -photogrammetry as the method for creating the 3D model. Close –range photogrammetry outstands for its ability to apprehend camera positions and orientation automatically without the pre-requirement of a set of control points (Micheletti et al 2015,2). Moreover, a series of tools for performing this type of photogrammetry exist. A crucial distinction is made between those that enable the uploading of images to server's companies, with the ability of downloading the final 3D model, and those that manipulate the data through a local server. For the second category known examples are the Visual FM and the Agisoft software. Of course, apart from the option of PC software, nowadays even smartphones can be used for generating 3D models based on the close-range photogrammetry method (Micheletti et al 2015,3). Also it is preferred for objects with a size between 0,5m to 200m (Luhman and Robson 2013, 5). During the photogrammetric process a number of parameters are taken into consideration such as the light source or the nature of the object's surface (Stephen et al 2013,3).

To conclude close –range photogrammetry is widely used in the digital recording of the cultural heritage sector and it is considered to be a feasible and economical approach compared to other methods such as laser scanning (Kalinka and Rutkovska 2005 1). More specifically laser scanning accumulates some disadvantages such as high cost, low portability and extensive processing time (Skarlatos and Kiparissi 2012,299).

CHAPTER 2: THE PHYSICAL SHIP MODEL IN THE DUTCH MARITIME HISTORICAL CONTEXT.

2.1) THE DUTCH NAVY BETWEEN 1720-1750

At the start of the 18th century the Dutch navy found itself in a situation wholly different from that of the previous one. De Bruijn refers to it as a “second rate “Navy, lacking in comparison to other European naval forces such as Great Britain or France (De Bruijn 1993, 168). Despite of these problems, improvements and innovations did occur in the period between 1720 and 1750. The improvements mainly concerned ship design, the introduction of naval plans, training for naval officers scaled ship models and the construction of new port facilities (De Bruijn 1993,170). A number of admirals at the time recognized the need for changes in Dutch ship design. For example, in 1721, Admirals Van Wassenaer together with Pieterson and Van Aersen, suggested that the ship design must change and that the Dutch Admiralties should build a number of large and fast warships (De Jong 1993, 33). Admiral Cornelis Schrijver commented the lack of skill of the Dutch shipwrights and the inferior quality of the Dutch warships, compared to those of the British. After 1689 cooperation between both fleets provided Dutch naval officers with the opportunity to study British warship design (De Jong 1993, 35). Influenced by the British, the Dutch Navy decided to build stronger and faster ships according to their example, starting with the launch of the warship Wageningen in 1723. Fortunately, the plans for this specific vessel have survived and are in the Moll Collection in Utrecht **(**fig.2.1**).**

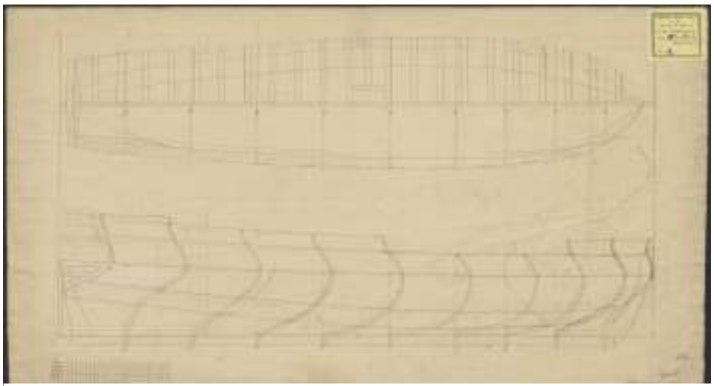

Figure 2.1: Plans of the frigate Wageningen (Bibliothec.Rhen-Traj d.d Vir.GI. G. MAPPAE ARCHITECTONICAE Section 2 Architectura Naval 4).

Although it is uncertain whether these are technical drawings or copies from a two-dimensional model, these drawings provide a rare, detailed illustration of an 18th century Dutch warship (De Jong 1993, 33).

A few years later the Admiralties decided to call upon British shipbuilders to assist with improving the fleet. Consequently, two British shipwrights were employed by the Amsterdam shipyards in 1727: Charles Bentham and Francis White (De Jong 1993, 38). Also in April of the same year another British arrives with the name of Thomas David arrived. As I mentioned above, Charles Bentham was considered to be one of the most prolific and experienced British shipwright of his time. The advent of the British shipbuilding in the Netherlands initiated a heated debate concerning the credibility of the introduced British methods as an alternative to long-established Dutch practices. The British introduced a more scientific approach to naval design – characterized by increased use of mathematics – which profoundly limited the role Dutch shipbuilders had played in the past. (Brandon 2015, 201).

2.2) SHIP MODELS IN THE DUTCH ADMIRALTIES

One of the changes that Bentham initiated in Dutch shipbuilding was the introduction of scaled ship models, both for the VOC and the Admiralties. Of course models of Dutch warships existed before Bentham's arrival. However, these were not used for shipbuilding but rather to confer social status to the owner of the model. This is true for the ship models which decorated the assembly of the VOC directors in Amsterdam, for example (Hoving 2005, 24). The best known example of such a decorative model is from 1651 and depicts the William Rex, a Dutch East Indianman (Hoving 2005, 23).

Bentham did introduce the use of scaled ship models to provide shipbuilders with a guide for construction – a practice the British were already familiar with since around 1650 (Williams 1971,59). These sort of models, i.e. those intended to serve as a design template, are divided into two major types:

“Navy Board “and “Georgian”. Characteristic of the first type is that they include details of the interior framing of the vessel. Those of the second type are fully-framed and include many details on the ship’s rigging and the decoration (Stephens 2009,15).

In the Rijksmuseum there is a special room in which a number of Bentham’s models are exhibited. One of the most famous ones is that of an East Indianman (fig.2.2).

Figure 2.2: The model of Bentham’s East Indianman (after http:www.rijksmuseum.nl).

Bentham presents all the structural elements of the hull and the decorative features of the bow and stern in great detail. The wooden structures which are positioned on the sides of the model were called camels. They were used to assist the ships in passing shallow waters (Hoving 2001, 64). Another known item from this collection is the half-model again by Bentham dated in 1740 (fig.2.3).

Figure 2.3: The half model by Bentham (after http://www.rijksmuseum.nl).

Apart from these two models another valuable model matches with the Bentham's design (MC503). The specific model is dated between 1740-1750 and represents a frame model of an East Indianman (fig.2.4).

Figure 2.4: The frame model by Charles Bentham (after Lemmers 1995, CD-ROM).

The most remarkable feature is that the model can be separated into two parts. This separation allows the viewer to see the internal framing of an East Indianman with the deck beams. Observing the image of the model I noticed that the hull up rises highly towards the lower part of the stern providing a more hydrodynamic performance. Moreover, the channels and the wales are present in the model. In relation to the decorative features they are characterized by a variety. For example, the quarter galleries are decorated with natural elements such as foliages. From these examples it should be clear that the presented ship models can provide the researcher with information about the armaments, the fittings and even the shapes of their hulls in relation to warships designed by Bentham.

2.3) THE PHYSICAL MODEL OF THE 50-GUN DUTCH WARSHIP.

The physical model used for this thesis belongs to the deposit of the Maritime Museum in Amsterdam. Consulting the Dutch edition with all the models of the Museum the specific one was described as a witnessed model of the 4th Charter with 50 guns (Cannenburg 1943,22). It is also dated in 1750. In the description of the model it refers that from 1682 the Admiralties defined Charters for their warships with those belonging in the 4th being equipped with 50 to 54 guns. The second interesting fact is that the model is based on the designs of the British shipwright Thomas David who has arrived together with Charles Bentham in Amsterdam. The feature which justifies this argument is the round shape of the lower part of the stern as it is similar with the Dutch warship “Provincien De Utrecht “dated in 1727. The “Utrecht “was designed by Thomas David the same date. The text in the description of the model specifically states that the British shipbuilders introduced that constructive element in 1727. It is true that the Dutch, during the previous century, usually preferred the square shape as it is seen on the next figure (fig.2.5).

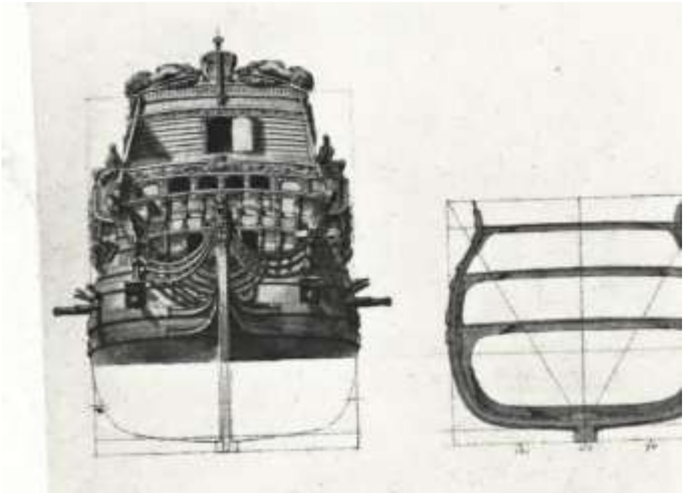

figure 2.5: The bow section of a 17th century Dutch warship (Cannenburg 1943, pl.10).

Despite that the square shape remained in some of the VOC ship models dated between 1720-1750.

Another major issue with this model is that is not scaled. However, I established a reasonable scale using a calculation by Robert Napier in his book about the VOC ship Valkenisse dated in 1717 (Napier 2008). More specifically in this publication Robert Napier attempts to reconstruct a model of the real ship Valkenisse consulting the written sources. Also they measured the length of a warship from the stem. The Dutch shipwrights used a variety of units for measuring their warships. For example, one Amsterdam foot was equivalent to 28,3cm.

The calculation uses the length of the model and the equivalent of the real ship. It is as follows:

-Length of the model (x)=length of the real ship x 28,3cm.

In my case the issue was that since the model did not depict a specific warship rather than a type, I should find a relative length for an equivalent ship in real dimensions. The manuscript of Blaise Olivier (I will refer more in the sources section) provided a list with the charters of the Dutch warships between 1720-1730. In the 5th Charter he includes ships with 50 to 54 guns with a length of 41,19m and a breadth of 11, 37m.Knowing the length of the model (96cm) the final value was 42,9. That means a scale of 1:43. Multiplying the length of the model with 43 provides a result of 4128cm (41,28m). In Olivier's manuscript it is noted that the ships belonging to the 4th Charter are designed by British shipwrights thus by the English shipbuilding method. More specifically, according to Olivier, they were built by Thomas David and they had a length of 44, 34m.As we see the is not much difference in the metric values for the length. Consequently, the model could represent a warship from the 4th Charter between 1720-1750. In relation to identification of historical ship models principal dimensions are considered to be a safe choice. For example, the recognition of the model of the Hollandia, dated in 1664, was confirmed as such based on its dimensions and the ornament features (Crone 1914, 106).

Despite that there is a controversy in relation to the number of the cannons. While in the list the ships of the 4th Charter are equipped with 60-to 62 guns in the model 50 guns exist in total. That is not strange since ship models, from that era, are not considered a totally reliable source to inform us on how the armaments were arranged. Especially the distribution of gun ports may have changed during the lifetime of the model (Williams 1971, 71). In some cases, gun ports may also have been added for pure decorative purposes.

Observing the model, I noticed the series of external horizontal layers of the hull and the decks. That indicated that the specific model was constructed based on the “bread and butter construction “. In this method first the main body of the model's hull is created and then the bow and the stern are connected. (Brien 1986,37). Another characteristic of this method is that a set of drawings is required as to create the model. Probably the modeler who made it could have consulted Davis plan of the" Utrecht".

Having presented the basic features of the model I will proceed to the brief outline of the rest of the ornamental characteristics (together with the gun- ports) and the rigging. Considering the second not much information is provided in the edition of the Museum. The only thing that is mentioned is the double number of the deadeyes in the lower shrouds (Cannenburg 1943,22). In the text the reason for this preference is explained, in the edited text, as "the firing of one of the traineeships did not immediately result in the mast lacking the support of traineeship". To my perspective that phrase indicates that this model indeed could be used as a specimen of a 4th Charter Dutch warship for the cadets in the Naval Colleges of the Admiralties. That means that in a real ship the incident of firing a shot close to the lower shrouds could result in a loss of one of the deadeyes thus reduce the sailing power. We should not forget that at the start of the 18th century one of the improvements was the creation of more scientific training for the officers with the creation of Naval Colleges.

