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Monitoring of Underwater Archaeological Sites with the use of 3D Photogrammetry and Legacy Data

Case study: *HMS Maori (Malta)*

By

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Abstract

A photogrammetric survey has proven to be a reliable method for documenting underwater archaeological sites. Still, the potential which photogrammetry could have in the monitoring of underwater cultural heritage has been just briefly discussed in the past. The purpose of this dissertation is to test if a cost-effective and time-efficient monitoring scheme can be created, for a modern shipwreck site such as *HMS Maori*, by using photogrammetry and legacy data. The credibility of legacy data (old video footage) was explored, alongside software capable of producing deviation analysis (*Cloud Compare*). Some of the key findings of this research confirmed that it is possible to geo-reference and extract information from legacy data 3D models by using the method of 'common points' (*PhotoScan/Metashape*). Also, a comparative study confirmed that deviation analysis could generate quantitative data of an underwater archaeological site. This research demonstrated that a reliable monitoring scheme could be constructed with the help of legacy data and deviation analysis. The application of this methodology provided a better understanding of the change that is continuously happening at the shipwreck site of *HMS Maori*. A possibility to track site formation processes gives a chance for creating a proper management plan. Ultimately, this dissertation recommends various actions to be undertaken in the forthcoming period, such as: the On-site Conservation Survey, monitoring of the site and its further degradation (Citizen Science) and others.

Keywords

Photogrammetry; Legacy data; Monitoring; *HMS Maori*; Site formation process; Deviation Analysis; Underwater Cultural Heritage; *Cloud Compare*; *PhotoScan/Metashape*; Citizen Science;

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Table of Contents

List of Figures

List of Tables

CHAPTER I:

Introduction

3D photogrammetry has transformed the way how underwater archaeological research is performed today. It is considered to be a powerful tool capable of recording underwater archaeological sites and subsequently producing high-quality data that aids archaeologists in creating adequate site assessments. Also, it allows researchers to conduct a low-cost and time-efficient survey, which is highly appreciated when compared with other methods commonly used in underwater archaeology (i.e. manual recording, remote sensing, etc.). The potential use of 3D photogrammetry for monitoring underwater cultural heritage sites has been explored in the past few years without any noticeable breakthrough. Being a relatively young idea, it is still developing, and not many studies have been written about it. A large number of wreck-sites are lying unprotected and are probably severely affected by their dynamic environment, which is why an effective and more global way of monitoring archaeological sites should be established. One of the main objectives in this dissertation will be to produce several reliable 3D models of the *HMS Maori* shipwreck site. Modern shipwreck sites are probably one of the most endangered types of UCH sites that need protection. Because of their metallic composition, the number of chemical processes they undergo is severe, which influences their rate of deterioration. For this and many other reasons, monitoring should provide a fast and reliable solution which will help in constructing a suitable conservation procedure for the future.

In this dissertation, the methodology will rely on performing a standard photogrammetric survey for creating 1:1 scale-constrained 3D model of a wreck, and monitoring of the site will be done through the implementation of 3D models created from legacy data (old video footage). Through the use of deviation analysis software, the author should be able to track any alteration that happened at the archaeological wreck-site over the years. With a better understanding of site formation processes, archaeologists should be able to predict future changes in the condition of the site with more accuracy, which will help in creating an adequate management plan. The main reason why the author decided to focus solely on the *HMS Maori*, is the fact that this is one of the most accessible wreck sites in Malta, and due to her popularity as a dive site, the amount of data (videos) available online is ideal for testing the proposed methodology. If proved feasible, the methodology used for this research could be applied on every endangered UCH site.

1.1 Scope, Aim and Objectives

A revision of the historical background and the desk-based research will be done first, to provide a better understanding of the site development (i.e. ships characteristics, wrecking and the status *HMS Maori* has today as a wreck-site). The idea is to conduct a non-intrusive photogrammetric survey on the site, to document its extent and the condition of the archaeological remains. One of the key elements of the research will be to create 3D models of the wreck through the use of photogrammetric survey and legacy data survey (online videos). Created 3D models will then be used for comparative purposes in order to analyse the data and to deduce whether such information can be used for monitoring modern shipwreck site and its deterioration throughout the years.

<u>Research questions and objectives of this dissertation are:</u>

- To better understand site degradation processes of a modern historic shipwreck in shallow waters.
- To explore the effectiveness of 3D Photogrammetric survey and its potential role in preserving underwater cultural heritage.
- To explore whether we can use the results from the constructed 3D model of a shipwreck as a source of reference for the smaller 3D models that will be created out of old video footage (Legacy data), and to see if we can compare the data and learn more about site formation/ degradation process.
- Whether if we can use “Legacy data” (Citizen science) to construct a monitoring scheme that will use past records of the site in an effort to predict future events.

Before the objectives mentioned above could be completed, a number of dive sessions have been performed, where the author alongside Dr Yamafune conducted a photogrammetric survey of the wreck-site. The data collected this way created a basis for testing the research questions proposed in the dissertation.

1.2 Literature Review

Many aspects represented in this dissertation have been individually discussed or researched by experts from various disciplines. That is why a conglomeration of different sources and themes will be integrated for creating a comprehensive research work. Eventually, the author’s responsibility will be to consciously use the acquired information to justify the application of different methods shown throughout the work.

The literature review will follow the same general structure as the dissertation. Firstly, a study about the historical background and the sources that contain the most relevant information on the Tribal-class destroyers will be covered. Furthermore, a discussion will be made on the topic of creating appropriate site assessment and desk-based research of the *HMS Maori* shipwreck site. Secondly, the literature related to 3D photogrammetry will be presented, including the most credible publications and case studies dealing with the themes such as surveying, recording and interpretation of underwater archaeological sites. This will help to create an accurate explanation of different theoretical and methodological approaches that can be found in the present-day. Also, a brief comment will be given on the author's plan to integrate already established knowledge into the research of his own. Thirdly, limited literature concerning deviation analysis will be inspected. The focus will be to illustrate how this method can contribute to creating a monitoring scheme as proposed in this research.

Historical Background and Desk-based Research

To holistically approach the question of monitoring and to explain why this method should be used for the research, part of the focus will be on the role which *HMS Maori* had during the Second World War, as well as, the position she has in today's society. By doing so, a clear statement about the cultural/ historical value of the site should be made. Firstly, it is important to mention that over time many books and articles have been written on the topic of Tribal-class destroyers (Hodges, 1971; Whitley, 2000; Friedman, 2006; to name a few). Only the basic information about the *HMS Maori* could be found in such sources (i.e. manufacturer, built date, modification, etc.). A collection of general information about the idea behind developing such vessels can be seen, alongside a good description of the ship constructions and the most memorable campaigns during the war. Hodges makes an emphasis in his book on the change in the ideology of Tribal-class destroyer's development. He makes a detailed record about the armament, the structure and modifications that happened throughout the war (1971). Whitley's Encyclopedia about destroyers from the Second World War is a large-scale and comprehensive record of all destroyers built between 1939 and 1945 by the navies of the world (2000). A small section is dedicated to Tribal-class destroyers, where the author focuses mainly on design, modifications and service, alongside important dates, builders and performance. One of the more recently published books about British destroyers and frigates was published by Norman Friedman (2006). There, Friedman in a much broader sense tries to cover a period before the beginning of the Second World War and explains the political situation which led toward breaking the Treaty previously signed in

1936 (regulations about vessel size, tonnage, armament, etc.). This situation subsequently left room for generating new ideas on improving naval warfare. These sources provided valuable information about Tribals and *HMS Maori*, and have given the author a much needed historical perspective of events in the Second World War. Nevertheless, more factual information about *HMS Maori* is required for constructing a detailed service record of the vessel. Such materials could be found in The National Archives (Kew) in London. Because the records about the *HMS Maori* have not been digitized (visiting the archive in person was not an option), it was impossible for the author to acquire official information through Kew's online depository (except in one case - online source). Papers written by people who did have access to these documents will be used for recreating more detailed war service record (Mason, 2001; Haarr, 2009; Clarke, 2017). Mason catalogues the entire history of the ship, from the launching in 1939 to the sinking in 1942 (2001). These records, available online, are highly informative and valuable since they possess information about the ship's entire journey through the war, with the accent on the war service and the logistics (i.e. the number of crew members, Captains, ship repairs, relevant dates, campaigns, etc.). Mason presents information systematically and chronologically as a list of moments or situations *HMS Maori* went through. Here is where books mentioned above played a key role because they provided context and the story behind factual information collected by Mason. An attempt will be made to use previously mentioned sources and to chronologically illustrate the course of events *HMS Maori* went through over time (i.e. building, war service, sinking), and by doing so, the author will be able to make an emphasis of *Maori's* historical significance.

Research papers or reports about the *HMS Maori* wreck-site are non-existent. Information about the wreck can be found on various dive club websites. Because of this, the overall site assessment will be possible through the use of personal experience of the author diving at the site, through the communication with dive instructors and available information about the wreck online. This way, it is possible to extract information about environmental conditions (i.e. currents, visibility, tidal movement, etc.), marine life that resides at the site and how popular the dive site is inside the diving community. After successfully documenting the site, the author will try to use the previously acquired information to highlight the cultural significance and the role which the wreck-site has in present-day. Every discussion made in this segment of the dissertation will follow directions and regulations set by the most credible authorities in the field today (Bowens, 2009; Maarleveld and Guerin, 2013; Manders and Gregory, 2015). The author will use these books to assess the cultural significance of the site and to eventually propose a management plan for adequate preservation of a modern shipwreck site such as *HMS Maori*. The focus will be to utilise UNESCO's manual as a guideline for assessing the cultural but also the research value of the site since it presents one of the most relevant documents that contain instructions and information concerning the protection of underwater cultural heritage (2013).

Methodology

The proposed methodology used for this dissertation will discuss the method of acquiring, processing and analysing 3D data. All this will be done through the use of photogrammetry (also called Computer Vision Photogrammetry, or Multi-Image Photogrammetry). The aim is to use this method to survey and subsequently create a 3D reconstruction of the underwater shipwreck site. The final analysis of the results will present how attainable and reliable the monitoring scheme is, based on 3D models created through legacy data. The author will use the methodology previously designed by Dr Yamafune and presented in his PhD dissertation (Yamafune, 2016). Dr Yamafune's PhD is considered to be one of the most comprehensive research studies dealing with the use of photogrammetry for recording underwater shipwreck sites. Many sections covered in this dissertation will use the work of Dr Yamafune as the primary reference, such as the segments where he is explaining how to construct a proper dive path while recording the site, the workflow (in *PhotoScan/Metashape* software) used for creating 3D models, as well as, scale-constraining and geo-referencing the 3D models. Furthermore, the inspiration to test legacy data and its capability for monitoring of the shipwreck site *HMS Maori* derived from the work of Dr Yamafune's PhD.

The MA thesis submitted by Thomas Van Damme (2015) will also be explored and analysed to test the credibility of information extracted from legacy data. Van Damme presented extensive research on the topic of recording underwater archaeological sites with the use of photogrammetry. Although he covers a wide area of the study, the most relevant part concerning this thesis will be his case studies. Van Damme shows three different case studies, and all three of them are applicable for the research of the *HMS Maori* shipwreck site. These are video-frame photogrammetric survey, legacy data survey, and low visibility photogrammetric survey. It happens to be that the legacy data, the essential part of this dissertation is video footage (which requires the use of VFP), that was filmed in a low visibility environment. Also, the author will try to test and compare the workflow process which Van Damme presented in his case studies, where he demonstrated and advised to process the data in lower settings because it is how he managed to create more reliable 3D model. That is something that will be tested in this research by the author since the legacy data video footage (made by amateurs) used for the analysis of the *HMS Maori* is different in comparison with the one used by Van Damme (systematically taken). Another good source on video frame photogrammetry can be found in the case study written by Torres (2019). He was trying to demonstrate the credibility and efficiency of the final results when using VFP. Torres developed a highly reliable method of processing video footage in such a way. Aforementioned sources are important because legacy data (video footage) in this dissertation will partly follow different methodologies developed by practitioners in recent years. At the same time, the author will test how applicable these methods can be for the research of the *HMS Maori* shipwreck site.