Through this outline I will examine if those features confirm the date provided thus 1750. With respect to the ornamental features, ship models are considered more reliable and very valuable as a resource in the case of sufficient detail on a model (Laughton 1925,26). Thus by examining the ornamental features, an approximate date for the model can often be established. Finally, ship models are considered relatively reliable sources for the rigging and are also used, sometimes, to identify ships. However, as with the armaments, the rigging may also have been modified containing anachronisms (Williams 1971, 71).

2.4) GUNPORTS LIDS AND ORNAMENTAL FEATURES

Staring with the gun ports-lids the first element to comment is their square shape 1 . In Dutch ship models from the 17th century, like that of the William Rex, square gun ports are always present. The second element to comment is their wide non-symmetrical arrangement. That arrangement can be found also in the Valkenisse model which is supposed to represent a VOC vessel. That gap defines enclosed spaces such as crew's compartments such as the ship's galley (kombuis) or the officer's space (bottelarij) (Napier 2008,10). That enables the viewer to define, relatively, the boundaries of these spaces in comparison to the rest of the model even though those are shown internally on the model.

Moreover, the model's gun port lids on the lower and the upper gun deck present a similarity with English ones. However, since both nations adopted square port lids we cannot accredit their presence to British influence with certainty.

At the level of the upper gun deck in the model some ports enable decorative features. They were usually called wreath ports (Laughton 2001, 222). Apart from the wreath ports additional decorative elements should be mentioned as the following known as chesstree (fig.2.6).

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1 As port lids we define the hanging doors which protected the cannons when they were not engaged in combat (Falconer 1784,240).

Figure 2.6: The chess tree of the model (by the author 2019).

The chess tree is defined as a timber fitted after the bow and is used for passing part of the rigging (Laughton 2001, 241). Similar forms of chess trees with more ornamental style are present in other models of Dutch warships as that of the Prins Willem dated in 1651.

Apart from those decorative features more are worth to mention:

1) **The rails and the hanging pieces**: The rails were horizontal planks that were fitted to the sides of the vessel and served ornamented purposes. In the model only the waist rail exit above the channels. In Dutch warships the habit was to position all the rails right aft and that trend was copied by other nations such as France (Laughton 2001, 209). Considering the hanging pieces or hance as they were also called, they can be described as the step that is shaped by the drop of the rail from a top level to a lower one (Laughton 2001, 210). Usually we have three types of hances. The first is positioned where the rail of the poop decks ends while the second is connected with the quarter deck. As for the third it ends at the waist. In the model we

can observe all the three types such as the poop hance or that which drops from the quarterdeck to the waist (fig.2.7).

Figure 2.7: The hance dropping from the quarter deck to the waste (after the author 2019).

A final feature of the quarterdeck are the medium size guns that are fitted at that level (fig.2.8).

Figure 2.8: The medium size guns on the quarter deck of the model (after the author 2019).

2) **The figurehead:** The second striking feature is the red painted lion figure head (fig.2.9). This type of figurehead was used frequently by the Dutch at least until the half part of the 18th century.

Figure 2.9: The lion figurehead of the model (after the author 2019).

3)The cathead : Lastly notice that above the head rails a horizontal bomber is protruding which was known as the “cathead 2“ . The cathead was supported by an ornamented knee as it can be seen also on the model (fig.2.10).

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2 Catheads can be defined as two timbers that project horizontally over the ship’s bow. Another use of the cathead was to suspend the anchor when the bow should be clear. (Falconer 1784, 91).

Figure 2.10: The cathead of the model (after the author 2019).

The Dutch started to adopt catheads from 1630 and they placed them at the bow and not at the corner of the forecastle. The placing of the cathead at the top of the head rails and close to the forecastle started to be applied after 1630 and almost most of the 18th century (Laughton 2001, 60).

4) **Decorative elements of the stern**: The major difference of the stern's decoration with models from the previous century is the reduction of the ornamental features. By the start of the 18th century, the Dutch adopted lighter carvings following the British tendency (Laughton 2001, 146). Such tendency can be seen on the tafferel of the stern since no decorative figures exist (fig.2.11).

Figure 2.11: The tafferel of the physical model (after the author 2019).

An interesting detail of the stern is the stylistic arrangement of the decorative features. More specifically the top edged of the taferrel end at fashion pieces forming an arch above the lanterns. Moreover, the reduction of the ornamental elements provides to the viewer a clear picture about the size of the stern. That stylistic tendency was transferred to the Netherlands by the works of Charles Bentham when he arrived in Amsterdam (Peters 2013, 129). Moving from the tafferel to the board of the stern (the central part) the major elements are the windows of the galleries and the series of columns (fig.2.12).

Figure 2.12: The tafferel of the model (after the author 2019).

The columns are of Corinthian type and they were frequently used during the 18th century in British warships. During 1715 the artistic movement of Palladianism (from the architect of the Renaissance Palladio) influenced in a great extent the British architecture. That influence was also spread to the carving of warships. The ornamental elements that characterize this style are the scrolling acanthus and columns (Peters 2013, 125). An additional structural element that highlights this influence are the quarter galleries (fig.2.13).

Figure 2.13: The quarter galleries of the physical model (after the author 2019).

5) **Stern lanterns**: they are similar to those in British ship models from the same era. They belong to the standard type of 1707 with a hexagonal section (Laughton 2001, 143).

Apart from the decorative elements a number of structural features incline British influence. For example, as such is the reduction of the knee of the bow to the height of the figurehead (fig.2.14). That structural modification was adopted by the French during 1720 in Dutch warships (Laughton 2001, 93). By that modification the lion figurehead could stand more efficiently upon the knee of the bow.

Figure 2.14: The knee supporting the figurehead (after the author 2019).

The second important structural element is the vertical position of the figurehead close to the forecastle. It is true that the evolution of the European warships owned by the strongest naval powers, including Britain and the Netherlands, between 1670 and 1720 resulted in shorter heads close to the forecastle (Anderson 1921, 181). By comparing the same element in 17^{th} century Dutch warships we can see that the figurehead was protruding much forward.

The last structural element I would like to comment on is the presence of the canopy place before the poop deck. In Dutch it is known as the zonne-deck meaning that it was used for protection from the sun. Robert Napier strongly suggests that this element was typical for VOC vessels as it is found in that of Ary (fig.2.15).

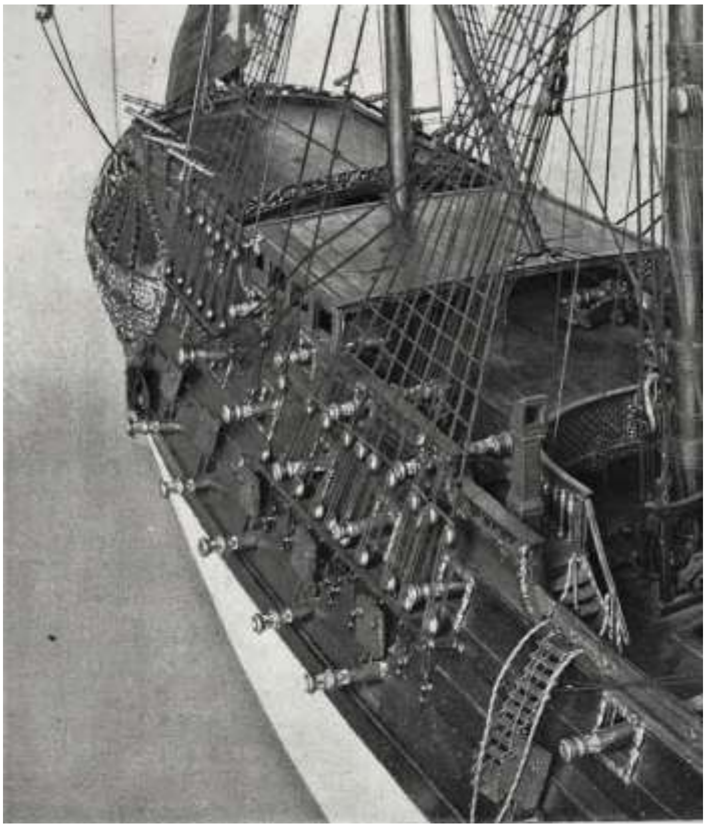

Figure 2.15: The zonnedeck of the VOC model Arys (Cannenburg 1943,27).

Above the sundeck an arch is also fitted an element which is also present in my model. Since I have proved that the model of the Thesis represents a 4th Charter warship and even maybe used officially as a learning tool in the Dutch Naval Academies the zonnedeck and the arch could be a common element in both warships and vessels of the VOC dated between 1720-1750.

2.5) RIGGING

In that section I will present only the elements of the rigging which are useful for the confirmation of the date of the physical model. Those are the following:

1)The bowsprit: Starting from the bow, the first mast as such (boegspriet). The bowsprit was a heavy spar which protruded forward and up to an angle from the bow (Schairbaum 1990, 18). The main purpose of the bowsprit was to support the rigging parts of the next mast (the foremast). The bowsprit itself was strengthened by a separate rope with was called the " bobstay"3 . A second important element of the bowsprit is the heavy lashing that occurs at the after end of it above the head rails(fig.33).

Figure 2.16: The gammoning of the physical model (after the author 2019).

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3 A simple definition of the bobstay is that of a rope running from the end of the bowsprit to the stem of the vessel. It should be emphasized that the specific part appeared after 1670 (Schairbaum 1990, 17).

2) The spritsail yard: Vertical to the bowsprit a vertical spar was placed which was known as the such. Between 1600 and 1715 in Dutch and British ships an extra mast existed at the end of the bowsprit known as the spritsail topmast. During the 18th century the spritsail topmast was replaced by an extension of the bowsprit known as jibboom (kluiverboom in Dutch) (fig.34).

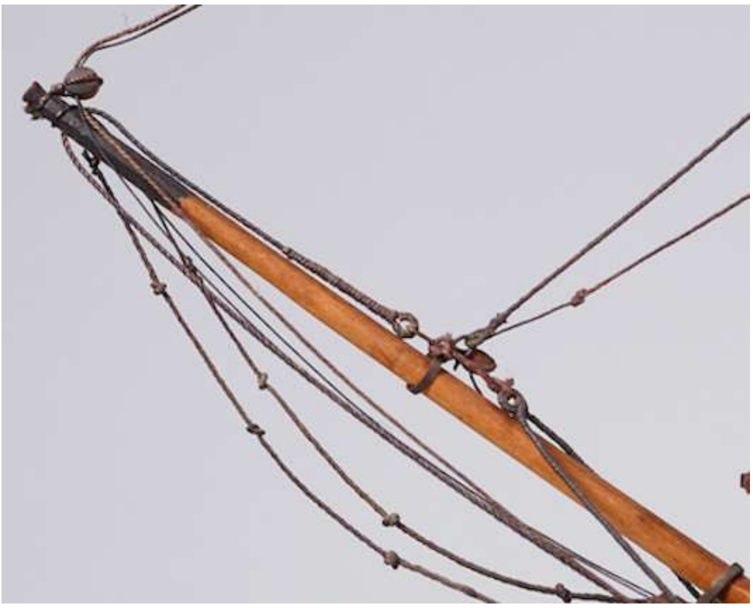

Figure 2.17: The jib boom of the bowsprit from the physical model (after the author 2019).

3) The yards: The center of the yard was usually known as the “bunt” but sometimes the term “slings “was also used (Harland and Myers 1984, 22). The extreme ends of the yard were the “yardarms “. Apart from the yard-arms and the slings one additional part should be commented. The extra part was called the “cleat” (fig.35).

Figure 2.18: The “cleat” of the physical model (after the author 2019).

The shape of the cleat is similar to that which is presented in Anderson (Anderson 2015,56). The main purpose of the cleats located at the yardarms was to provide extra strength to the ropes of the braces and the lifts so as not to be separated from the yard. The earliest evidence of cleats in Dutch models are found in William Rex (Anderson 2015, 56). Moreover, the yards were named after the mast they were attached to. For example, on a topgallant mast we would have the topgallant yard. The yards were lifted or lowered by ties, halyards and jeers. The second term refers to the lines that were employed as to lift the yard. The ties were the ropes that assisted the halyard in order to provide extra force. The system of ties and halyards functioned when there were no blocks on the yards. The ropes passed upwards from the yard and by being attached in a block they came down the mast (Anderson 2015, 133).

On the contrary in the jeers system we have blocks on the yards so the pulling of the ropes is assisted by those blocks. Based on my own estimation and the depictions from Harland I believe that the model follows the first system. Apart from those elements we have also the lifts and the braces. The lifts were mostly used for keeping the sail in horizontal position while the second for moving one of the ends of the sail forward or aft (Anderson 2015, 132).

4) Standing and running rigging: A major dissection that was applied to the rigging during both the 17th and 18th century was that of the standing and the running type. The former supported the masts while the second operated the yards and sails (Lavery 1984, 89). In the former category the mechanism which provided the strength of the masts was the system of shrouds and stays. The shrouds were located behind the mast while the stays forward of it. The stays were called according to the mast they were attached. In the model all stays and shrouds are present such as the main stay (fig.2.19).

Figure 2.19: The main stay of the rigging of the physical model (after the author 2019).

In relation to the shrouds of the lower part of the foremast and the main mast they were positioned above the channels of the hull. The shrouds were connected, for greater strength, with the sides of the vessel with blocks known as “deadeyes”. The deadeyes were also attached to another type of block with the name “lanyards” (fig.2.20).

Figure 2.20: The deadeyes of the model (after the author 2019).

Those were based on metal platforms which were called “chain-wales or “channels” (Anderson 2001, 62). In the model the channels are above the level of the upper gun deck. That tendency was preferred by the British especially between 1620 and 1740. The Dutch adopted this method by almost the same period (Anderson 2015, 64). The transfer of the channels to this level allowed for less damage of them by the waves and the rough weather and also resulted in the movement of the oars to the waist (Gardiner 2012, 45). A final feature that I would like to comment on are the tops of the masts. One of their aspects is their square shape which is typical for Dutch warships especially after 1720 (Anderson 2015, 34). In relation to the tops two more elements should be mentioned: the caps and the cross trees The former assisted in connecting the end of a lower mast to the start of the higher. The caps of the model are of square shape indicating British influence. As for the cross-trees they were traverse plans that were supporting the tops. Apart from the cross trees another set of timbers were positioned vertical to the cross trees known as trestle trees. More accurately they were aft and fore timbers providing extra support to the tops (Shairbaum 1990, 46).

In conclusion the presence of British influence is strong in the model judging by the decorative features. The rigging does not differ from the standardization of a 18th century ship model even though some elements are British. That proves that the specific model is one of the few exceptions which does not contain any anachronisms. Concerning the information extracted from the physical model I could say that it functions as a reliable visualization guide for the rigging and the ornamental features of a Dutch warship c.1750.The viewer can shape a clear idea not only about the shape of the hull but also about the layout of the upper decks or the decoration of the stern. On the other hand, since the internal planking is not visible, as in the frame models built by Bentham, it is difficult to acquire a sufficient notion about the dimensions of the frames and the planking. Also still some issues exist such as the number of cannons which does not agree with the Olivier's manuscript. Last but not least the fragility of the model does not allow for performing extra measurements such as the length of the masts. After having presented the physical model I will proceed to the presentation of the rest of the sources concerning Dutch warships built about 1750. A separate section will be devoted to the value of the digital model.

CHAPTER 3: **SOURCES** OF INFORMATION FOR DUTCH WARSHIPS: A COMPARISON**.**

3.1) THE DIGITAL MODEL AS A SOURCE.

The ongoing developments in the digital documentation of cultural heritage items have initiated a debate about the benefits of 3D models of these items. Without any doubt one of the most profound advantages is the preservation of these items not only in the field but also in the museum context. The motivations for creating a sustainable 3D model of the original vary. For example, one of the main ones is to ensure that the shape and appearance of an object will not be lost in case of a damage or physical catastrophe. Secondly, another equally crucial motive is the record features of the object that cannot be seen in the real object. A photogrammetric model can fulfill these motives and provide the archaeologists and the museum with a digital replica which will stand in time. In addition, a photogrammetric version of the original item can solve issues with restricted storage space in the museum (Otto 2018, 2).

Furthermore, the integration of photogrammetric 3D models in VR (Virtual Reality) applications even allows for the exploration of cultural heritage items from remote locations (Galeazzi *et al* 2015, 463). Researchers can evaluate the quality of the digital image in mere seconds and make improvements if necessary (Galeazzi et *al* 2015, 5). Moreover, photogrammetry is flexible, low-cost method that captures the most minute details of the smallest objects while preserving their texture and geometrical features. Furthermore, the time required for the creation of a 3D model is much shorter with photogrammetry than with other methods, such as laser scanning.

Conclusively the creation of the photogrammetric model based on the physical one, accumulates all the benefits mentioned before. Especially the fragile nature of the original justifies the use of the photogrammetric model for performing measurements and calculations of features which cannot be acquired on the physical model. Those calculations can be used as to create a digital database accessible to the researchers and the public.

3.2) COMPARABLE SOURCES

After presenting the benefits of creating a photogrammetric model based on the physical one I will proceed to the presentation of the rest of the comparable sources concerning Dutch warships between 1720-1750. Those are as follows:

1)Written sources: In 1737 Blaise Olivier, one of the most prominent French shipwrights of his time, visited the shipyards of Britain and the Netherlands on a secret mission to observe and compare the methods that these two countries used with those employed in France. Afterwards he wrote an extremely detailed report of what he observed. This report is one of the most valuable sources for British and Dutch shipbuilding during the first quarter of the 18th century (Roberts 1992, 1). Olivier meticulously describes every element and compartment of the Dutch warships he found, providing measurements. Olivier also compares the quality of the Dutch warships with those of the French and the British. He particularly admired the ability of Dutch shipbuilders to construct the planking and framing of their vessels from memory, without using plans (Roberts 1992, 234). He also noticed the Dutch preferred not to install bolts in the ship’s timbers. He also interestingly remarks that he considers the Dutch methods of shipbuilding very slow, mentioning that they leave the frame timbers to dry out for six or even seven months before installing the planking (Roberts1992, 223).

During his visit to the Dutch shipyards Olivier noticed three different methods of constructing a ship. He respectively called them: the old manner, the new manner and the English manner. Since the physical model of the Thesis is connected with Thomas David I will briefly refer to the English manner.

Concerning this manner, is distinguished for the edge to edge planking of the hull and is usually called “skeleton-first”. An alternative term, which is used frequently by maritime archaeologists, is that of “carvel-built”. In that method the frames are raised first and then the planking of the hull is connected to the frames. The characteristic of that method is that the shipbuilder cannot make major alterations in the building process of the ship. For that reason, usually this method is connected with naval plans (Eriksson 2010, 77). By providing a shipbuilder with a plan he knows which steps he should follow before the initiating of the process thus he can avoid any alterations or deviations from the plan. It should be noted that the Admiralty in Amsterdam did embrace the British methods. However, this decision led to the decrease of the role of the local shipbuilders and to an increased standardization as the building process was dictated by the design process (De Jong 1993, 46).

Finally, I would like to emphasize that Admiralties outside Amsterdam did not accept neither the shipbuilding methods introduced by the British nor their naval plans. They believed that the shallow waters of the Netherlands were not suitable for the large draught of the British-designed vessels. In fact, the master shipwrights of Rotterdam, Middelburg and Enkhuizen published a memorandum in which they supported their opinion about the unsuitability of these vessels (De Jong 1993,45).

To conclude I believe that even though the manuscript of Olivier presents useful information it focuses more on the dimensions of the different compartments of a Dutch warship at the time he visited the shipyards. However, as I proved with the scaling of the model, it can be used as a cross reference source, for dimensions, with ship models of Dutch warships dated between 1720-1750.

Another publication is that of who includes a list of all the Dutch warships between. However, few warships are mentioned dated in 1750.

2) Iconographical sources: As Netherlands was a maritime nation, artists extensively adopted issues connected with the sea and nautical Dutch history (1993,3). The types of works are divided into paintings, drawings and prints. The majority of them cover the last decades of the 17th century and few the start of the 18th century. Even though from 1700 paintings and prints present an amount of accuracy they should always be cross-referenced with other relevant sources such as ship models.

The most prolific maritime artists covering the last decades of the 17th century and the start of the 18th were the De Veldes. Both of the painters passed most of their life at sea, having instant access to the ships of the Dutch Navy (Peters 2013, 72). William Van De Velde the Elder lived between 1611 and 1693. He painted in great detail drawings and prints of Dutch warships majorly between 1665-1669. The second De Velde was the son who followed the steps of his father and lived between 1663 and 1707. Most of his works cover the last period of the 17th century including paintings with Dutch warships in mild and rough weather.

Despite the lack of sufficient iconographic sources after the end of the17th century I actually found two rare iconographical examples (fig.3.21 &fig.3.22).

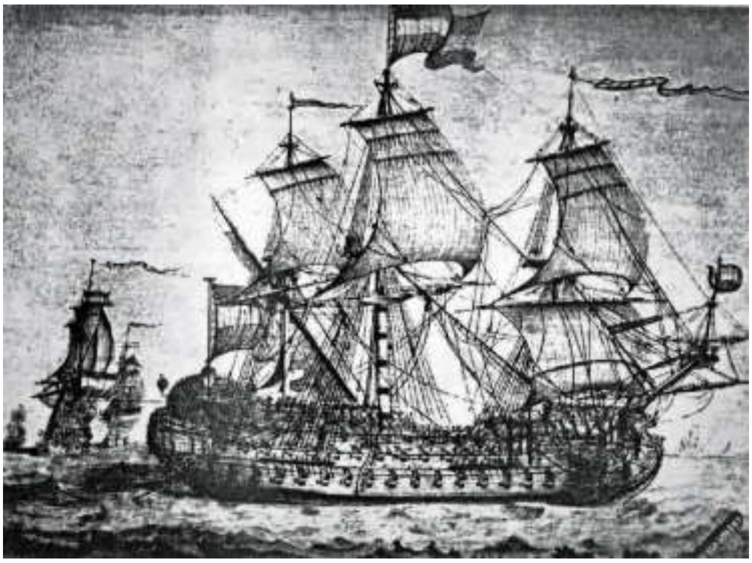

Figure 3.21: A Dutch three decker from the start of the 18th century (Peters 2014,285).

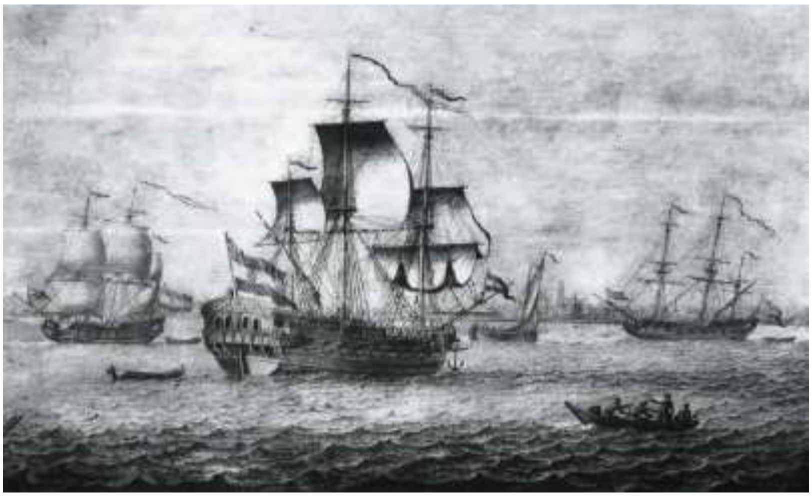

Figure 3.22: A painting of a Dutch 18th century frigate (Peters 2014, 287).

The first is an anonymous engraving and depicts a three-decker (probably the Dutch warship Eendracht dated in 1703). Notice the absence of the high rise of the stern and the large amount of cannons. However, the large number of gun ports does not agree with the standard naval ornament at the start of the 18th century (Peters 2014, 285). The second figure is a painting by Adriaen Van Salm depicting, probably, a Dutch frigate of 26 guns. One possible candidate is the Vollenhoven dated in 1708 (Peters 2014, 287).

Moreover, another interesting depiction origins from the book of David's Mortieir with the title "L'art de Batir les Vaisseaux "published in 1719. The specific illustration it supposes to depict a Dutch warship at the start of the 18th century (fig.3.23). Despite that it is more probable that refers to the Zeven Provincien dated in 1694 (Peters 2014, 281).