Photogrammetry is going through a rapid evolution in recent years. Nevertheless, aside from a few research studies, photogrammetry has not been used for processing and analysing legacy data in high quantity (Van Damme, 2015; Green, 2019). Van Damme has experimented with legacy data both in video/ image formats as mentioned before, but these examples used old photo/video documentation from archaeological excavations in Scandinavia. Van Damme had for a goal to test the credibility of the software (*PhotoScan/Metashape*) and its capacity when processing data from older excavation campaigns. Monitoring of the site was not one of the topics in his thesis, but he did prove that legacy data is reliable, and that the information could be extracted from such datasets (2015).

A similar use of LD can be found in Green's investigation of the old legacy data records (images) from two different excavations in Cyprus and Kenya from the 1960s and 1970s (2019). Green also attempted to demonstrate how LD can be beneficial to the study of site formation processes, and how photomosaics generated after creating a 3D model can be used to extract specific information that is valuable for archaeologists and the interpretation of the shipwreck site. In both examples, the data was systematically recorded during one of the previous excavation campaigns. LD used for this dissertation will be based solely on older amateur video footage of the site, which should take the idea of creating a monitoring scheme one step further. Besides aforementioned research studies, many papers written on the topic of photogrammetry and its application in recording UCH sites will be explored (Drap, 2012; McCarthy and Benjamin, 2014; Yamafune et al., 2016; Balleti et al., 2016; Costa, 2019;). Research papers and articles in the past few years used similar methodology, while their aims, objectives and the conditions in which they were testing photogrammetry was not the same. Drap, Costa, or McCarthy and Benjamin explored how to survey and record various shipwreck sites, and they all had similar ambition, which was to demonstrate the potential of photogrammetry in documenting underwater archaeological sites. These are all valuable sources, illustrating the evolution in the subject area, but also, they are useful for forming a substantial background understanding of the methodology. Previously mentioned case studies and experiences will be explored and used accordingly for explaining the different processes presented in this dissertation.

Analysis/ Comparative Study

As one of the critical segments of the dissertation, where the monitoring hypothesis will be put to the test, it is necessary to mention that no research has been done so far on the subject of monitoring UCH sites through the use of photogrammetry and legacy data. Deviation (deformation) analysis software called *Cloud Compare* will be used to compare 3D models, and by doing so, the author will be able to evaluate the change that happened at the site over time. That being said, research papers have been written on the topic of deviation analysis on land, which will be used for constructing an equally credible analysis for underwater archaeological sites (Neuner et al., 2016; Holst et al., 2017; Schroeder and Klonowski, 2019). These authors have been using terrestrial laser scanning (TLS) technology alongside photogrammetry (image-based technique) to test the level of change (deviation) on various structures such as tunnels, bridges, dams and others. Mainly German and Austrian geoscientists are prone to use deviation analysis as a mean to monitor specific structures more actively. Various case studies can be seen on the topic of point cloud comparison (deviation analysis) for revealing deformation of natural and artificial objects (Holst et al., 2017; Schroeder and Klonowski, 2019). Holst probably gives the best explanation on how to conduct the analysis and subsequently, he clarifies how to interpret final results properly (2017). This will be one of the most constructive pieces of advice given by him since when it comes to interpretation, underwater or on land, the methodology stays the same. In the case study done by Schroeder and Klonowski, the capacity which deviation analysis has in monitoring the slightest ground and surface displacement is shown (2019). Overall, it left a good impression that similar inspections and calculations could be applied underwater.

That being said, research studies dealing with different methods of monitoring do exist. It can be standard photogrammetric monitoring through visual inspection of submerged cultural resources in California (Maus et al., 2017), or trying to study marine benthic communities in

Antarctic (Piazza et al., 2018). These examples represent recent trends in marine sciences for creating a monitoring scheme that could provide a better understanding of natural processes, commonly found at endangered underwater sites. The methodology and the subject of research might not be the same, but the need to develop a more quantifiable monitoring concept is evident. During one of the excavation campaigns in Croatia, on the shipwreck site Gnalic, Dr Yamafune tested how reliable deviation analysis can be when it is used for tracking the excavation progress (Yamafune, 2016; Rossi et al., 2019). The research done by Dr Yamafune is the only record where deviation analysis is applied for investigating the underwater archaeological site. This research study provided a better understanding of the stratigraphic layers presented at the site. As something hard to record underwater (stratigraphy), this analysis gave an insight into how different processes (such as excavation) can affect the site formation. The author will follow a similar method, in an attempt to record and track the site formation processes as in the previous example. The only difference is that instead of using systematically collected data as presented in the Gnalic excavation, legacy data (amateur video footage) will serve as the primary source.

To conclude, in this literature review, a wide range of publications from different scientific disciplines has been presented. As previously discussed, one of the first objectives will be to collect all available information on the *HMS Maori,* for creating a chronological account of events, which will present all essential details about this Tribal-class destroyer. The author's contribution will be to demonstrate a historically significant role which *Maori* had during the Second World War. Furthermore, due to the lack of contemporary records about the wreck-site, the author will conduct a site assessment of the HMS Maori shipwreck site. This will define its significance as a dive site, as well as its importance as an artificial reef.

Two premises will be questioned and analysed. The first one will be to demonstrate how credible legacy data can be as an indispensable source of new information. Various case studies already proved that when using older archaeological records (images, videos), some knowledge can be acquired about the site characteristics. The author will try to question how quantifiable legacy data can be to serve as a reference for conducting deviation analysis. That is also the second premise, where a well-known method of analysis commonly used on land, will be tested in an underwater surrounding. What makes the use of this methodology specific is the capacity which legacy data has, standardized application of photogrammetry and the potential credibility of results created through deviation analysis. By trying to combine the three, an opportunity to create a monitoring scheme is granted.

CHAPTER II:

Historical Background

Tribal-class destroyers played an important role in almost every operation they participated in during the Second World War (Mason, 2001; Heckman, 2017, p.30). For that reason, an explanation will be given for the demand of such warships, their impact on naval warfare and the influence they had on the course of events that followed. Recognizing the significance and scientific potential of the *HMS Maori* is something that will be feasible through understanding the context in which these vessels were created. With this, in later sections of the dissertation, the evaluation of the importance of having a potential preservation plan will be possible. Nevertheless, the focus of this chapter is on the *HMS Maori*, specifically, its origin, structure, service during the Second World War and the final resting place.

2.1 Tribal-Class Destroyers

As war broke out in September 1939 the British still possessed the largest and most formidable Navy of the combatants, with nine aircraft carriers and six under construction, fifteen capital ships with five others being built, sixty-four cruisers with nineteen being built, 216 destroyers and escort vessels with many more planned, and thirty-eight submarines with eleven under construction (Robertson and Dent, 2007, p.14). It clearly shows the level of attention given to the naval forces and the role they played in the outcome of the war. However, this vast naval infrastructure did not come at a low price. The Royal Navy was under terrible financial strain as it tried to contend with rapidly-changing technology and with an evolving strategic context. Often its approach was extremely creative, for example, blending nominally different types of ships, so that an affordable force would cover the full range of roles (Friedman, 2006, p.9).

The Tribal-class destroyers, when compared with the older destroyer types, had upgraded armament capacity compared to larger ships. The reason behind such a decision was the desire to increase the overall gun power of Destroyer Flotillas, as well as to keep up with naval trends in shipbuilding worldwide. (Lenton, 1998, p.164). The role of the Tribals, which was usually integral to the fleet, changed radically during the interwar period. One of the major changes after the First World War was that the fleet was expected to cover a significant distance, even before engaging an enemy fleet. Thus, destroyers would have both the central role in battle and a screening role en route to battle (**Fig.1**). Built to withstand submarine, air and mine threats (Friedman, 2006, p.9). Being equipped with depth charges as part of their arsenal made them an appropriate answer to the enemy submarine attacks and as convoy protection.

Figure 1. *HMCS Haida* (RCN), the last Tribal-class Destroyer that survived WW2 is located and displayed in Canada as a museum ship. (Source: https://theheartofontario.com/operator/hmcs-haida/)

The ship had to be small enough to avoid becoming too obvious a target, but large enough to be a good gun platform with sufficient firepower and to have good sea-keeping. The guns became far more important than before because the key role was to protect the battleships from the enemy torpedo force (Friedman, 2006, pp.29-36).

Their construction was performed in more than one shipyard, such as the William Denny and Brothers, or the yards of John Thornycroft and Company. Although the initial order was for seven and a leader type destroyer, that number doubled, and sixteen of them were built. The British ships were laid down in 1936-37 and completed in 1938-39. Within a single year, all of them were launched, and all were in commission by early 1939 (Chesneau, 1980, p.40). After the war had started, destroyers were dispersed in two flotillas: one in the Mediterranean Fleet (4th) and the other with the Home Fleet (6th)[1]. Nevertheless, this would change soon, and they would be used more on a piecework basis as casualties mounted. Out of all

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[1] 4th Flotilla was attached to the Mediterranean Fleet, while 6th served with the Home Fleet (Kostam, 2017, p.42)

destroyers they were considered as the elite class, and this is backed up by the number of times these ships played an important part in various actions and missions (Heckman, 2017, p.30). The Tribals had a great fighting record in the war and, since their heavy armament often led to their use in hazardous actions, their losses were heavy with three-quarters of the sixteen British ships being sunk (Brown, 2000, p.246). Inspired by the concept of the Tribal-class destroyers, two of the largest Commonwealth navies, Australian and Canadian chose to build similar versions of this class for themselves (Friedman, 2006, p.34).

2.1.1 Design and Armament

The Tribal-class shape is typical for many destroyer classes worldwide, with moderately high stacks and forecastle, which then breaks down to the main deck at the bridge (**Fig.2**). A strongly raked stem was introduced, adding 10ft to the forecastle deck (Chesneau, 1980, p.40). The armament was always the main focus, because the purpose of the ship was, at the end of the day, to prove efficient in battle. That being said, much of the discussion was made on the topic of armament layout. At one time it was envisaged to install no less than ten 4.7-inch guns in five twin mountings. After considerations of maximum speed and top-weight of the vessel, it was decided to fit four twin 4.7in guns placed in the conventional positions (two twins on forward part (A and B) and two in the after part (X and Y) controlled from a DCT)[2]: one quadruple 2-pdr pompom on the forward end of the long after superstructure; 'sided' multiple 0.5 inch Vickers machine-guns between the funnels; and one quadruple torpedo tube mounting abaft the second funnel (Hodges, 1971, p.6).

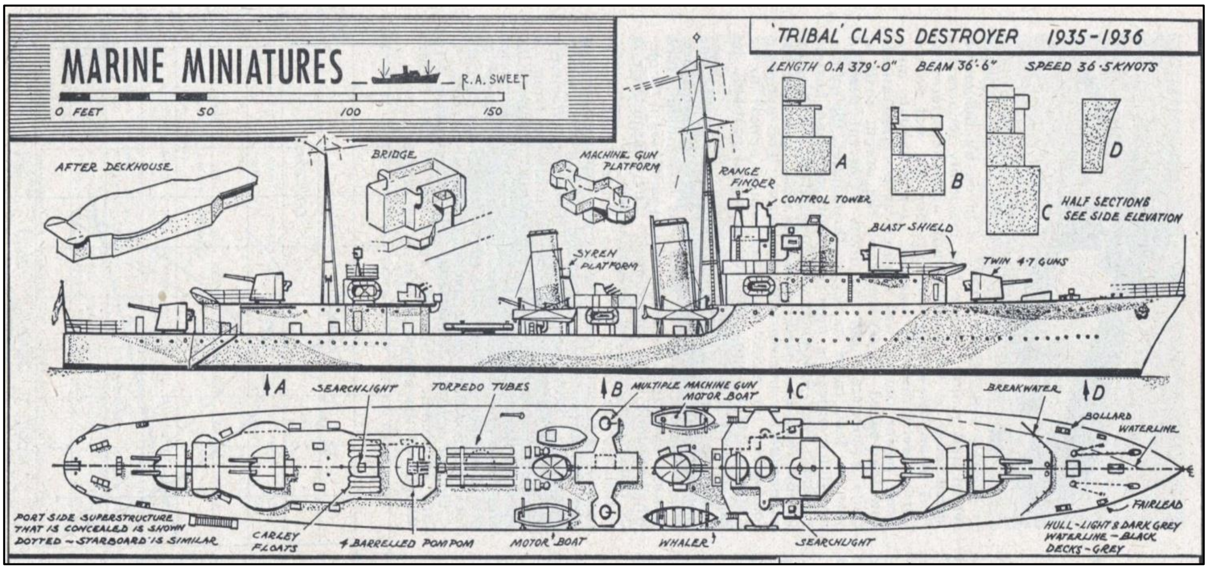

Figure 2. Ship plans for Tribal-class Destroyer. (Source: https://bit.ly/2uUMTtt)

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[2] DCT: Director Control Tower - used when engaging targets which are difficult to select (Type 285 radar)

The ship also had good communication facilities, could develop the speed of 35 knots, and had a torpedo outfit for the night and low visibility. The idea to use the 4.7-inch armament for long-range AA fire existed[3], and to this end, a 40º elevation was considered desirable. Later on, this elevation of 40º was shown to be inadequate in wartime, especially against dive-bomber attacks (Whitley, 2000, p.115). The propulsion unit consisted of the standard three Admiralty 3-drum boilers, with a working pressure of 300psi. The machinery arrangement stayed the same as it was in the previous classes, i.e. boiler rooms ahead of the engine room. It remained unchanged because every modification that was made had to agree with the Treaty definition[4]. Also, while building these ships the radar system was not incorporated, something that changed during the war (Hodges, 1971, p.7; Whitley, 2000, p.116).

2.2 *HMS Maori*

The name of the ship was inspired by indigenous people of New Zealand called Maori. Not just the *HMS Maori*, but also the rest of the two destroyer flotillas, were named after well-known tribes and their people (i.e. *Zulu, Eskimo, Tartar* etc.). Construction of the *Maori* started on June 6, 1936, in Govan, Scotland. The appointed manufacturer was Fairfield Shipbuilding and Engineering Company. After the launching on September 2, 1937, the ship was commissioned on January 2, 1939 (Chesneau, 1980, p 40). From 16 Tribal-class destroyers, *HMS Maori* and *HMS Gurkha* were built by the same shipbuilding company. Every vessel had its coat of arms and a motto. *Maori's* motto was "Aki Aki, Kia Kaha", which meant "Push on, be brave". On the badge, they had a representation of the "Tiki" god (Hodges, 1971, p.70).

All Tribal-class destroyers had similar construction procedures, and the only differences were modifications which occurred as the war progressed. Since the Admiralty had to use them more frequently in the hottest zones where the war was being fought, they successfully recognized the faults these ships possessed (Heckman, 2017, p.30). That was how they were able to modify and upgrade ships that had not been lost. *HMS Maori* had few of these modifications before she was sunk (**Table 1**).

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[3] AA fire: Anti-aircraft fire

[4] The London Treaty in 1930: had international regulations regarding vessels size, tonnage, armament etc. In 1936 the Second London Treaty had lowered the restriction rules by some degree, while every agreement that existed was annulled on September 1939 and the beginning of Second World War.

HMS Maori	Built Specifications	Modifications
Displacement	1,854 tons,(standard); 2,519 tons (deep load)	
Dimensions	Length overall: 377ft (114,9m); Beam: 36ft (11.12m); Draught: 9ft (2.75m)	The mainmast was cut down to a short pole and the height of the after funnel reduced (improving guns-arc)
Propulsion	Three Admiralty boilers, two Parsons geared turbines, driving two shafts and generating 44,000shp; maximum speed 36 knots	
Capacity	524 tons	
Range	5,700nm at 15 knots	
Armament	Four twins 4.7in QF guns Mark XII, one quadruple 2-pdr pom-pom AA guns, two quadruple 0.5in machine guns, four 21in torpedoes in one quadruple, 20 depth charges	Twin 4in AA mounting replaced the Twin 4.7in mounting in 'X' position. Four extra single 20mm Oerlikons were mounted on the bridge wings and aft shelter deck.
Complement	190 men	

Table 1. *HMS Maori* had modifications done in 1940/41. (Source: Kostam, 2017, p.43; English, 2001, p.12; Whitley, 2000, p.116)

2.2.1 War service

Maori was in the 1st (Tribal) Destroyer Flotilla, just like the rest of the ships from the first group. After doing some test runs and trials in Home Waters, she got her pennant number F24. In January 1939 the permission was given to join the 4th Destroyer Flotilla[5] in the Mediterranean Fleet located in Malta. The Royal Navy had a significant presence in the Mediterranean, with Malta in the centre of the British naval activities there. While in the Mediterranean Sea, *HMS Maori* had an escort role, and she also participated in various exercises (Mason, 2001).

Soon after the war had begun, in October 1939 an order had been received for *Maori* to return. She was transferred with the 4th Flotilla to serve in Home Waters. Upon arrival, she was deployed to the North Sea, and part of her patrol duties was to control and to intercept enemy German vessels in their attempts to transition to the Atlantic (Mason, 2001). A few months later, she had to go back to Govan, in Scotland for some repair work (Turbine blade defects). As soon as she was operational and repaired *HMS Maori* joined The Royal Navy forces in the Norwegian campaign.

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[5] Captain: P.L. Vian, RN

The Norwegian Campaign (April 1940)

Allied forces attempted to liberate Norway from Nazi Germany at the very beginning of the Second World War. This action followed right after the Germans had successfully occupied Norway (Haarr, 2010; Grove, 2011). Allied operations began on April 9, 1940, and lasted until June 10, 1940. The campaign was unsuccessful, and eventually, King Haakon VII left his country in the company of his family to seek refuge in Great Britain (Haarr, 2010, p.12). The strategic importance of Norway and the fact that a significant amount of iron ore had been regularly exported from Sweden through numerous ports (i.e. Narvik) was of key importance for both sides of the war (Shirer, 1990, p.673).

On April 10, *HMS Maori* was deployed with the Home Fleet to assist in military operations in the North Sea, and the Commander of the ship was GN Brewer, R.N. (Mason, 2001; Haarr, 2009, p.783). Although her principal role was being an escort or support for various missions and troops, this did not mean that *Maori* did not actively participate in the campaign. On April 19, she took part as an escort of four French Troopships while moving toward the port of Namsos (Mason, 2001). After the destruction of the city of Namsos in the German air attacks on April 20/21, all of the equipment, ammunition and docking area was non-existent, a supply of vehicles and various stores became a necessity.

On April 23, *HMS Maori* escorted *SS Blackheath* into Namsos (Mason, 2001). *SS Blackheath* was a 5000-ton freighter that was able to pass the wooden jetty in the port and unload its military cargo. Since the process of unloading the freighter was too slow and danger was always lurking, they had to return three days in a row to complete the task. Also, throughout the whole process of unloading, the crew of *Maori* played a considerable role since they cleared the dumps themselves and also cleared Namsos harbour on April 25. After completing all of their tasks, they charted a new course to Scapa Flow (Haarr, 2010, p.239).

On May 1/ 2, 1940, *Maori* participated in the evacuation of all remaining troops located in Namsos. Vice Admiral Cunningham led this mission with the cruisers, French transports and the destroyers. At some point, *Maori* missed the signal to turn seaward, and at 10 PM she was located close to the entrance of the harbour. At that moment, she was joined by three more destroyers in an attempt to embark as many troops as possible (Haarr, 2010, p.330). Four destroyers were covered by fog until early in the morning when a decision was made to reverse the course and wait for the next evening for extraction. All four destroyers were hidden well under the veil of fog, until one moment when *Maori* found herself at the edge of the fog bank and unknowingly her masthead protruded above the haze. This mistake could have easily been fatal for *Maori*, but luckily the air attack did not manage to land their bombs on target but barely missed it in two cases. These misses still caused extensive damage to the upper deck fittings. Twenty of the ship's company were wounded, while five of them later succumbed to their wounds (Mason, 2001). She was promptly evacuated and sent for repairs. Besides this incident, the rest of the operation was successful, and all of the troops were rescued on time (**Fig.3**).


Figure 3. British ships after suffering air attack-off the coast of Norway in 1940. (Source: https://bit.ly/2HBI62J)

After repairs had finished, *Maori* continued her service for the Home Fleet (Screening and patrolling) and also had her pennant number changed to G24. On June 20, *Maori* and two other tribal destroyers (*HMS Mashona* and *HMS Tartar*) had a mission to capture two destroyers and two torpedo boats, located in the Faroe Islands during their transit from Italy to Sweden (built for Swedish RN). These ships were taken to Scapa Flow, and after some complaints from the Swedish Government, they were returned (Mason, 2001).

On October 16, 1940, *Maori* alongside two destroyers (*HMS Ashanti* and *HMS Fame*), was set out off Tyne estuary to a high-speed operation in which their task was to detonate the mines before battleship *King George V* finishes its voyage from Newcastle to Rosyth. In this mission, she sustained minor damages of her underwater submarine detection dome. The other two destroyers ran aground and suffered more extensive damage (Mason, 2001). *Maori* had continued her standard deployment as part of the Home Fleet Flotilla. Possibly the most prominent event, in which *Maori* participated in the Second World War, was the hunting and destroying of the German battleship *KMS Bismarck*.

Hunting Bismarck (May 1941)

KMS Bismarck was a German battleship, which the Germans claimed was unsinkable. It was also considered a worthy adversary to the best ships the Royal Navy had to offer. That is why she posed such a big threat to British naval forces in the years when she was active (1940/41). The main objective for the Germans was to sink enemy merchant ships, and by doing so contribute to bringing Britain to her knees through the strangling of her mercantile lifelines (Kostam, 2011, p.66). The battle of the Denmark Strait started when Germans tried to break out into the North Atlantic on May 23, 1941. The German Navy had *KMS Bismarck* with her sister ship *Prinz Eugen*, while the Royal Navy deployed *HMS Suffolk* and *HMS Norfolk, Prince of Wales* and *HMS Hood*. The battle was intense, and both sides suffered significant damage and losses. However, the biggest loss for RN was losing the leading Battlecruiser *HMS Hood* (Mullenheim-Rechberg, 1980, pp.58-64). The day after, *Bismarck* alongside *Prinz Eugen* had reached the North Atlantic in search of a French port for repair work. The British Fleet was trying to locate the *Bismarck*, and after some time they successfully managed to do so.

It was at this moment that the *HMS Maori* joined the RN forces after leaving her escort mission of the Convoy WS-8B (which was heading for the Indian Ocean)[6]. Accompanied by destroyers *HMS Cossack*, *Sikh*, *Zulu* and *ORP Piorun*, *Maori* was heading towards the last known location of the *Bismarck* on May 26. After their arrival, their order was to join the battleship *King George V* (Mason, 2001).