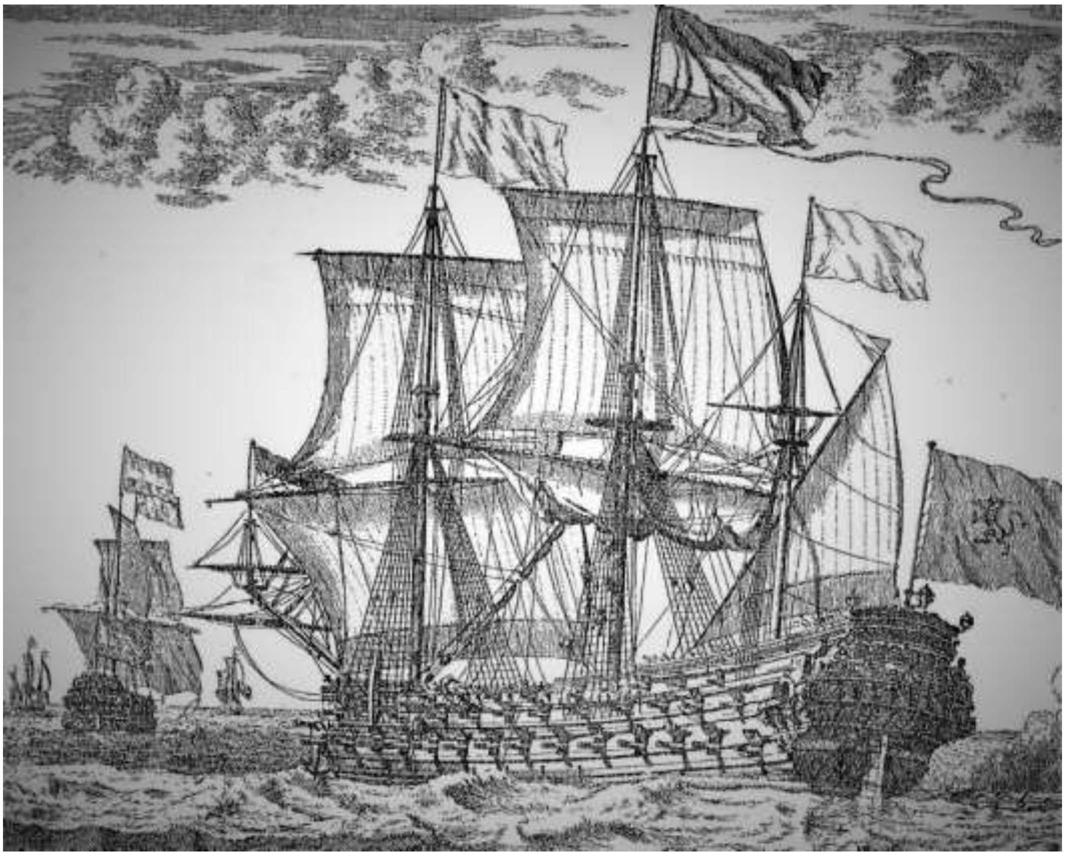

Figure 3.23: A Dutch warship as depicted in an 18th century French naval book (Peters 2014,281).

A last example is an excellent illustration of a Dutch warship built by the English way as it is written on the top of the illustration(fig.3.24). The interesting element is the fact that it provides the names of all the rigging in Dutch and thus could work as a consulting guide for anyone who wishes to learn about the rigging from the early decades of the 18th century.

Figure 3.24: The rigging plan of a 44-gun warships built by the British way (Bibliothec.Rhen-Traj d.d Vir.GI. G. MAPPAE ARCHITECTONICAE Section 2 Architectura Naval 2).

To conclude, as it is proved by the presented examples, there is a lack of sufficient iconographic evidence concerning Dutch warships between 1720-1750. Even those that they are dated from the early decade of the 18th century they are not are totally reliable. For that naval plans suggest a more detailed and efficient source since they provide measurements of the basic dimensions of a warship and an inside view of the compartments

In Britain and France, the first scaled naval plans started to appear by the first decades of the 17th century. However, already in the preceding century, British shipbuilders produced plans using the whole molding method. Whole molding allowed for the production of more accurate drawings by using tools like compasses and triangles to establish reference points. After the drawing was complete, the wooden frame would be constructed using the drawing as an outline. (Ferreiro 2007, 40). This method was extensively described by Mathew Baker in his 1586 manuscript “Fragments of English Shipwrightery’’ (De Jong 1993, 41). Within the next century, British naval drawings became more sophisticated (Deane 1670). The full plan for the British warship Centurion (a modified 60-gun of the Fourth Rate), for example, includes many inboard details (https://collections.rmg.co.uk) (fig.3.25).

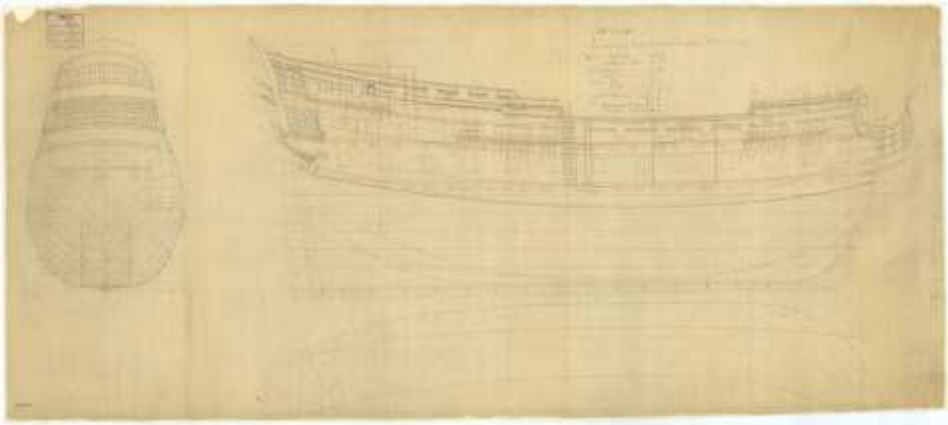

Figure 3.25: Naval plan of the British warship Centurion of 1732 (https://collections.rmg.co.uk).

The plan also includes individual sections which are: the sheer plan, the half-breadth plan and the body plan. The sheer plan was also called the elevation plan. This type of plan actually offers the profile of the vessel. In it all the dimensions are listed and all the features of the vessel are described, such as the frames, armaments, rigging, etc. (De Jong 1993,39). The sheer plan was divided by a number of vertical lines arranged in an arbitrary interval and curved lines were drawn in the inside of the outer profile of the hull (Williams 1971,189). The second view depicts the top of the vessel or the half-breadth, as it is called. In plain terms: this is the submerged part of the hull of the vessel. The third plan is more complex than the two previous ones and consists of two halves. In one half, the frames from the stem towards the widest main frame are presented while in the other half the frames from the stern to the widest frame are depicted. In the plans three basic dimensions were listed. The first was the length of the lowest gun deck. The second dimension was known as the “breadth mould”: the length of the frame with the greatest breadth. In most cases the shipbuilder used the amidships breadth as a guide to measure this dimension. The third dimension was the depth of the hull (Williams 1983, 5).

One naval plan influenced by the British is that of the Dutch frigate Amazon (fig.3.26).

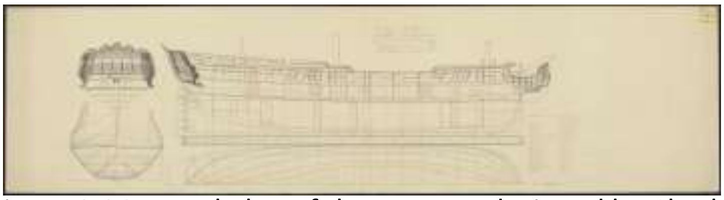

Figure 3.26: Naval plan of the Amazon designed by Charles Bentham (after Bibliothec.Rhen-Traj d.d Vir.Gl. G. MAPPAE ARCHITECTONICAE Section 2 Architectura Naval 14).

At the top of the plan the length of the lowest deck is noted together with the depth of the hold and the width. All the three measurements are in English foot which was equivalent to 30cm.That of the lower deck is 39m. On the other hand, at the bottom right, the plan provides measurements of the masts in Amsterdam foot this time. For example, the length of the mainmast was 25m.In the same plan all the compartments with the stairs and the ladders are depicted in detail. Moreover, the decorative features of the bow and the stern are highlighted.

Overall Dutch naval plans provide important information about the layout of a Dutch warship from the first decades of the 18th century. By studying those plans researchers can comprehend the basic dimensions and features, the decks arrangement together with the number of guns and the decorative features. However, they are considered to be a static method of illustration since they provide specific views of a Dutch warship.

CHAPTER 4: SHIPWRECKS.

4.1) FORMATION PROCESSES IN WOODEN SHIPWRECKS.

A shipwreck is usually described as a dynamic archaeological assemblage: it contains a large number of different materials, ranging from personal items to structural parts of the vessel (Gibbins 2006, 280). It can function as a system in which those materials interact with the natural elements such as tides or waves (Quinn 2006, 1419). This interaction creates the so-called "formation processes". Those processes are divided into cultural and the non-cultural ones. The first are related with the human intervention in a wreck site while the second are connected to the environmental influence (Gregory and Phil 1996, 2). Environmental influences can lead to the deterioration of a wooden shipwreck. Three distinct types of deterioration can occur. The first type is the physical deterioration. This type of deterioration is caused by strong waves or the movement of sediment (Ward *et al* 1999, 565). With the sediment moving around the wreck the fluid velocity increases creating the phenomenon of scouring. Especially if the wreck is located in shallow waters the scouring presents a high rate.

The second type of deterioration is the biological one. This type of deterioration occurs when the micro-organisms attack the directly the wreck or its surrounding environment (Ward *et al* 1999, 566). The most serious micro-organism, in terms of deterioration, is the so-called "Terredo Navalis". This shipworm buries itself deep into the wood thus causing major damage to its structure leading in many cases to serious damage. Apart from the Terredo Navalis a series of bacteria can also affect a wooden shipwreck without however cause serious damage in comparison with the Navalis (Eriksen et al 2015, 10). The effects of micro-organisms are depended in a number of factors. One of these factors concerns the depth at which the shipwreck is found. If a wooden shipwreck is sunk in deeper and colder waters, sea organisms are less likely to deteriorate the wreck, as there is little to no oxygen present in such surroundings (Thockmorton 1987, 17). Sea organisms will also be prevented from interacting with shipwrecks covered by sand.

The third type of deterioration is chemical. This kind of deterioration is characterized by direct contact between the wreckage assemblage and the underwater environment, which causes phenomena like corrosion. The degree of salinity in the water has a strong influence on the state of wooden shipwrecks. The Baltic sea, for example, contains a large number of historical shipwrecks in a satisfactory state of preservation, due to its low salinity and great depth (Fors et al 2012, 2521).

Keith Muckleroy proposed a model of formation processes in 1976 which has become widely accepted among the maritime archaeological community (fig.4.27).

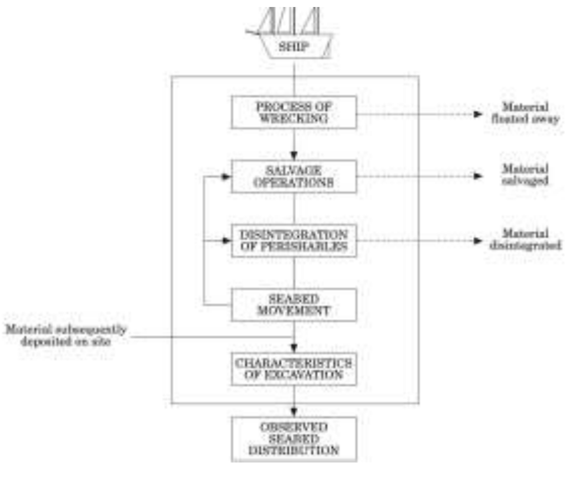

Figure 4.27: The wrecking process diagram according to Muckelroy (after Ward et al 1999,562).

According to this model the wreckage deteriorates in five steps. The model understands the ship as a collection of items which are arranged spatially at the site during the wreckage. Two major forces are affecting this arrangement. They are the extracting filters and the scrambling devices. The former lead to the loss of the wrecks material such as a salvage operation or floating items from the wreck. On the other hand, the second result in the absence of contextual information about the wreck. For example, wave action, movement of sediment or scour are one of these forces. By examining each of these processes it is possible to reanimate the loss of the vessel and to reposition the artefacts in their original position (Grosso 2014, 57). A later, significant improvement on the model includes the sedimentation process as one of the factors in relation to the preservation of a wreck-site (fig.4.28).

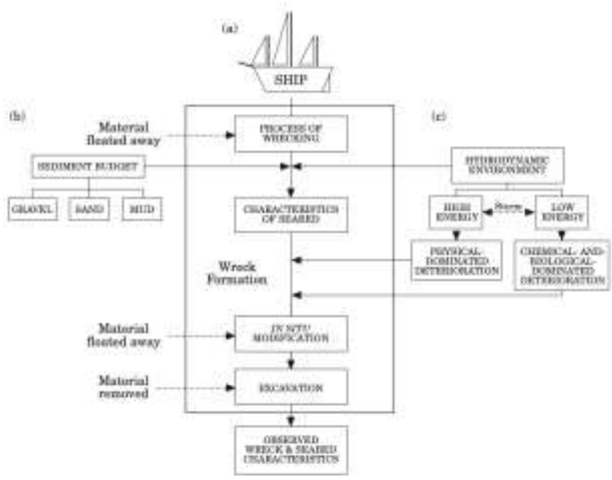

Figure 4.28: The improved version of Muckelroy’s diagram (after Ward *et al* 1999,564*).*

4.2) DUTCH SHIPWRECKS BETWEEN 1720-1750 AS A SOURCE.