Since they needed the destroyer fleet to escort *King George V* and *Rodney*, destroyers from 4th Flotilla were the closest ones to them. *HMS Maori* and *ORP Piorun* (a Polish destroyer) were supposed to meet *HMS Rodney*, but as it turned out, they were the closest ones to the German battleship. They were steaming at full speed toward the enemy's position, and at 10:30 PM, they intercepted the German ship (Skwiot and Prusinowska, 2006, p.161). Torpedo attacks began immediately, and they continued until the next morning. Even though no hits were scored, the Bismarck crew was alerted and awake throughout the night until the rest of the fleet was able to join them (Kostam, 2011, p.165). When they eventually met the offensive had started. British aircraft attacked from above and torpedo attacks were doing irreversible damage to the ship's hull. During that time, *Maori* informed the admiral of the fleet (Adm. Tovey) about the change in position of the German battleship. Not long after, the

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[6] Commander of HMS Maori was H.T. Armstrong, RN

steering system of *KMS Bismarck* malfunctioned due to substantial damage imposed by the British forces, which subsequently left *Bismarck* more exposed and vulnerable (**Fig.4**). After pounding the ship for a whole day, the *KMS Bismarck* was sunk on May 27, 1941, and the rescue operation started (Skwiot and Prusinowska, 2006, p.178). *Maori* participated in this operation, and successfully picked up twenty-five survivors (Mullenheim-Rechberg, 1980, p.137; Mason, 2001).

Figure 4. The Sinking of the KMS *Bismarck* depicted by Charles E. Turner. Showing the final salvo of torpedoes that eventually sunk the Bismarck. (Source: Kostam, 2011, p.184)

From June to July 1941, *Maori* had numerous escort missions in NW Approaches (North Sea), was part of military convoys and spent more time in the Mediterranean Sea as part of the Maltese convoy system. She was under refit until December 1941, and then joined the Mediterranean Fleet as a part of the 14th Destroyer Flotilla (Mason, 2001).

On December 13, 1941, after receiving information that Italian cruisers were heading towards the North African coast, *Maori* alongside *HMS Sikh*, *HMS Legion* and *HMNS Isaac Sweers* (Dutch ship) conducted the interception of *Alberto Da Barbiano* and *Alberto Di Guissano*, not far from Cape Bon (Clarke, 2016, p.2). On December 14, these two sides engaged in battle. In a short amount of time, after an efficient torpedo attack, both Italian cruisers were destroyed. The Italian destroyer *Cigno*, which served as their escort, fled from the scene (Mason, 2001). On this occasion, the rate of fire and mobility of the Tribal-class destroyers proved their ability to deliver the force and strength expected from them. The Commander of *HMS Maori* at the time was Cdr. Rafe Edward Courage DSO, DSC, RN, and it was noted down that, as soon as Maori opened fire at the enemy ship, many hits could be observed on its bridge. At one point she fired two torpedoes, one of which was a confirmed hit. Soon after this, the leading cruiser was undoubtedly sunk (TNA, 1942; Clarke, 2017). The second cruiser quickly went down as well.

In general, Tribal-class destroyers were used collectively in decreasing numbers as their sister ships were lost. Eventually, the Tribals were found among other destroyer types, something that was heavily discussed at their inception. As the war in Europe progressed, there were never enough fleet destroyers to meet demand, and they had to operate in groups of between three and five ships (Hodges, 1971, p.11). On December 17, *Maori* sustained an air attack and briefly engaged enemy ships in the 1st Battle of Sirte[7]. She continued her service as part of the 14th Flotilla in the Mediterranean fleet and was conducting regular Malta Convoy activities until February 12, when she sank at her moorings in Grand Harbour, Malta (Mason, 2001) (**Fig.5**).

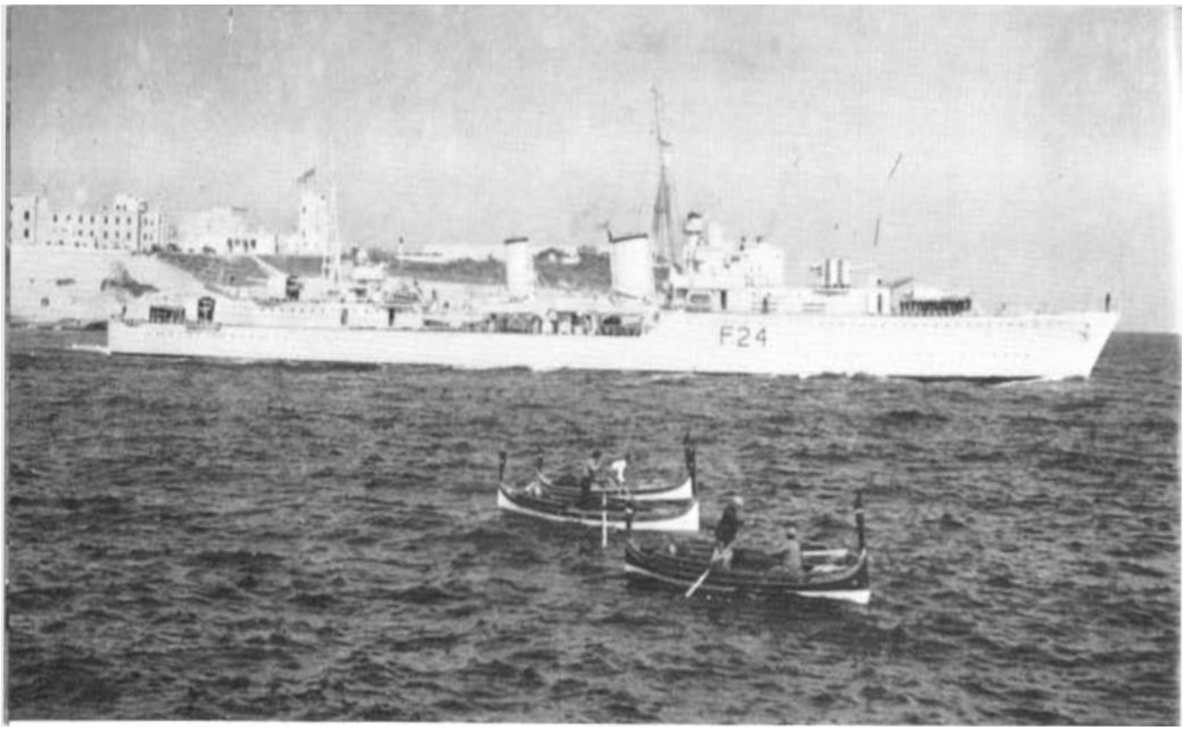

Figure 5. A typical view of Malta (background), with local 'dghaisas' in the foreground and *Maori* located in between. (Source: Hodges, 1971, p.30)

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[7] Italian Royal Navy fought against the British Royal Navy as part of the Mediterranean campaign.

2.2.2 Sinking

On the night of February 12, 1942, the destroyer was moored at one of the buoys in the centre of the Valletta port (Dockyard Creek) when, around 02.00 AM, a German air raid had begun (Whitley, 2000, p.117). Most likely, it was a solitary Junker Ju 88 that managed to land its bomb in the centre aft area of the vessel. The explosion caused the burning of some fuel deposits, which in turn, besides destroying the stern engine, triggered the explosion of the reserves for the anti-aircraft ammunition of the stern guns (Mason, 2001). The fire was out of control, and about to reach the aft ammunition depot, the crew had to be sent away from the vessel. At 02.10 AM the explosion completely ripped open the ship, and she immediately started to sink to the bottom, with only the forepart still visible above the surface and slightly leaning towards the starboard side (**Fig.6**). The burnt gasoline spread all around, threatening other vessels that were nearby until the fire was extinguished (Caruana, 1995, p.8). Later that day, the water slowly penetrated the bow section until it also went down. The only visible part of *Maori* that was not submerged was the top of the mast alongside its fore hull, which in this case marked the tomb of the ship and one of its crew members.

A decision was made to scuttle the wreck because she was interfering with the traffic inside the harbour. The recovery work started at the beginning of 1945 by the South African rescue ship *Gamtoos* who cut the hull of the destroyer in two sections (Caruana, 1995, p.8). The forward one (bow) was raised on July 15, 1945, with the help of push cylinders and then towed to the entrance of Marsamxett Harbour, where it was sunk in shallow waters and where it still stands today. The aft (stern) section was scuttled in the following September and was towed out of the harbour offshore and sunk in deep waters (Mason, 2001; Heckman, 2017, p.32).

Figure 6. *HMS Maori* after she was bombarded in Grand Harbour, Malta; Mast pole alongside one section of the fore hull can be seen protruding from the water. (Source: https://bit.ly/2x5J7y2)

CHAPTER III:

HMS Maori Today

What remains of the bow section of the wreck of the destroyer *Maori* lies at a depth of 12m on the silty bottom of the Marsamxett Harbour, in front of the San Gregorio bastion of Fort St. Elmo. As previously mentioned, *Maori* originally sank in the Dockyard Creek, the central area of the Grand Harbour in Valletta. The aft part of her hull was scuttled offshore, while her bow was towed to the south side of the Marsamxett harbour's entrance (**Fig.7**). Despite being fragmented, the ability to easily approach the wreck makes her a popular destination for scuba divers that are fond of wreck-diving. The opportunity to dive on a historically rich site, adds up to the excitement of a dive. In this chapter, the author will try to explain the current state of the site, its role in modern society, and the potential of scientific methods used for this research.

3.1 Dive Site

Not much is left of the *Maori*. Only the forward section of the ship is present, with a large part of it buried in the sediment. Until recently, divers had an option to swim through the battery bridge for about twenty meters along its entire length. It is no longer a possibility since the whole section collapsed during a big north-easterly storm in 2019. The whole wreck is covered with a dense layer of concretions, and plating sheets appear to be heavily corroded by rust (Malta Dives, 2017).

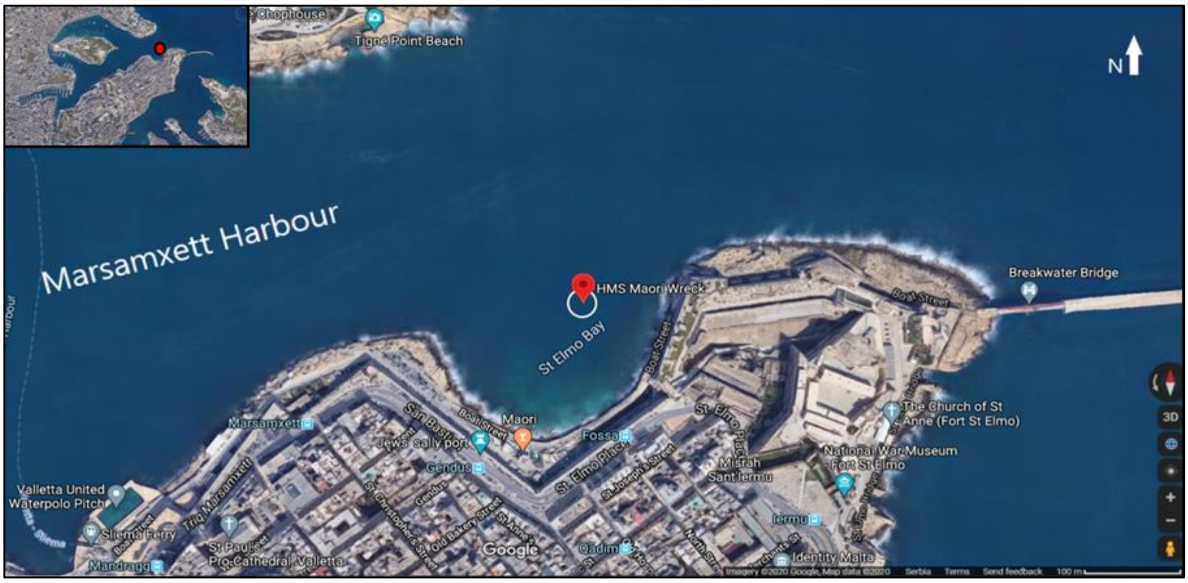

Figure 7. Location of the wreck inside St. Elmo Bay/ Marsamxett harbour, Valletta (Source: Google Earth)

Her forward superstructure still exists and includes the forecastle deck and the portion of the upper structure. In this upper structure, one large round hatch can be seen and two mounting gun bases where two twins 4.7in guns once stood. Both ‘A’ and ‘B’ guns were still working correctly, so an effort was made to recover and mount them on the Ricasoli Breakwater in 1942, so the army could use them (Quintano, 1999). Her total length is around 42 meters, and she is slightly tilted onto her port side with an overall upright position (**Fig.8**). The upper structure is 9m deep while the starboard side, as the lowest point, lies at 15 meters.

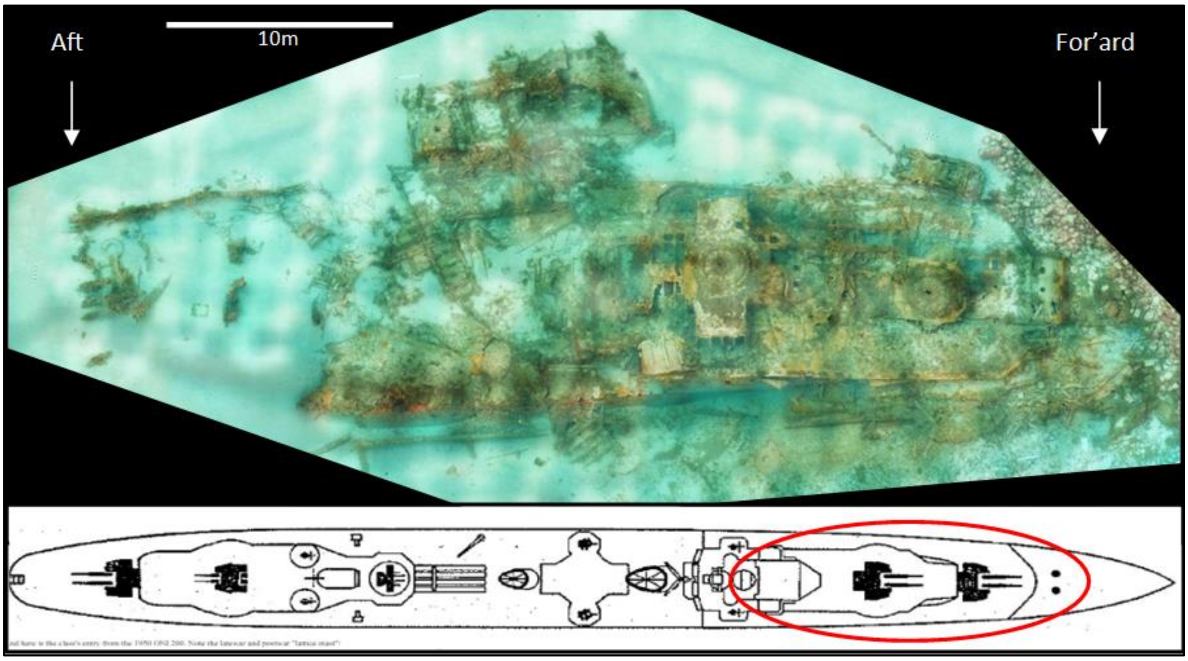

Figure 8. Site plan (Orthophoto) created after the Photogrammetric survey in June 2019 (42m length). (Source: K.Yamafune); Two mounting bases for a gun can be seen in the forward section. Marked circle on the blueprint represents the bow section which survived (total ship length 114.9m).Overall condition: Poor.

3.1.1 Environmental Conditions

Maori has deteriorated a lot throughout years due to her position underwater in a so-called ‘high energy zone’. A combination of natural elements, including massive wave caused by winter gales and the prevailing north-westerly winds, create conditions that contribute to destructive site formation processes. The shallow water does not help the situation, because she is also positioned right underneath the rocky slope of the reef where currents are strong. Also, the entrance to the harbour is nearby, where open sea, waves and storms are continually pushing the water to be more active than in other areas of the port[8]. These

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[8] On February 2019, a huge storm followed by strong winds brought chaos to the island, where the entire seafront was heavily affected by this (Times of Malta, 2019). It is certain to say, that after or during this storm the upper structure of *Maori* collapsed.

physical-mechanical factors[9] are already, by themselves, creating a harsh and highly unstable environment for *Maori*. On top of that, the wreck site is under constant threat from human interference, water pollution and ship movements.

Like many wrecks from the Second World War, *HMS Maori* has become an artificial reef where marine life has been thriving for decades (**Fig.9**). Here, one may observe a variety of marine life that resides inside or on the outer part of the wreckage. Depending on the time of year, the metal structure can be covered with green weed, tube worms, shoals of fishes, octopus and with cardinalfish swimming close to the upper structure. A considerable number of hermit crabs and fireworms can be found on *Maori* herself. Also, species such as scorpionfish, moray eels, cuttlefish, or even sea horses can be seen nearby. The information presented on marine life was created by combining the personal experience of the author and discussions with dive club personnel, as well as, general information shared on different dive school websites (Dive Med, 2020; Dive Booker, 2020; Divers Guide, 2020).

Figure 9. Diver passing along the starboard side (**1**), mounting base for twin 4.7in gun (turret) (**2**), forepart (forecastle deck) leaning on the rocky slope - breakwater and anchor windlass can be seen (**3**), a section of the upper structure before 2019 with shoals of fishes (**4**) (Source: Google)

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[9] Physical-mechanical factors: “Erosion and abrasion by currents, tidal movements or change in water circulation” (Maarleveld and Guerin, 2013, p.111)

3.2 Significance Assessment

Although sometimes it can look subjective, significance assessment should be based on an objective point of view. For that reason, every decision made needs to be grounded on facts (Manders et al., 2012, p.9). The idea of the last two chapters was precisely that, to cover the historical perspective and to present the current state of the *HMS Maori*. Future management plans will be better defined if the importance of the past and the present has been fully comprehended. Besides desk-based assessment, which was covered in the previous section of the dissertation, attention will be focused towards exploring cultural, economic, and primarily research/archaeological values of the site (Maarleveld and Guerin, 2013, p.84). To this date, no academic effort has been made to investigate the story of *Maori* after the ship had sunk in 1942, and this left much room for data to be collected and for different research methods to be implemented for the first time. This means that her historical background and war service was well documented in various books and articles, but nothing beyond that.

3.2.1 Research Value

The key element that drives every research investigation (such as this one) is the possibility of gaining access to the new source material, which in return will provide a new flow of information for scientists to process and analyse (Manders and Gregory, 2015, p.31). With this in mind, being able to document the site and its condition, for the first time in its history will present evidence in formats never seen before. These newly acquired results can be used not just for scientific purposes but also in promotional services of underwater cultural heritage, as well as, for educational purposes (Maarleveld and Guerin, 2013, p.85). Analysing the condition of the *HMS Maori* shipwreck will provide valuable information, regarding the development of the appropriate management strategies for the future (Manders, 2011, p.13)

3.2.2 Social and Economic Value

Objects from the site might not have any tangible economic value, but the value that *Maori* has can be expressed in a different form, such as the impact it has on tourism in Malta (Manders et al., 2012, p.10). Diving, as a form of touristic attraction, is one of the most popular activities Maltese islands can provide (Visit Malta, 2020). Because of its relatively shallow depth (9-15m), the shipwreck site attracts a variety of divers, from amateurs to more experienced individuals. Maltese authorities appointed to protect cultural heritage sites have recognized the value and the importance of the endangered archaeological/ historical sites such as HMS Maori, and had created a way to legally protect and promote their existence in the most efficient way[10]. The social value of the *HMS Maori* is embodied in the attributes such as the research potential, historical significance and in the way how people perceive the historical importance of the site and relate with its story. That being said, the level of *Maori's* social significance is believed to be high.

To sublime everything aforementioned, knowing the role *HMS Maori* had in the Second World War, and how she continued to exist even after she was bombed and scuttled, with her purpose modified into what she is today (a popular diving historical site and an artificial reef), marks an incredible journey for one ship to traverse. Recognising *Maori's* significance as the only available Tribal-class destroyer to be open for the public to explore underwater, and to serve as a fertile ground for new research methods to be tested, makes her role in today's society even more valuable.

3.3 Photogrammetry Based Site Monitoring

The time spent in water (78 years) has left some irreversible consequences on the structure of the ship (i.e. metal construction collapsing and breaking, sand deposition and rock erosion on top of the wreck). Finding out the extent of the degradation processes that happened over the years will undoubtedly be one of the main tasks towards which this dissertation will gravitate. An effort will be made to track and assess site degradation processes through a meticulously planned monitoring scheme based on 3D photogrammetry. Potentially, this method, if proved relevant, can be used for creating appropriate preservation plans (in situ or ex situ) for endangered archaeological sites.

The monitoring scheme used for this dissertation, in its core, has the same idea as already widely accepted monitoring approaches used worldwide, to systematically observe and record data for the reason of examining the state of a site and the change that happens through time (Bowens, 2009, p.163; Manders and Gregory, 2015, p.4). Nevertheless, the execution and implementation differ between the two. While standard monitoring approach might be time-consuming (demanding longer periods for data to be collected) and subsequently may result in raising the budget needed for completing the task, the proposed monitoring method, if deemed successful, may turn out to be cost-effective and time-

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[10] Declaration of Underwater Cultural Heritage: Maltese government had created their enhanced regulations for the management of UCH. They can: "declare remains that have been found on the seabed that are situated in the territorial waters of Malta and are at least fifty years old as UCH" (Cultural Heritage Act, 2019, p.35) Benefit of such act is that it automatically protects wreck sites from the Second World War.

efficient. More accurately, the idea is to use 'Legacy data'[11] (photo/video footage), as a source of information for tracking the changes of the wreck throughout years, and the 3D photogrammetry as a tool to collect, process and analyse the data (Eric et al., 2013). The capacity which legacy data has in comparative studies can be seen in various examples through visual inspection (**Fig.10**).

Although the example given in figure 10 shows the apparent magnitude of change that happened in 14 years, the need for the more quantifiable approach is required. One of the critical elements of the research will be to create a 3D model of a wreck through the use of underwater photogrammetry. Such a model can provide a precise representation of the current state of the site, and after testing the Legacy data (3D models made from video footage), both can be used for comparative purposes. Thus, an opinion can be developed as to whether such information can provide a better view of site degradation processes throughout the years, and how to use the newly gained knowledge to properly plan future management projects.

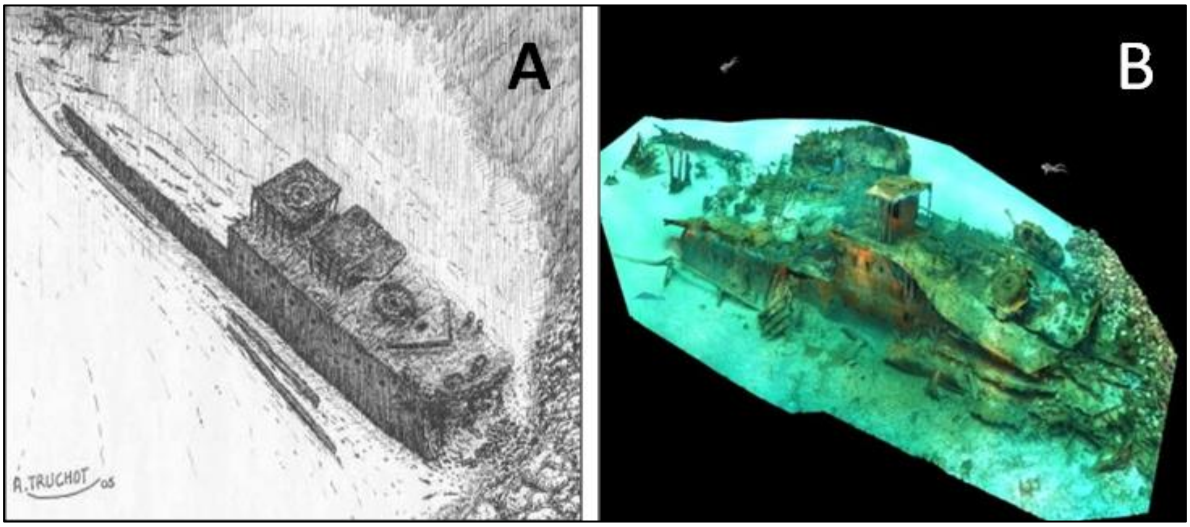

Figure 10. Site representation from a hand drawing in 2005 (Legacy data/image) (**A**), Reconstruction of the site in 2019 with the use of 3D Photogrammetry (**B**); (Source: (A) Google, (B) K. Yamafune)