Jeremy Gawronski in his publication about the shipwreck of the East Indianman Hollandia provides 6 categories of artefacts related to the VOC shipwrecks (Gawronski et al 1992). Those are:

1)**The ship:** All of the parts of the vessel: the rigging, its structural elements and other components like the doors or stairs between different decks (Gawronski et al 1992, 27).

2) **The cargo**: All commodities that where transferred to the East Indianmen of the VOC. In most of the cases in the outward journey the vessel carried the necessary provisions for the trip and the merchandise that was to be sent to the final destination. The merchandise consisted of all kinds of European products. On the return trip the cargo usually contained exotic products from Asia such as spices or tea (Gawronski et al 1992, 27). 3).

3)**Ship's armament**: In addition to the guns that were mounted on the gunports, small firearms and edged weapons are also included in this category (Gawronski et al 1992, 27).

4) **Ship's equipment**: This category includes navigational instruments, but also technologies only indirectly related to seafaring, such as carpenter's tools or spoons and knives (Gawronski et al 1992, 27).

5) **Personal items**: This includes jewelry and domestic goods like clothing (Gawronski et al 1992, 27).

6). **Environment**: The category consists of all non-artefactual materials which are found in the wreckage, such as the remains of livestock that was present on the ship (Gawronski et al 1992, 27).

In what follows, I summarize what the shipwrecks of Dutch vessels, from the period between 1720-1750, have taught us about artefacts belonging to these categories:

Starting with the first category the artefacts found provide us with fragmented information about the type of rigging used on board. From the wreck of Amsterdam (VOC vessel wrecked in 1740 off the coast of England) a series of iron bolts and a mast (probably the main one) providing an insight on the technology of rigging in relation to VOC retourships. In the same category a deadeye (fitting connecting the ropes of the rigging) suggests another find which offers a view of the sailing technology at that age (Gawronski et al 1984, 25). The most important find from the Amsterdam wreck in this category is the series of structural remains from the vessel. They provide us with an insight of the structure of a VOC Indianman. In contrast to the upper gun deck section, the beams of the lower deck are mostly preserved (fig.4.29).

Figure 4.29: The remains of the lower gun deck from the Amsterdam wreck (after Gawronski 1986,24).

Jerry Gawrosnki strongly claims that the disposition of those does not coincide with the model of an East Indianman built by Bentham (fig.4.30).

Figure 4.30: The East Indian Model built by Bentham (after Gawronski et al 1992, 53).

More specifically in the model the lodging knee that connects the wind transom to the port side is located on the lower gun deck .On the actual ship, the knee is positioned under the lower gun deck (fig.4.31).

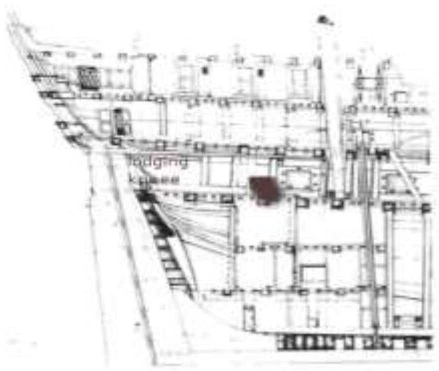

Figure 4.31: The lodging knee on the actual ship (after Gawronski 1986, 27).

The third category presents an abundance in the majority of the shipwrecks between 1720-1750. In the Amsterdam wreck the finds connected with the armament of the vessel were concentrated to the master gunners room located on the lower deck of the vessel. That provides a clue to the archaeologists concerning the location of the armament 's compartments in a VOC vessel. The wreck of the Hollandia also gathers a lot of artefacts concerning the armament on board and especially the typology of firearms used by the crew and the soldiers. More specifically a large amount of muskets was recovered bearing the insignia of the VOC Amsterdam Chamber. They are preserved in fragmentary condition. In another VOC wreck, the Zeewijk, a pistol was found with the inscription of the 'Kamer Zealand "indicating "the Admiralty. Apart from those wrecks I would like to refer to that of Curacao since it is the only excavated wreck of a Dutch warship from this period. Five swivel guns were recovered bearing the proof mark of Amsterdam. All these finds offer an excellent insight in the technological aspects of firearms on board a VOC vessel or a Dutch warship. Also by examining the typology of these artefacts we can discover the military hierarchy of the soldiers that were on board the vessel and even indicate exactly if they were marines or regular detachments.

The category of the cargo is also well represented in the archaeological record. For example jars of various sizes were found on the Zeewijk wreck (fig.4.32).

Figure 4.32: Types of jars from the Zeewijk (after Ingelman-Sundberg 1978, 73).

Those can provide us with information not only about the typology of the cargo on board but also can pinpoint the final destination of the Zeewijk and any other VOC vessel. As for the ship's equipment category the most interesting artefacts are the navigational instruments which are considered to be a typical find for VOC shipwrecks. Also they have been recovered in most of these wrecks. A characteristic example is the instruments discovered at the wreck of the VOC vessel Zuytdorp. In the Hollandia wreck also a number of bronze dividers were found together with a compass (fig.4.33).

Figure 4.33: The bronze divider from Hollandia (after Bruyns 2006, 270).

Secondly another astonishing find was that of a bronze case which contained more navigational instruments such as folding rules (Cowan et al 1975, 287). In the category of the personal items we do not have so many examples from shipwrecks. The only characteristic example is a large number of plates, wooden barrels and clay pipes which were discovered in the Hollandia wreck (Cowan et al 1975, 291). Moreover, in the wreck of Curacao a number of cooking items such as plates and forks were additionally found.

In the last category the only relevant example is the seats of carrots that were discovered in the Amsterdam wreck. The importance of these finds is that they offer a unique an insight on the dietary habits of the crew on board.

To conclude the information extracted from the typology of the artefacts provide us with a valuable insight about the armament that was used on board and their technology. Moreover, the presence of a number of jars indicated the nature of cargo mostly for the VOC vessels. The navigation instruments provide an insight on the navigation technology which is very important for understand how the VOC vessels travelled to their destination. On the other hand, the fragmentary condition of the artefacts, related with the rigging, does not provide us with a lot of information about the technology or even the real dimensions of the rigging's elements especially about a Dutch warship. The photogrammetric model could cover this gap. Also taking into consideration that only one known example of a shipwreck of a Dutch warship exists, from the first decade of the 18th century, the value of this argument is enhanced more. The digital model can function not only as a visualization source but also as a tool which can provide with extra data such as volumetric ones. Using that data, we can learn, for example, how much space each deck acquired or how heavy were the tops of the masts.

CHAPTER 5. METHODOLOGICAL REQUIREMENTS.

5.1) LONDON CHARTER ANS SEVILLE PRINCIPLES.

Due to the technological developments in digital recording coupled with the increasing number of digital projects in archaeology the need for a set of methodological standards for creating reliable 3D models in the cultural heritage sector has been aroused. Two recent attempts to provide such standards are the London Charter and the Seville Principles. The London Charter was created in 2006 and has since been translated into many languages (Hermon and Nicolluci 2018, 38). The London Charter offers 6 principles to ensure intellectual transparency, intellectual accountability and reproducibility of the visualization results. These principles can also be applied to evaluate the authenticity of a 3D model applied to cultural heritage (Hermon and Nicolluci 2018, 39). The Charter's 6 principles are:

1: **Implementation**:This principle is valid when a computer-based visualization is related to the field of the cultural heritage .Of course each time this principle should be applied according to the aims of each individual project. Moreover, the economic value of the project and the final product must be encoded into the visualization process (The London Charter 2009, 75).

2: **Aims and methods**: This second principle urges that 3D modelling should only be applied when it is the most suitable means of visualizing the object at issue. This demands a comparison of all visualization methods in order to determine which is most suitable before applying 3D modelling ((The London Charter 2009,75).

3:**Research sources**: The sources used for a digitization project should be presented in a structured way. The Charter defines as sources every information, digital or not, that is used during the visualization process. Also, those sources should be structured in accordance with the best practices inside the digital community (The London Charter 2012, 76).

4:**Documentation :** The methods and the results of a digitization project should be addressed and evaluated in the context of the purpose of the project. The documentation should provide other researchers with a detailed and clear analysis of the digital process (The London Charter 2012,77).

5: **Sustainability:** Within a digitization project, long-term strategies for the preservation of the final results and their embodiment in the social, cultural and intellectual heritage should be stated clearly. Those strategies should choose the most trustworthy and analytical manner of archiving and storing the produced visualization data but and the metadata (The London Charter 2012, 78).

6: **Accessibility**: This last principle aims to ensure the digital project induces public engagement, management and analysis of the cultural heritage to the greatest possible extent. This principle calls upon researchers to think about what individuals will (not) be able to access the final digitization product (The London Charter 2012,79). Furthermore, all these principles are meant to ensure authenticity in computer visualization projects. If the creation of the digital replica is based on solid and reliable scientific data, it can be characterized as an authentic cultural product.

The London Charter was later extended with the "Seville Principles"(http://smartheritage.com/seville-principles/seville-principles). The principle that I would like to emphasize, concerning the Seville Principles is that of authenticity. This principle emphasizes on the fact that visualization reconstructs artefacts or archaeological sites according to our belief for the past. For that in the text authenticity is defined as a "permanent operational concept". In the case of virtual restorations there should be a clear separation of the levels of authenticity in which the reconstruction is based (http://smartheritage.com).

5.2) PHOTOGRAMMETRIC PROJECTS WITH SHIP MODELS FROM MARITIME MUSEUMS.

Studying the relevant literature found two groups of projects which have been initiated into the maritime museum context. In the first the specimen included recorded shipwrecks which were excavated and then transferred to the museum. The second was related to ship models as basis for digital documentation. Also I would like to emphasize that most these projects combine photogrammetry with laser scanning as a digitization method. Since in my project I used photogrammetry, as the sole digitization method, it would be interesting to compare those projects in terms of efficiency in digitization methods.

In the first group I will refer to the project for the digitization of the Swedish warship (lost in 1628) Vasa which now stands in the Maritime Museum in Stockholm. Vasa was designed by Dutch shipbuilders during the 17th century. The main purpose of the project was to create a realistic digital model through the aid of laser scanning for animation purposes. For that one of the major research questions focused on which workflow should be used in terms of funds, availability and time frame. The project also attempts to define if the 3D model can be considered as authentic based on the measurements extracted by it (Carlson 2011,1-3). The Museum provided the researcher with scans of the physical model which were consisted of 750 to

2.500,00 points. The specific scans were acquired from 350 locations (Carlson 2011, 9). The researcher imported the scans into the Autodesk Maya software as to create the mesh. The creation of the mesh was conducted in different parts according to the structural characteristics of the physical model. Thus the hull, the deck and gunwale, the stern together with the statues and the decorative features, the bow and the rigging (Carlson 2011, 12-17). In relation to the last the mesh did not represent the actual size of the real mast. As for the ornamental details, especially on the stern the following issue occurred. While the shape of the statues and animal figures was successfully rendered on the mesh the small details such the clothing were not transferred on the mesh. Another problem was that the heights and the widths of the statues could not be measured even with hand measuring (Carlson 2011, 14-15). The main reason was that parts of them were broken. Considering the bow, the problem was the lack of sufficient points as for the bow to be rendered efficiently in the mesh (Carlson 2011,17).

Two major conclusions were derived from the final 3D model which was included 788,123 triangles (Carlson 2011, 25). Firstly, the authenticity was preserved in the digital replica of the physical model. According to the researcher size and shape agreed with the real ship. Secondly, despite the controlled and suitable workflow for the specific project, the final 3D model lacked in the visualization of some details such as the ornamental details of the stern. Perhaps a larger number of polygons could aid in this matter (Carlson 2011, 25).

In the second group the first project concerns the creation of a 3D model based on the physical model of the HMS Falmouth, an item in the collection of the Imperial War Museum (UK). The HMS Falmouth was lost after being hit by German submarines during the First World War. While the details of the incident are well documented, this ship and its wreck site have received little attention considering their historical significance. Historic England, the national heritage agency in the UK, therefore decided to create a 3D replica of the ship model to raise public awareness (Firth et al 2019,181).