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[11] This term refers to the data that has not been digitised or geo-referenced. Usually needs to be manipulated and prepared before its use in any digital format. (i.e. old maps, photos, videos, etc.) (Alison, 2008)

CHAPTER IV:

Methodology

In the previous chapter, the methodology was briefly touched upon, to explain the value of the site, as well as the overall idea of the proposed research. An in-depth discussion will be made about the application of underwater photogrammetry[12] in recording and documenting the site of *HMS Maori*. An emphasis will be put on collecting and processing data obtained through the use of Computer Vision Photogrammetry. Besides standard underwater photogrammetric survey used in this research, an attempt will be made to use online video footage (non-professional) from past years, in the form of legacy data, to create 3D representations of the shipwreck site. The author will try to follow the methodological workflow constructed by maritime archaeologists in previous years, in addition to some new approaches implemented by the author himself. The plan will be to use 3D data acquired through the survey and presented in this chapter, so that in Chapter V its plausibility in creating deviation analysis of the wreck, and potential monitoring strategy could be tested (Yamafune, 2016, p.151; Baleti et al., 2015; Rossi et al., 2019, p.56). This will be possible by using 3D models created through an underwater photogrammetric survey (diver-based) and processed in *Agisoft Photoscan/ Metashape* software. After scaling and geo-referencing the model, more than one type of results can be derived from it (exact measurements, orthophoto, DEM, etc.). For the dissertation, 3D models created out of legacy data will then be referenced through the main model, and by doing so, more information can be drawn from the site itself. Besides being able to extract some information previously mentioned out of the 3D models, the final goal will be to compare and analyze the data and to try to deduce whether such information can give us a better view on the degradation process of a modern shipwreck site, throughout the years.

4.1 About Underwater Photogrammetry

Archaeology is, in most cases a destructive activity (excavation, probing, sampling) (Tuttle, 2011, p.114). To conduct a non-intrusive survey of the site that can be cost-effective and time-efficient, while providing high-quality data at the same time, is something that every archaeologist aspires to achieve. Photogrammetry gives this chance to everyone in the field,

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[12] Photogrammetry: “the use of photography in surveying and mapping to ascertain measurements between objects” (Oxford Dictionary, 2020)

by providing a considerable number of options for one to explore (i.e. creating 1:1 scale representation, understanding site formation process, monitoring excavation, etc.). Although its application can be seen in various disciplines (i.e. game industry, aerial mapping etc.), photogrammetry has become one of the key tools that maritime archaeologists use for creating and interpreting 3D data (Van Damme, 2015; Yamafune et al., 2016; McCarthy et al., 2019). In 1960/70s George Bass was the first to experiment with underwater photogrammetry, while recording the Byzantine shipwreck Yassi Ada 2 (Bass, 1966, p.148; Drap, 2012, p.112). At the beginning of the 2000s, a rapid development happened in surveying methods and the use of Multi-Image photogrammetry[13]. With the help of the technology available today, underwater photogrammetry has become an accessible and cost-effective tool for monitoring submerged cultural resources through the acquisition and analysis of accurate and comprehensive data (Eric et al., 2013; Maus et al., 2017, p.57). In addition to that, collected 3D data stays preserved in a digital form for the future generations of researchers (Yamafune, 2016, p.7).

The main objectives of this chapter will be to:

- Explain the procedure of the underwater photogrammetric survey carried out at the site of *HMS Maori* (equipment, recording the site, conditions, etc.)
- Represent the overall potential of Legacy data and its availability online (Challenges)
- Demonstrate the workflow of processing data in diver-based approach (Multi-Image Photogrammetry) and Legacy data survey (Video Frame Photogrammetry), as well as, advantages and disadvantages in both cases.

4.2 Data Collection

4.2.1 Photogrammetric Survey

Besides desk-based research conducted at the early stage of the investigation, test dives were also carried out at the site. The author did this for the reason of identifying the overall condition of the wreck, and its position underwater. This also prepared the author for the recording sessions of the photogrammetric survey. The survey was done by Dr Yamafune, a 3D photogrammetry specialist from Texas A&M University. The author of this dissertation assisted in both the recording of the site and, subsequently, data processing and 3D modelling.

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[13] Multi-Image Photogrammetry, Computer Vision Photogrammetry, Structure from Motion. Terms commonly used to describe 3D photogrammetry (Van Damme, 2015, p.13; Yamafune et al., 2016,p.521).

Equipment

For creating an accurate 3D model using photogrammetry, it is necessary to take good photos. This does not mean that the camera has to be on a higher end of the spectrum. This refers more at choosing the right camera and the accessory equipment used for capturing fine images, alongside knowing the right way of positioning the camera with the area that is being surveyed (Shortis, 2019, p.12). The Sony - Alfa R37 camera was used for the underwater image acquisition. To reduce the optical noise, the wide-angle lens was utilized (FE 12mm – 24mm). A hemispheric dome-shaped underwater housing was used, which, overall, minimizes the refraction caused by the change of density between water and air (Yamafune, 2016, p.8). Two strobe lights served for recapturing the true colours lost by the light absorption, which occurs underwater (**Fig.11**) (before every recording, a white balance had to be adjusted on the camera). That being said, the factors that disrupt the use of photogrammetry underwater are limited visibility, light absorption and light refraction. This will dictate the way how the survey will be planned (Van Damme, 2015, p.17).

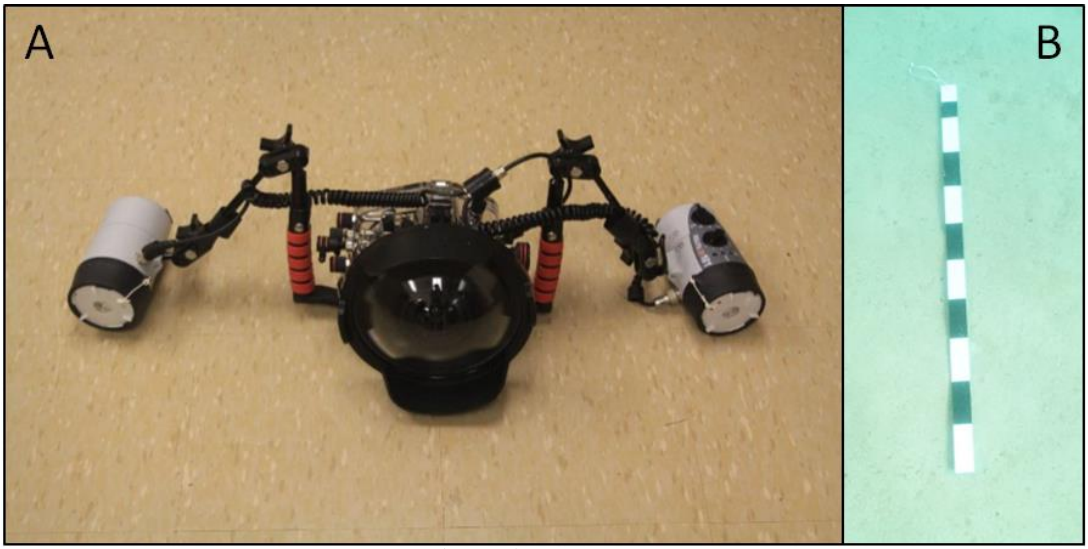

Figure 11. Underwater camera housing (Ikelite) used for 3D survey, with two strobe lights and a hemispherical dome port (**A**), Scale bar used for the survey (**B**) (Source: K. Yamafune)

Besides standard Scuba diving gear, drawing plates and buoys, which marked the dive site, a GoPro 5 camera was used for creating photo-documentation throughout the process of surveying. Five one-meter long scale bars were placed on different parts around the wreck for computing the scale of the model and for increasing the accuracy of photo alignment. Scale bars also served for creating a network of control points (depth measurements were taken) to fully geo-reference the model afterwards in the *Agisoft Photoscan/ Metashape* (Drap, 2012, p.114; Yamafune, 2017, p.532).

Recording the Site/ Image Acquisition

Data collection is the most important task done in a field project, which is why it is essential to understand the object (site) that is being recorded and to have a clear idea of the purpose and objectives for the survey. By following these rules, archaeologists can choose their interest zones based on the informed decision. Knowing the main objective of the survey, the next phase would be to create an appropriate flight path (Yamafune, 2017, p. 530) (**Fig.12**). Here, the most important factor for successful photogrammetric modelling is to have good photo alignment. This is done by holding the camera in a perpendicular position while taking photos of the top view of the shipwreck site, in a 'lawnmower pattern' (Green, 2004, p.166; Van Damme, 2015, p. 36) (**Fig.13**). Through the implementation of such technique, the picture overlap should be between 60/80% (one object has to appear from three to five times), depending on the path direction[14] (Yamafune, 2016, p.27). Since the position of the wreck varies from the shallowest section at 9m to the deepest point on 15m, additional photographs were taken from the side (tilted) to capture vertical surfaces as well. What can be noticed in Figure 12 is the poor visibility induced by strong currents and human interference.

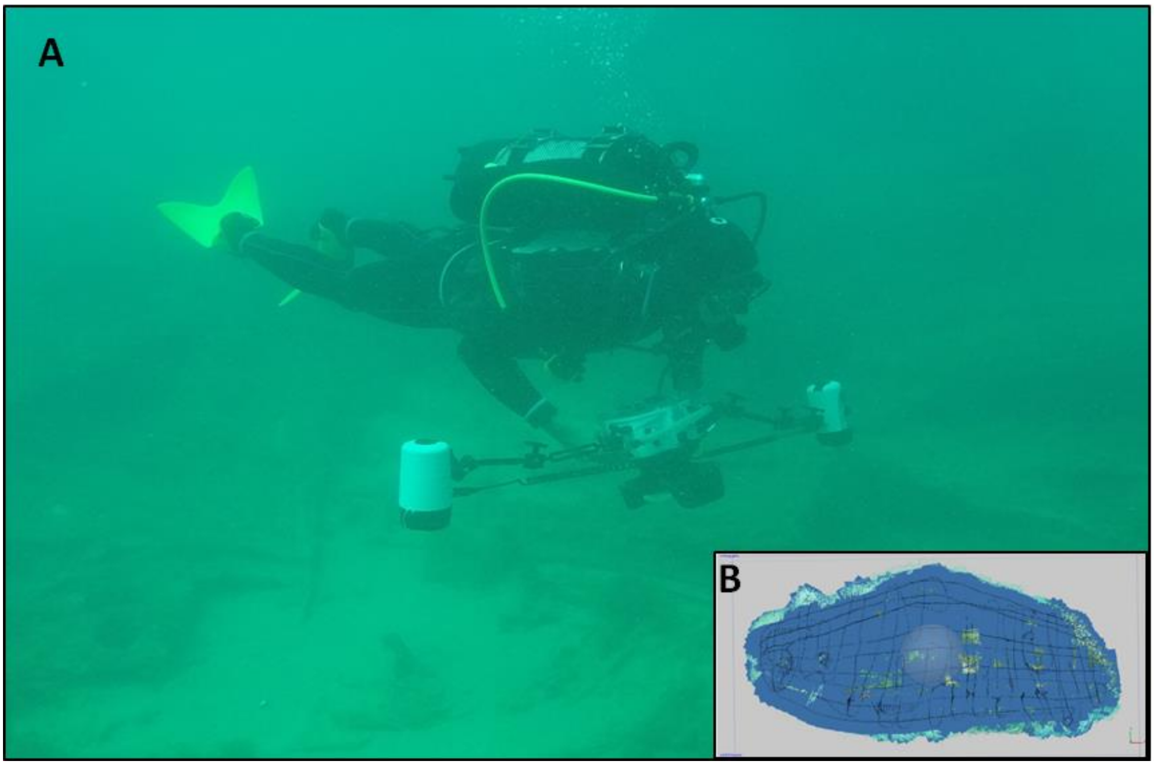

Figure 12. Dr Yamafune conducting a photogrammetric survey, by implementing a proposed flight plan **(A)**, Final image coverage of the survey **(B)**. (Source: Dj. Cvetkovic)

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[14] The key factor for the flight path is to create many intersecting lines. The surrounding area should be captured first to close (lock) the site, after which Transversal and Longitudinal paths can be done. If this method is properly used, the distortion on images can be reduced (Yamafune, 2017, p.531).

A good example of demonstrating the unexpected situation, which occurred during an on-going photogrammetric survey of *HMS Maori*, was when a group of recreational divers arrived on the site and lifted the sediment up. This seriously affected the overall visibility, and unwillingly forced the plan to be changed. Instead of waiting for the sediment to settle down (and by that time potentially losing the air inside the tanks needed for the mission to be completed), a new path was improvised. This time, an area which was not disturbed by the sediment was covered first. In such situations where the visibility is not ideal, a re-evaluation of camera positions should be taken into consideration. While reducing the distance between the camera and the surface of the object, the distortion (noise) of the image can be minimized (Drap, 2012, p.114; Yamafune et al., 2016, p.532). Two days of image acquisition created enough material for constructing a 3D model of the shipwreck site. Since it took two days for the survey to be finished, settings used on the camera had to be adjusted[15] (**Table 2**).

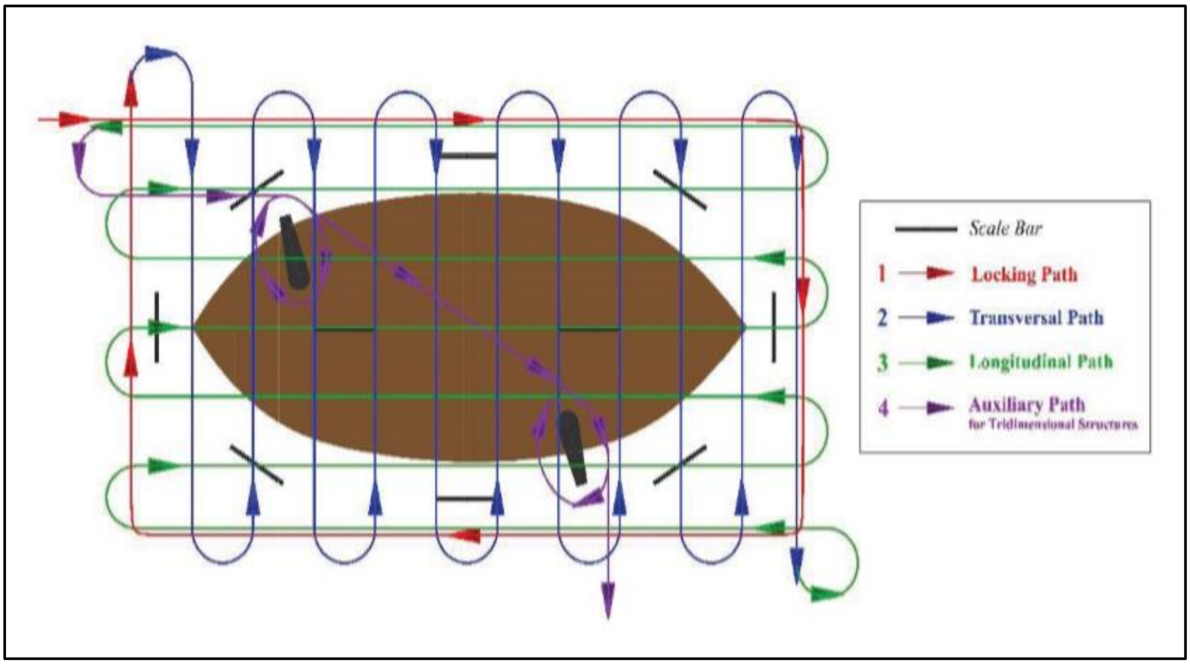

Figure 13. The recommended flight path for the 3D survey (Source: K. Yamafune)

Sony Alpha – A7R III (12-24mm)	Day 1	Day 2
Aperture (F)	22	22
Shutter Speed (SS)	200	160
ISO	6400	10000

Table 2. Camera settings used for the 3D survey. (Source: Dj. Cvetkovic)

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[15] The conditions were different. This can be seen in the ISO and SS settings, which points towards the conclusion that pictures from the second day were initially darker than the ones from the first day. Lower SS allowed more light into the camera sensor, also ISO had to be raised to 10000 (higher ISO- brighter image).

4.2.2 Legacy Data Survey

Many examples for the use of legacy data in maritime archaeology can be seen in the past few years (Van Damme, 2015; Green, 2019). Usually, this type of data, in the moment of its creation, was never intended to be used for scientific purposes. Nevertheless, today's technology allows archaeologists an additional source of information to be recovered from the archaeological sites, with the help of legacy survey data (Van Damme, 2015). For this dissertation, online video footage of the wreck will present legacy data, and in this case, video-frame photogrammetry will be applied to construct a 3D model. But before this, a selection of most suitable videos online has to be done first.

The importance of legacy data might be overseen by many, while the truth is that in many cases, these old videos/images may contain a record of the site which no longer exists, and had been destroyed by some type of natural or human disturbance (Ullah, 2015, p.332). An opportunity to re-visit the site at one point in the past gives big amplitude of choices to be applied to scientific research. Therefore, in this dissertation, after collecting and processing a certain amount of video recorded data, 3D models which were created out of that material will then be tested. How reliable the data truly is will be seen in Chapter V, after the comparative study has been completed.

Process of Selection/ Video Acquisition

A decision was made to use the most accessible online video platform available for the public, *YouTube*. Following the idea of a cost-effective and time-efficient survey, this approach fitted ideally in the proposed plan. Knowing how popular the site was inside of the dive community, the author had expected to find a significant number of video footage related to the wreck. The number of videos found on *HMS Maori* exceeded twenty[16]. Of course, the possibility to utilize all of them was low, mainly because there was not enough displayed content to be used for processing. For the most part, cameras were used by the divers who had no intention to use their material for a scientific purpose[17]. Only 10 to 20% of video footage could be exploited. Also, *HMS Maori* does not lie flat on top of the sediment, but she is protruding vertically, and her depth variation goes from 9 to 15m. This makes the site more complex to shoot, and it diminishes the chance of finding useful video data.

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[16] Most likely, GoPro cameras were used for filming the site.

[17] Shaky footage, not holding the camera perpendicularly towards the object, no artificial lights, filming divers and the environment, low visibility

Having in mind everything previously mentioned, some of the key factors to look for in videos are:

- When the camera is close to the object (reducing noise/water – clearer image)
- Steady camera movement (sudden change of perspective or angle makes processing hardly possible)
- Flat surface (easy for the program to compute)
- Good video quality – 720p, 1080p; (this leaves more room for image adjustments before building a 3D model)

Editing is a practice commonly used by people who post videos on *YouTube*, and this in general presented a huge challenge for finding a segment inside the video that lasted for more than 30 seconds without a break. In addition to everything aforementioned, when the decision has been made and desired videos have been chosen, the way how the footage will be downloaded is equally important. The author used an online open-source program for downloading *YouTube* videos. It is necessary to adjust the video settings on high, before copying the URL code to the desired destination for downloading, if neglected this can jeopardize the process of 3D modelling due to lower video/ image quality. Video files were downloaded in an mp4 format.

4.2.3 Challenges

While the difference between these two methods of data acquisition can be noticed, both have their own sets of advantages and limitations. Despite being a more accurate and reliable source of information, the photogrammetric survey still demands from the surveyor to have some prior knowledge in planning and conducting the mission (Fight path, diving, camera settings, scale bars, etc.). Additionally, the equipment used for the survey was specifically intended for photogrammetry purposes (camera, water housing, strobe lights, etc.), and acquiring such items can sometimes be expensive. That being said, this survey could be done with more affordable equipment, capable of producing high-quality data.

On the other hand, collecting legacy data in comparison with the 3D survey does not require any advanced equipment. The entire survey can be performed in a short amount of time; meanwhile, the only required piece of the equipment is a computer with an active internet connection. As previously mentioned, this advantage does not come without some limitation. The video material was not taken systematically, the data quality is not high, and the scope of obtainable information is questionable (no metadata[18]). Having said that, if the person dealing with such type of data had an idea of what to expect from it and how to carry out the research, the results could potentially be used for scientific purposes. Photogrammetry has become a standardized survey method used in maritime archaeology worldwide, and new recording strategies are continually being developed (Drap, 2012; McCarthy and Benjamin, 2014; Costa et al., 2015; Yamafune, et al., 2016; Rossi et al., 2019). Legacy data survey can be the evidence for such a claim.

4.3 Data Processing

Before commencing the image editing procedure and eventually the data processing, it is essential to point out the way how the files should be organized, to avoid any unnecessary confusion. By meticulously saving and arranging the data, clearly and fashionably, all the files will easily be manageable by the user and the overall productivity will increase (Yogeswaren and Cormier, 2017).

The workflow for the 3D photogrammetric survey has been already covered in details by archaeologists who previously dealt with this subject in the past years (Balleti et al., 2015; Van Damme, 2015; Yamfune, 2016; Torres, 2019). However, a brief description will be given, since it is relevant for the credibility of the dissertation, as well as, for understanding the comparative study covered in Chapter V.

4.3.1 Photogrammetric Data Processing

To complete the task of data processing, more than one computer software had to be used, as well as a computer with robust characteristics (enhance time-efficiency). For the majority of the time, an Hp Pavilion laptop was used[19]. Before any processing had begun, extra room in storage memory had to be available. Since all the images were taken with a professional camera and equipment, with already pre-determined settings, pre-processing was not required. A 3D modelling programme *Agisoft Photoscan/ Metashape*[20] was used to manipulate and process the data for this dissertation (Agisoft LLC).

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[18] Metadata: Contains information such as the camera settings, focal length, date, file size, etc.

[19] Processor: Intel (R) Core(TM) i5-8250U CPU 2.40 GHz/ 2.60 Mhz; Graphics card: NVIDIA GeForce: 940MX; RAM memory: 16GB;

[20] *Agisoft Photoscan*: Older version (Professional 1.2) and the newer version (*Metashape* 1.5) (both were used)

Workflow

The workflow for the Multi-Image Photogrammetry used for this research follows a methodology constructed by Dr Yamafune (2016). The first step was to upload the pictures to the software interface. The files were in the jpeg format, although *PhotoScan/Metashape* can process images in different types of format if needed. The workflow process has four steps (**Workflow** > **1. Align Photos** > **2. Build Dense Cloud** > **3. Build Mesh** > **4. Build Texture**). *PhotoScan* is mainly automatic processing software, still, each step requires some fine-tuning and adjustments that need to be performed, for creating the desired 3D model.

When performing the first '**Align Photos**' step, *PhotoScan* compares each image in the dataset to every other image to find matching points (features) (Agisoft LLC). That is why overlapping plays an important role just as much as good flight path while photographing. More images create more matching point comparison, which subsequently increases the accuracy (alignment) of the 3D model (Van Damme, 2015, p.59; Costa, 2019, p.72). Alignment settings were set on the highest, with 2996 photos successfully aligned out of 3002. What makes this data valuable is the .EXIF metadata which every digital picture contains, such as information about the camera, settings used, or focal length which *PhotoScan* uses for calibration and correction of camera positions (Van Damme, 2015, p.37).