The 3D model was created using a combination of laser scanning and photogrammetry. During the photo-session, 891 photos were taken with a Sony ILCE -7RM2 digital camera. In total, 104GB of photographs were taken. The photos were processed through the RealityCapture software (https://www.capturingreality.com). This software allows for the combination of laser scanning and photogrammetry. Although the masts and rigging were excluded, the final 3D model managed to depict almost every other detail of the original models (Firth et al 2019, 230).

The second project that is relevant in the context of my research, includes a number of ancient ship models in the collections of the archaeological museums on the island of Samos (Greece). These models are dated between 650 and 600 BC and provide the archaeologists with important information regarding the typology of ships and maritime culture at Samos in the period (Diamanidis and Valanis 2012,365). The models probably represent warships and were all made from single pieces of wood. Initially researchers tried using photogrammetry to capture the surface details on the models. Due to the curved shape of the items, making it difficult to render all the data into a single digital model, photogrammetry proved inadequate. Hence, laser scanning was used for this purpose. Photogrammetry was employed afterwards to add photorealistic details, such as texture, to the meshes of the 3D models that were created by the scans. The final 3D models enabled archaeologists to reconstruct elements of the hulls, providing them with valuable insight into the nature of the boats of Samos during the 7th century BC (fig.5.34). For example examining the final 3D model ,of the original ship model with the number H90, it was concluded that the underwater part of the hull was symmetrical to the middle framing of the original vessel (Diamanidis and Valanis 2012, 371).

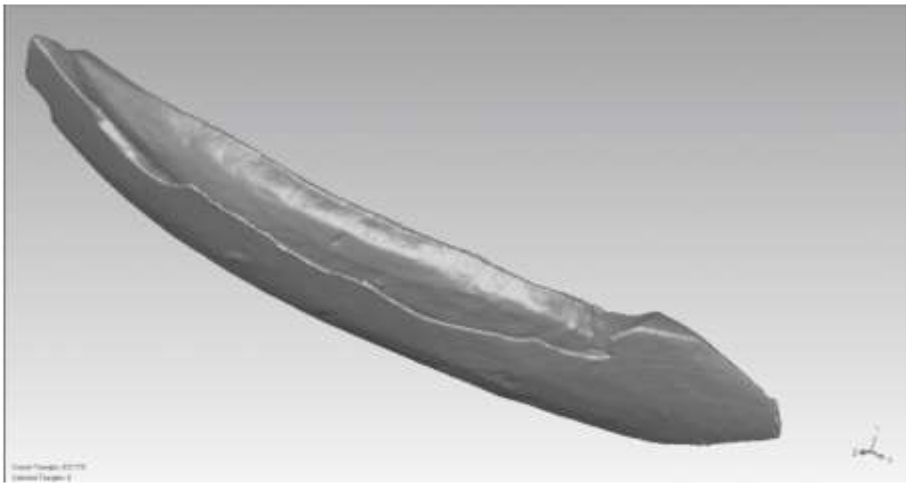

Figure 5.34: The digital replica of the H90 ship model (Diamanidis and Valanis 2012,371).

The next project attempts to emphasize the value of creating 3D models of historical vessels. Historical vessels and their scaled models suggest part of the cultural heritage as they provide valuable information about the technological aspects of the type of ship they depict. The preservation of these cultural items in the Maritime museums suggests a crucial task for the curators and the maritime archaeologists to invest. In this project, as a specimen, a model of the Italian torpedo-class destroyer with the name "Indomito" (fig.5.35).

Figure 5.35: The original model and the digital version (Menna et al 2011,238).

Fortunately plans of the “Indomito” have been kept by a ship-modelling association. By acquiring a 3D replica of the model the team was able to investigate if the model agrees with those plans. In relation to the digital workflow photogrammetry was combined with laser scanning. This combination provides more precise measurements in a short range of time especially since a ship model bears a complex structure.

The photogrammetric session was separated into different phases. First the hull was documented and then the superstructures of the model. In the hull’s case photogrammetry was used. The team used a Nikon DSLR camera equipped with a 35mm lens and set a distance of 1m between the camera and the model. Also 200 targets, as reference points, were positioned on the hull. Moreover, flashes were added as to avoid reflections and shadows. As for the photos 80 were taken in total. Even though photogrammetry was the primary method used in the model’s hull scans were also performed. The scans were matched with the photogrammetry targets as to establish a common reference system. After that step a point cloud was formed consisted of 14 million points (fig.5.36)

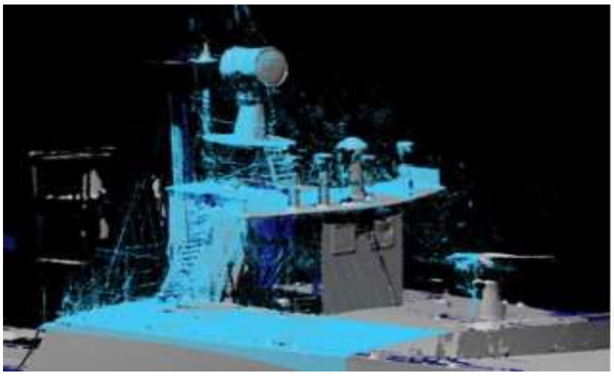

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Figure 5.36: The dense point cloud of the main deck of the original model (Menna *et al* 2011,249)

As soon as the cloud was completed a mesh was created (fig.5.37).

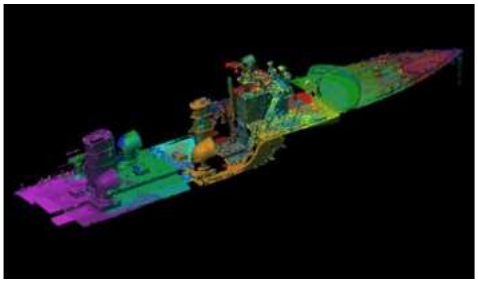

Figure 5.37: The mesh of the original model (Menna et al 2011,250).

The total time for the creation of the digital replica of the hull was estimated to 3hours while the time for the equivalent replica of the main deck less than 1 hour. In contrast the laser scanning needed more time to perform the same tasks (Menna et al 2011, 250). The complex structure of the physical model and the small distances between the model's parts created blurry areas in the photogrammetric model (Menna et al 2011, 251). These challenging tasks highlight the need for more accurate and effective digital methods for producing high quality photogrammetric digital replicas of historical ship models.

Continuing another similar project is that of Kotaro Yamafune (Yamafune 2016). More specifically he used a 1:10 wooden ship model, known as the Saveiro, as to test the efficiency and the accuracy of the photogrammetric replica. Two photogrammetric models were created one for visualization purposes and one for archaeological ones. In total 611 photos were taken and coded targets were places around the model. Surprisingly the photogrammetric model consisted of 2,000.000 faces indicating a large number. Thus it was reduced to 500,000 faces (Yamafune 2016,77). The important conclusion from these two models is that, in order to reach a satisfactory result, modifications should be made taking of course into account the purpose of the photogrammetric model. An equally crucial issues which is commented is the rendering of the sails. Agisoft has a difficulty to capture objects with thin surfaces. For that it is proposed to export the mesh and texture of the digital models in another software for improvements such as Autodesk Maya. As soon as the result is satisfactory then the mesh can be reimported to Agisoft (Yamafune 2016,80). Kotaro Yamafune applied this method for constructing a photogrammetric model of a Chinese traditional ship model. Additionally, the Ship Reconstruction Laboratory in Texas initiated a project relevant to that of Kotaro Yamafune (Lewis and Oswald 2019). More specifically it aimed to test the Agisoft software with a low-cost smart phone application for creating 3D models. The application is known as Qlone and it enables the user to digitize physical objects with low cost as the only charge is for downloading the created 3D models (Lewis and Oswald 2019,107). As a specimen two models, one large and the other small, of traditional Chinese boats were used. Three parameters were checked accordingly: the quality of model, the time and the cost. Another interesting factor is that the lighting conditions were similar to those in a Maritime Museum (Lewis and Oswald 2019, 108-109). Comparing the Agisoft with the phone application it was noted that the second did not enable the user to make significant modifications on the final photogrammetric models. For that the shape was characterized by a low level of accuracy. On the other hand, the photos taken by the DSLR camera were clearer thus the quality of the mesh of the photogrammetric models by Agisoft was superior to that of the phone. The difficulty which aroused during the rendering process was the thin shape of the masts. Agisoft was not completely successful in capturing every detail of the mast and the sail (Lewis and Oswald 2019,110). Summarizing the results, it was proved that Agisoft presented a better performance in terms of quality while the values for time and cost were high compared to the phone application (Lewis and Oswald 2019, 111).

Another relevant project was initiated by the United States Naval Academy (USNA) which holds a large number of historical ship model (http://www.usna.edu). One of them is the model of a 50-gun British warship dated in 1699. The creation of the 3D model aimed in performing measurements and even analyze the stability and performance of the vessel in a digital environment. For the creation of the 3D model a number of photogrammetric software were used. One of them was the Agisoft software. The results proved that for the dense point cloud reconstruction and 3D modelling of ship models Agisoft software should be strongly preferred (fig.5.38&fig.5.39).

Figure 5.38 : The dense point cloud of the ship model using Agisoft (http://www.usna.edu).

Figure 5.39: The dense point cloud of the ship model using VisualFM (http://www.usna.edu).

Finally, I would like to mention two last projects. The first is that of John Mc McCarthy from Flinders University. The main aim of this project is to reveal more details about the VOC vessels dated from the 17th and 18th century. For that he scanned a series of relevant ship models from the Maritime Museum in Amsterdam Since it is an ongoing project it would be very beneficial to compare it with my results (https://sharedheritage.dutchculture.nl). The second project was initiated by Ab Hoving, former curator of the ship model collection of Rijksmuseum. Based on ship plans of a 17th century Dutch merchant ship he created a model with the aid of the Delft software ((https://maritime-heritage.com).

CHAPTER 6: THE WORKFLOW.

6.1) SELECTION OF THE SOFTWARE.

I decided to test the following software program for the creation of the photogrammetric model: the Agisoft. The main reason for this choice was its straightforward workflow and the frequent use of this software in projects such as those I have presented in the previous chapter. At that point I would like to mention a very useful article by Amandine Colson (Colson 2017). In this article the writer acknowledged the increase in digital projects concerning maritime heritage. She evaluates different methods such as CMM (coordinate Measuring Machine), TST (Total Station Theodolite) and laser scanning. For each of these methods advantages and disadvantages are presented. For example, concerning laser scanning requires a lot of expertise even though it produces large data sets (Colson 2017,4). Taking into account the available time frame for the completion of the Thesis and the type of equipment that I could use in the museum I believe that the choice of Agisoft photogrammetric software is a suitable choice. Depending of the quality of the final digital replicas that can be supported more. Additionally, the evaluation of the use of the specific software complies with the second requirement as it is addressed by the London Charter. Moreover, concerning the first principle of the London Charter I believe that it is equally covered. Taking into consideration the increase of projects concerning the digitization of maritime heritage I believe that the choice of digitizing a model of an 18th century Dutch warships can be considered as such. After all ships and their models are characterizing as the medium of knowledge and goods (Colson 2017,2).

For the processing of the images and the creation of the photogrammetric models I used a MAC laptop with the following features:

-Processor : 2,7GHz Intel Core i5.

- Memory: 8GB.

-Graphics: Intel Iris Graphics 6100 1536MB.

The Agisoft Metashape Manual suggests that a memory of 32GB and a i7 Intel Core processor (Agisoft Metashape Manual 2015, 1). One additional reason that I choose to perform the digitization in sections was the 8GB memory of the laptop. An 8GB memory would not enable me to construct single photogrammetric model since that would risk the possibility of destroying that model.

For the Agisoft the first step is the upload of the images in the interface of the software. The second step is the alignment of the images followed by a dense print cloud and then a mesh. The mesh is the surface of the 3D model. The final step for the completion of the 3D model is the creation of the texture (Agisoft Metashape User Manual 2019, 15). In the following figure I depict a diagram of the workflow I have applied for the creation of the photogrammetric models (figure 6.40).

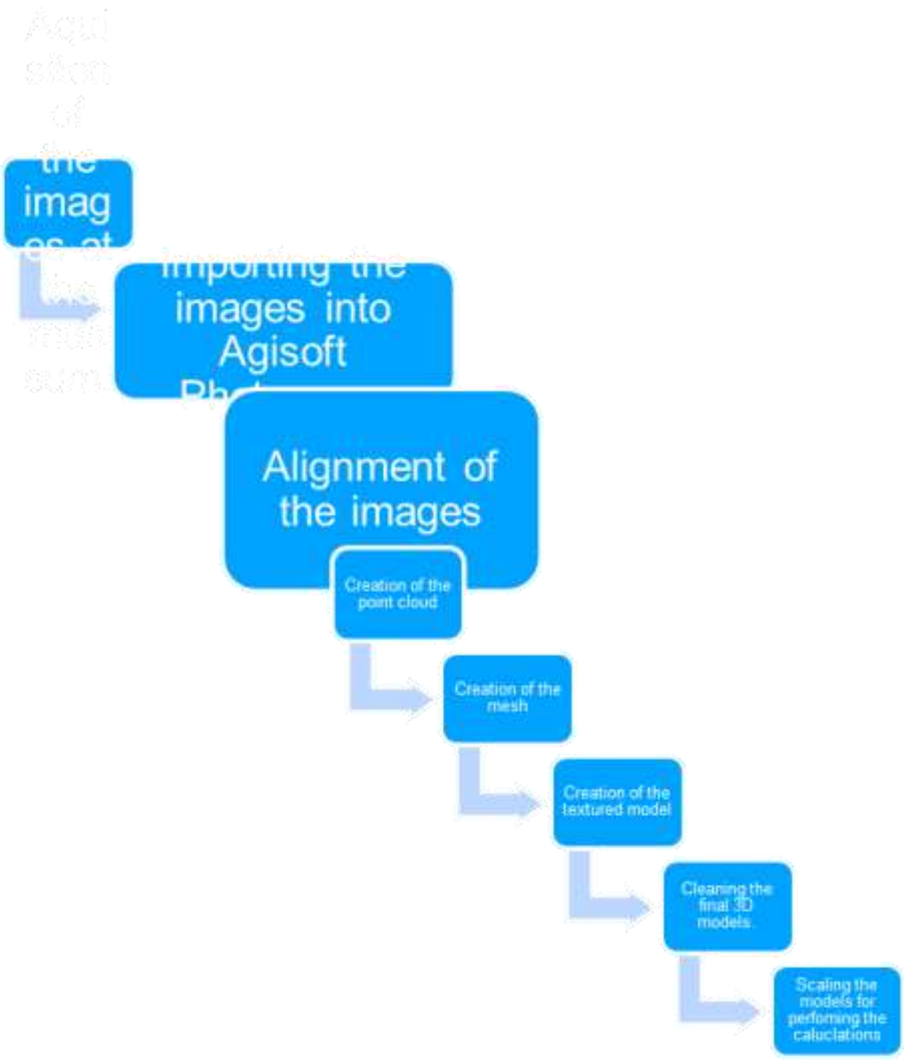

Figure 6.40: The workflow of my digitization process (after the author 2019).

6.2) CREATING THE PHOTOGRAMMETRIC MODELS.

The initial step in my project was to arrange the photoshoot of the model. After having discussed this with the curator of the Maritime Collections of the Maritime Museum in Amsterdam, we agreed to complete the photo sessions in 3 days. A professional photographer from the museum assisted me with the photoshoot. A steady 80mm lens was used. This type of lens is less likely to produce distortions or blurring compared to zoom lenses (Dey 2018, 20). A Phase One type P65 camera was used, which is considered one of the most reliable cameras and is used by many professionals (https://www.phaseone.com). The distance of the lens from the object was set to 68cm, the shutter speed was set at 1/50. Shutter speed refers to the amount of time the shutter is open when taking a photo(https://www.slr-photographyguide.com). By controlling the shutter speed, the photographer can estimate the amount of light which passes through the camera lens. Since artificial lighting was already installed, a medium shutter speed proved to be most suitable for ensuring sharp images. The value of the aperture was set to 1,8. I chose this value to prevent producing too bright images, which would negatively affect the quality of the 3D model.

The first day was devoted to the portside, of which 199 photos were made, ranging from 6,9MB to 7,7MB in size. These camera settings were also used during the other sessions. In the second session photos of the top, bow and stern were taken. The top view presented a significant challenge, as we had to take extreme care not to damage the original model. In total, 194 photos were taken of the top, bow and stern. On the last day, 343 photos were taken of the starboard side. The total number of photographs taken resembles that for similar projects, for the ship model of the Falmouth, for example, 891 photos were shot.

 The Museum was kind enough to provide me with a room and all the necessary installations. The model was placed in the middle of a large stage with a neutral background. In front of the stage a large supporting structure was placed, i.e. a tripod with a horizontal and vertical arm. The horizontal arm allowed the camera to be moved, in order to photograph the object from multiple angles. The use of a tripod is essential to ensure that the camera remains steady, thus avoiding blurry photos (Luna 2018,4). Secondly for the background Luna proposes a black one for light-colored objects while for dark-colored a grey /black one (Luna 2018,4). The model was positioned on a round table, which allowed me to capture most of the item's details. A round table is an excellent piece of photogrammetric equipment, as it ensures the safety of the item which is especially important for fragile objects. Another important factor for a successful photo session is the amount of lighting. Otto Luna recommends a 2-3 light setup. Secondly the light should be soft as to avoid reflections (Luna 2018,4). In my case I used the same set up parametrical to the original ship model.

The digitization of the physical model was conducted in separate stages. In each stage a specific section of the model was digitized. This separation agrees with the principle of documentation within the London Charter, which dictates the visualization process should be presented in a form suitable for analysis. By dividing the photogrammetric model in various sections, dividing the hull from the rigging, I can estimate which features from the original model were transferred to the photogrammetric replica. If the transfer of the shape and the details is successful, then I can say that the level of authenticity is maintained. By that I can examine if the photogrammetric models comply with the Seville Principles in relation to authenticity. Moreover, the same practice was applied to the digitization of the Vasa project (Carlson 2011).

The first section for the digitization was the rigging of the model. As it has been demonstrated in the case of Vasa the rendering of the rigging suggests a demanding task. An alternative solution would be to use an extra action camera, such as Go Pro, for the rigging exclusively. However, the wide angle of the specific camera would create difficulties in matching those images with that of the hull taken by a standard lens. In this case 176 images were uploaded. The next step was the alignment of the images. From the total 151 images were aligned covering the rigging of the side of the physical model. During the alignment a set of 41,901 tie points was formed. The amount of tie points indicates the upper limit of feature points on every image that was taken into consideration during the alignment (Agisoft User Manual 2016, 13). Furthermore, a number of parameters were selected for the procedure. The accuracy was set to medium, as to accelerate the process while ensuring high quality results. According to the Agisoft user manual, medium accuracy resizes the scale of the image 2 times (Agisoft Metashape User Manual 2019, 22). The matching time was 16 minutes and the alignment 2 minutes.

After the shaping of the tie points the software generates a dense point cloud. The visualization of the dense point cloud is based on the calculation of depth information for each camera by which the point cloud is shaped. In my case a dense point cloud of 8,218,290 points was created. Also a number of parameters were set such as the quality and the filtering mode. The former specifies the quality of the reconstruction of the point cloud and the second calculates the depth maps which are created during the specific process (Agisoft Metashape User Manual 2019,25). The mild choice ensures that all the important features of the original model are included in the reconstruction (Agisoft Metashape User Manual 2019,26). In my workflow I selected those two parameters. Since the rigging of the physical model is a complex structure, with many gaps between the masts, large areas of grey areas were present on the dense point cloud. They are known as noise. However, the software contains tools by which those areas can be cleaned manually. Starting with the side rigging rendering the dense point cloud required 2 minutes of processing and 17 seconds (fig.6.41).

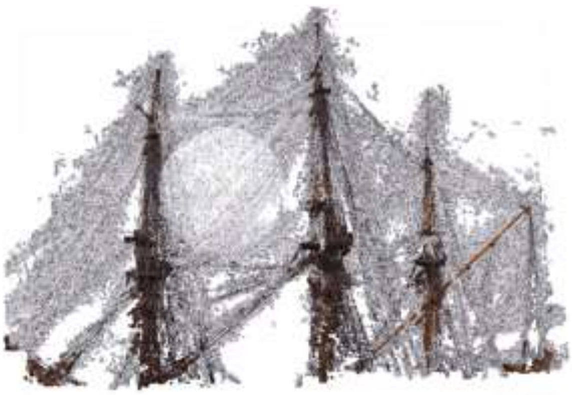

Figure 6.41: The dense point cloud of the side rigging (after the author 2019).

The next step was the creation of the mesh, i.e. the surface of the 3D model. Most of the elements of the rigging were rendered to the digital model. Notice, for example, that even the tops of the masts can be seen clearly. The final step was creation of the mesh and the texturing of the model, which required 15 minutes and 2 seconds. The textured model had 145,358 faces (fig.6.42). As soon as the model was textured model was complete I manually cleared it with satisfactory results. The only change was that the shrouds and the halyards were too thin so they were erased during the cleaning.

Figure 6.42: The textured 3D model of the side rigging (after the author 2019).

The 25 remaining images, of the rigging of the bow, were aligned separately. They were related to the rigging of the bow. The parameters were the same as in the previous session. All of the 25 images were successfully aligned. The matching time in this case was 49 seconds while the time of the alignment 13 seconds. The tie points reached the number of 7.322. The dense point cloud consisted of 2,338,893 points and the time required for its creation was 52 seconds (fig.6.43).

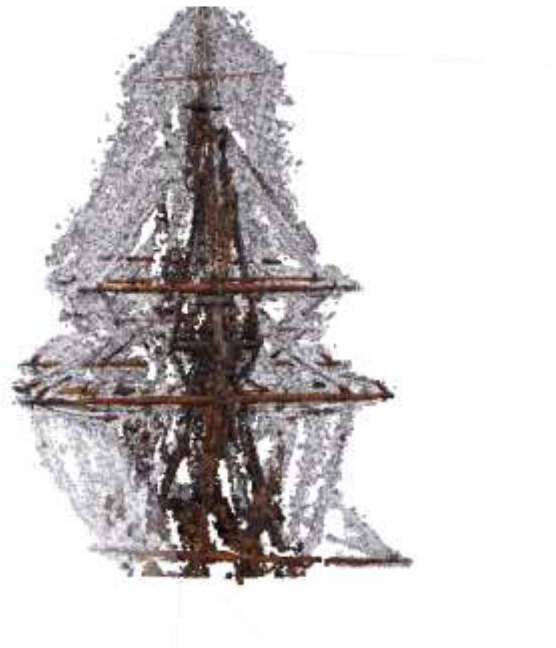

Figure 6.43: The dense point cloud of the bow's rigging (after the author 2019).

The processing of the mesh required 4 minutes and 53 seconds while that for the texturing 2 minutes and 34 second. The 3D model consisted of 166,766 faces and 87,506 vertices(fig.6.44).

Figure 6.44: The textured model of the bow's rigging (after the author 2019).

After completing the digitization of the rigging of the side and the bow, the stern section followed. This time 11 images were aligned. For improved results I attempted to mask any unnecessary elements from the images. The alignment time required 15 seconds while that of the matching time 6 seconds. A dense point cloud of 925,047 points was created. The processing time was 6 seconds. As soon as the dense point cloud was completed the mesh followed with 140,642 faces and 72,689 vertices. In comparison to the two previous models, the quality of the stern's digital model was rather low. The shape of the masts was distorted and did not provide a clear perspective to the viewer. Also the time required for the creation of the mesh was 3 minutes and 10 seconds. Since the final model was unsuccessful I did not include this models in the measurements neither screenshots.

Overall I believe that the digitization of the rigging in 3 sections suggests a logical choice for the structural presentation of the 3D modelling procedure. By having 3 separate photogrammetric models the researcher can decide which to use for performing measurements and calculations. Thus based on the results of these actions I can highlight the importance of each part of the rigging as a source of information in a digital environment. By that the first new methodological requirement is established which is related also to the London's Charter's principle for clear presentation of the data and the visualization procedure. Furthermore, a relatively low number of images managed to perform satisfactory visualization results. Based on that observation this low number can be established as a methodological advantage for the digitization of the original model and the high quality of the photogrammetric version.

In the following table I summarize the characteristics of the photogrammetric models(Table.1)

Rigging	Side	Bow	Stern
Dense point cloud	8,218,290 points	2,338,893 points	925,047 points
Textured model	145,358 faces	166,766 faces and 87,506 vertices	185,008 faces and 96,786 vertices
Processing time for the dense point cloud	2min and 17sc	52 seconds	6 seconds
Processing time for the textured model	15 minutes and 2 seconds	2 minutes and 34 second	3 minutes and 10 seconds.

Table 1: The characteristics of the 3D models of the rigging (after the author 2019).

The second section for the digitization was the hull. For that section I followed the same procedure as in the rigging. More specifically three separate photogrammetric models were created. That of the bow, the side and the stern of the vessel. Starting with the bow 7 images were aligned with 5,474 tie points. For the matching of the images 10 seconds were required while for the alignment 8 seconds. Afterwards a dense point cloud was formed consisted of 706,444 points and it was created in 4 seconds (fig.6.45).

Figure 6.45: The dense point cloud of the bow (after the author 2019).

The mesh of the photogrammetric model managed to capture the decorative elements with a high quality and a smooth surface in the textured version (fig.6.46). For the mesh 1 minute and 21 seconds were required while for the texture 32 seconds. Again a low number of images succeeded in producing high quality photogrammetric models.

Figure 6.46: The textured model of the bow (after the author 2019).

In relation to the model of the side of the original one 14 cameras were aligned with a matching time of 14 seconds and alignment time of 3 seconds. The number of the tie points reached the number of 17,154. In relation to the dense point cloud it consisted of 4,261,6119 points (fig.6.47).

Figure 6.47: The dense point cloud of the hull's side (after the author 2019).

The time required for the dense point cloud was 19 seconds. A mesh followed with 218,331 faces and 11,233 vertices (fig.6.48). For the creation of the texture 1 minute and 44 seconds were required while for the mesh 5 minutes and 39 seconds. An issue that I would like to comment is the fact that while rotating the model there was a revered mirror perspective. Despite that I could scale the model and perform calculations.

Figure 6.48: The textured model of the hull's side (after the author 2019).

An additional photogrammetric model was that of the stern. In this case 8 cameras were aligned with a matching time of 11 seconds and an alignment time of 6 seconds. The tie points were 6.178. As for the dense point cloud it reached 820,125 points (fig.6.49).

Figure 6.49: The dense point cloud of the stern (after the author 2019).

The time for the creation of the cloud was estimated to 6 seconds. After the completion of the cloud a mesh followed with a processing time of 1 minutes and 22 seconds. The mesh model consisted of 166,991 faces and 84,727 vertices. In relation to the textured version the time required was 47 seconds (fig.6.50). Considering the quality of the final photogrammetric model it is characterized by a smooth surface and a clear digitization of all the original features of the stern, especially the taferrel. Furthermore, a low number of images were sufficient for the creation of the three models.

Figure 6.50: The textured model of the stern (after the author 2019).

The final photogrammetric model was that of the top of the original model. In this case 45 cameras were aligned with 35,775 tie points. The matching time was calculated to 50 seconds and the alignment time 12 seconds. After the alignment the dense point cloud was formed consisting of 3,807,590 points in 2 minutes and 28 seconds (fig.6.51). Notice the noise around the dens point cloud.

Figure 6.51: The dense point cloud of the top of the model (after the author 2019).

In relation to the mesh 3 minutes and 36 seconds were required. As for the 3D model it consisted of 76,885 faces and 148,459 vertices (fig.6.52). The quality of the specific photogrammetric model can be characterized as satisfactory since the major elements of the original model are present in the digital version. However, the masts and the yards have some blurry areas. In contrast with the forecastle, the waist and the quarterdeck sustain their original colors and shape.

Figure 6.52: The textured model of the top's model (after the author 2019).

To sum up the following table presents the characteristics of the constructed photogrammetric models of the hull (Table.2).

HULL	SIDE	BOW	STERN	TOP
DENSE POINT CLOUD	4,261,6119 points	706,444 points	820,125 points	3,807,590 points
TEXTURED MODEL	218,331 faces and 11,233 vertices	140,642 faces and 72,689 vertices	166,991 faces and 84,727 vertices	76,885 faces and 148,459 vertices
PROCESSING TIME FOR THE DENSE POINR CLOUD	19 seconds	4 seconds	6 seconds	2 minutes and 28 seconds
PROCESSING TIME FOR THE TEXTURED MODEL	5 minutes and 39 seconds	32 seconds	47 seconds	3 minutes and 36 seconds

Table 2: The characteristics of the 3D models of the hull (after the author 2019).

6.3) CALCULATIONS ON THE PHOTOGRAMMETRIC MODELS.

Regarding the calculations, I performed two major types: the first considered dimensions' measures (such as mast's height and distance between gun- ports) and the second volumetric measurements (such as volume of the masts). Agisoft allows the user to perform measurements on the 3D models. For that a scale is needed to be established. That can be done either by establishing coordinate system before the capturing of the images or the model can be scaled based on known distances (Agisoft User Manual 2016, 48). I selected the second method because the first demanded the position of control points on the model. Due to the fragile and complex structure of the model it would require a lot of time to position those points on the model. For the performance of the measurements I choose the photogrammetric model of the side rigging since it contained most of the rigging elements including the tops. Also the photogrammetric model of the stern's rigging was excluded due to low quality.

For the side rigging two scales were created having an accuracy was approximately 0,001000m while the error parameter0.886678 m for the first scale and for the second 0.867843m. The error parameters in meters indicates the distance between the input source and the estimated positions of the cameras (Metashape Manual 2015, 70). Based on the small difference between the scales I can say that the scaling was successful.

Considering the hull sections, the hull's side was scaled and the top. Considering the first two scales were created with the same accuracy as in the case of the side rigging. However, the error parameter of the first scale was estimated to 0.305080m while for the second -0.114975m. As we see there is a significant difference. Regarding the top, the first scale had an error parameter of 0.178308m while the second a 0.03340m. I could say that it is a slight difference but not as much as in the case of the hull's side.

Since the scales were established I could proceed to the calculations. We should not forget that since I have connected my physical ship model with a real ship then it is easier to transform these measurements in real dimensions. It should be emphasized that the Dutch had established certain rules for the measurement of their warships. More specifically they selected the Amsterdam foot which is equal to 28,32cm. The length was measured over stem to stern on the uppermost continuous deck (Bender 2014, 40).

In relation to the first category the distance between the 2nd gun port and the 3rd was 8,14cm while for the 6th and the 6th the equivalent was 8,33cm. As we see there is not a big metric difference. As I have said before while observing the physical model with the naked eye I had the impression of an asymmetry between the distances of the gun-ports. Those calculations confirm that fact however they provide more sustained information about the amount of this asymmetry. Transforming those in real dimensions we have the follow values respectively: 333cm and 341.53cm. By that we can see that even in real dimensions there still a minor metric difference. Based on Olivier's manuscript it mentions that the gun-ports of a 90-gun ship have a distance between 2.28m. Combining all the information we can say that a 50-gun warship had less distance between its gun- ports than a 90-gun ship.

Moving to the height of the masts the following values were established: for the foremast 127cm, for the mainmast 143cm and for the mizzen mast 114cm (Table.3).

Foremast	127cm
Mainmast	143cm
Foremast	114cm

Table 3: The measurements on the masts (after the author 2019).

Those values indicate that the mainmast in the model as the tallest fact that is logical since the tops of the main mast were used for observation by the crew in case of hostilities. In the real ship the distances were as follows: for the foremast 520cm, for the mainmast 586cm and for the mizzenmast

467cm. As we see even in a real 50gun Dutch warship the height between the first two masts bears a minor metric difference. Concerning the Olivier's manuscript, it does not make much comments about the masts only that they have the same heights with French warships between 1720-1750(Roberts 1992, 225).

Continuing with the volumetric calculations for those concerning the hull I used the vessel's side and that of the top. The volumetric calculations were established as follows (Table.4).

Lower deck	6875 cubic centimeters
Upper deck	947520 cubic centimeters
Quarter deck	7079400 cubic centimeters
Orlop deck	932955 cubic centimeters

Table 4: The volumetric measurements on the decks (after the author 2019).

From the table we can see that the orlop (the deck beneath the lower gun deck) of the physical model accumulates a high volume. That is expectable since it carried the major provisions of the vessel. Also the volume of the upper deck accumulates the higher values maybe because the heavy guns were positioned in that deck.

6.4) DISCUSSION

Overall I believe that Agisoft proved to be a suitable choice for the creation of a photogrammetric replica of a ship model from the 18th century. The hull section was successfully rendered despite the issue with mirroring perspective. Also the photogrammetric models of this section were more suitable for taking volumetric measurements while those models connected to the rigging were adequate for dimensions' measurements such as the height of the masts. Another important positive outcome was the fact that the calculations could be connected with a real size vessel proving that a photogrammetric model is a reliable source for the maritime archaeology of the Dutch 18^{th} century warships.

Moreover, the processing time can be characterized as fairly short while the cost of the whole project low since I only needed a camera and a lighting set.

Finally considering the quality of the photogrammetric models I think that those connected with the hull were best rendered while most parts of the rigging, except the masts, were not successfully transferred into the photogrammetric versions.

CHAPTER 7. CONCLUSIONS.

7.1) GENERAL CONCLUSIONS AND FURTHER RECOMMENDATIONS

Considering the research questions, I think that all were answered with success. Regarding the compliance with the London Charter I think the photogrammetric models covered most of them. Especially since objective calculations were used to extract conclusions, regarding Dutch warships authenticity is preserved. Particularly for the photogrammetric models of the hull that authenticity can be connected to the decks since measurements were extracted from them. As for the rigging the difficulty in the rendering suggested an issue. However, since measurements were also completed from there we can say that the masts retain their authenticity in regard to the physical model.

Another important advantage is that these measurements can be connected with a real size equivalent vessel justifying the use of the 3D models in the Dutch maritime historical context. Additionally, the user can shape a clear idea of the physical model without even touching it. for the credibility of the photogrammetric model as a source the following can be stated.

From all these conclusions is clear that the photogrammetric models provide us with useful information which were not found neither in iconographical sources neither in written ones.

Finally, the photogrammetric models were extracted in the PDF format as for retain their future sustainability. That agrees with the principle of 3D models which can be used for further improvements and the implementation of long strategies in the digital heritage. In addition to this the existence of a high quality 3D model in the Maritime Museum in Amsterdam could rise the public awareness about Dutch warships between 1720-1750 through a series of interactive educational applications.

Abstract

Between 1720 and 1750 British shipbuilders arrived in Amsterdam in order to assist the local Admiralties as to construct faster and more seaworthy warships. Until then the Dutch shipbuilders used their experience and empirical knowledge in order to construct the hull of the vessel. The British initiated the use of scaled plans and ship models thus they challenged the traditional Dutch methods.

This Thesis will use a ship model of a Dutch warship dated c.1750. The main aims of this project would be to test if the method of photogrammetry is suitable for this kind of object. Secondly the methodological requirements will be examined in relation to the London Charter and the Seville Principles.

Moreover, the efficiency of the selected software will be commented. The last aim is to conclude if the created 3D models offer truly new information about the Dutch warships at that era.

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APPENDIX

- Cross trees: Traverse planks for supporting the masts (after Shairbaum 1990, 24).
- Draught: The vertical height of the part of the ship measured from the top of the keel to the submerged part of the hull (Roberts 1992, 355).
- Catheads: Two timbers that project horizontally over the ship's bow. Another use of the cathead was to suspend the anchor when the bow should be clear. (Falconer 1784, 91).
- Chess tree: A timber fitted after the bow and is used for passing part of the rigging (Laughton 2001, 241).
- Deadeyes: metal fittings supporting the shrouds at the lower level of the masts (after the author 2019).
- Foremast: The first mast of the vessel starting from the bow (after the author 2019).

- Frame: A series of timbers which support the strength of the inner structure of the vessel (after Shairbaum 1990, 28).

- Hanging pieces or Hance: the step that is shaped by the drop of the rail from a top level to a lower one (Laughton 2001, 210).

- Jiboom: A spar which is extended forward and is strengthened by the bowsprit (after Shairbaum 1990, 33).

- Keel: The central timber in which all the building process is based (after Shiarbaum 1990,33).

- Main mast: The tallest mast on a ship (after Shairbaum 1990, 35.).

- Mizzen mast: The third mast starting from the bow (after Shairbaum 1990, 35).

- Port lids: Hanging doors which protected the cannons when they were not engaged in combat (Falconer 1784,240).

- Quarter galleries: A closed gallery which extends from the sides of the vessel at the level of the stern to the upper decks (after Shairbaum 1990, 38).

- Shrouds: The main mechanism for the standing rigging which supports the mast (after Shairbaum 1990, 41).

- Stays: Part of the rigging which is located in front of the masts (after Shairbaum 1990, 43)

- Tops: Platform structures on the masts of a vessel (after Shairbaum 1990, 45).

- Yard-arms: Extensions at the end of the yards (after the author 2019).

LIST OF FIGURES

LIST OF TABLES

.