Building the '**Dense Point Cloud**' comes after the photo-alignment has finished. The second stage is crucial for the study this dissertation deals with because afterwards, the Dense Cloud will be exported and used for testing the proposed comparative study mentioned in previous chapters. It is based on building a point cloud much more condensed and detailed by using previously estimated camera positions from a sparse cloud (Costa et al., 2014, p.554; Yamafune 2016, pp. 57-61; Agisoft LLC). Still, this does not mean that Mesh and Texture are less important, quite contrary, as it will be shown in the next few pages, a rendered textured model is essential for testing the proposed theory about monitoring.

'**Build Mesh**' is the third stage where a 3D polygonal mesh is constructed. Here, a dense point cloud is used for creating the object surface, since it generates more details than a sparse cloud (McCarthy and Benjamin, 2014, p.98; Yamafune, 2016, p.62).

The last stage '**Build Texture**' is when the texture is applied on top of the polygonal mesh. *Photoscan* does this by creating a photomosaic which then goes on the surface of the mesh (Yamafune, 2016, p.65) (**Fig.14**).

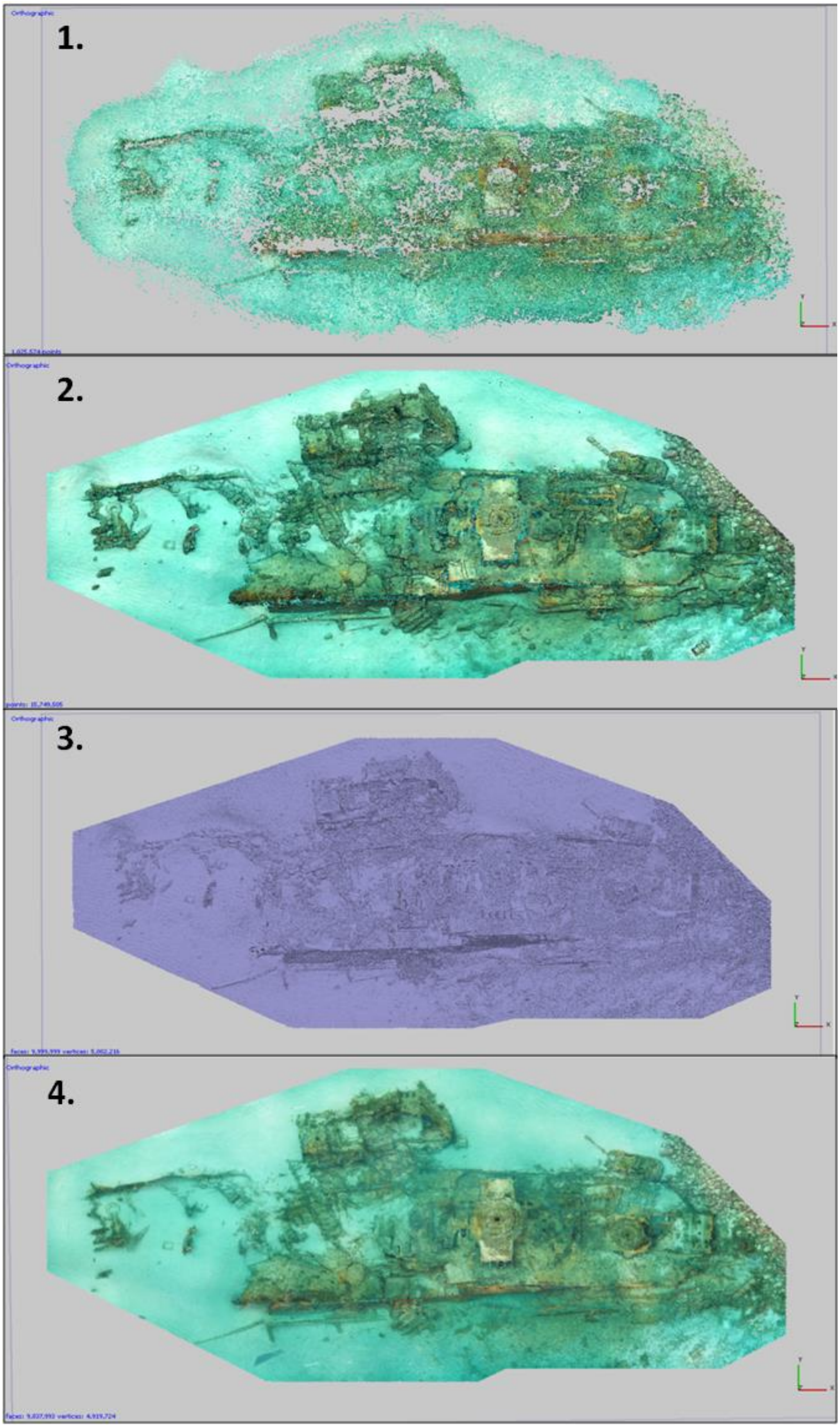

Figure 14. The workflow results represented in 4 steps: Align Photos **(1)**, Build Dense Cloud **(2)**, Build Mesh **(3)**, Build Texture **(4)**; (Source: Dj.Cvetkovic)

It is recommended to always adjust the photo-alignment on high, for the reason of creating a more accurate model. The remaining three steps can be altered (medium, low), depending on ambitions and goals set by the person who conducts the research[21](**Table 3**).

Align Photos	-Accuracy: High Points: 1,025,574	-Photos aligned: 2996/ 3002 -20 hours of processing time -Survey date: May 2019
Build Dense Cloud	-Quality: Low Points: 15,749,505	
Build Mesh	-Source data: Dense Cloud	
Build Texture	-Mapping mode: Generic Blending mode: Mosaic	

Table 3. Workflow adjustments for creating a 3D model of *HMS Maori* surveyed in 2019 (Source: Dj.Cvetkovic)

As mentioned previously, some adjustments in between these steps were taken to improve and enhance the final 3D model of *HMS Maori*. Such as :

- The method of Gradual selection and optimization; applied after the alignment process has completed, but before building Dense Cloud (Agisoft Online Forum, 2015). There, a list of actions was followed :
  - (**Edit > Gradual selection > Projection accuracy > 10% out of the total amount of points were marked and removed**). The next was Camera optimization/ photo re-alignment (**Tools > Optimize Cameras > here, all the boxes should be ticked except for the last three**). There is a possibility of doing this action two times.
  -The same procedure is done for Reconstruction uncertainty; the difference only being in the camera optimization, where only the last box should be left unchecked (2x).
  -The third part is Re-projection error, and everything here also stays the same, 10% out of the total number of points should be removed. Optimization does change, and all the boxes should be ticked for cameras to be correctly optimized (2x).By repeating these steps, and after ‘cleaning’ the model, the overall error should be reduced.
- After building the Mesh, it is highly recommended to cut the excessive parts from the model before doing the texture. Also, image quality can be estimated by selecting one or more images with the right-click. An option to exclude an image of low quality does exist(< 0.82) and should be performed for improving the final look of the model.

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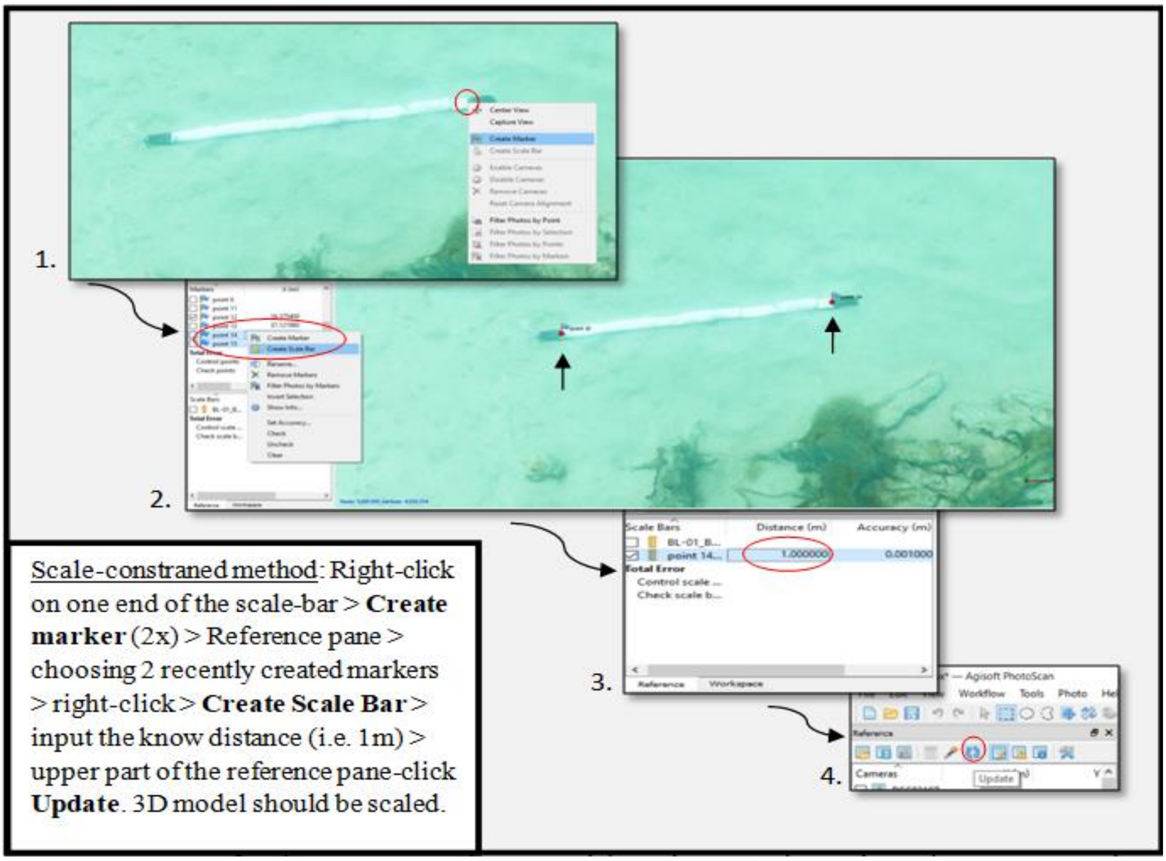
[21] High settings could be applied for creating orthophoto, detailed measurements of the site, DEM, etc. On the other hand, lower settings could find use in disseminating the results to the public (books, presentations, conferences, etc.)

Geo-referencing

For creating a 1:1 scale-constrained geo-referenced 3D model, the local coordinate system needs to be established. Direct survey method (trilateration), is a practice commonly used by maritime archaeologists, to create a local coordinate system (Green, 2004, p.87; Costa, 2019, p.70). The disadvantage of this method is the immense number of measurements needed to be taken from the site for geo-referencing, while *PhotoScan/ Metashape* allows the input of measurements differently. Since one of the aims of this dissertation was to properly geo-reference the 3D model of *HMS Maori* in a time and cost-effective way, a decision was made to use the scale-bars method (Yamafune, 2017, p.529). Five, one meter scale-bars were placed around the wreck, and by including scale-bars (known distances) into *PhotoScan/ Metashape* (after the texture has been finished), dimensions and distortions were able to be corrected (**Fig.15**). However, this does not represent a fully geo-referenced 3D model, and the implementation of a complementary method is needed for creating a local coordinate system. This stage of data processing is essential for testing the proposed monitoring hypothesis because for producing and extracting dimensional/ spatial information from the model, it is necessary to create an XYZ coordinate system.



Scale-constraned method: Right-click on one end of the scale-bar > **Create marker** (2x) > Reference pane > choosing 2 recently created markers > right-click > **Create Scale Bar** > input the know distance (i.e. 1m) > upper part of the reference pane-click **Update**. 3D model should be scaled.

Figure 15. Process of scale-constraining the 3D models in *PhotoScan/Metashape*. (Source: Dj.Cvetkovic)

XYZ coordinates can be created by placing three control points within the site[22]. Firstly, to establish XY coordinates on all three control points was possible by using known distances between the points to create a triangle. These control points had to be placed on the scale-constrained 3D model for measuring the exact distance between them (Yamafune, 2017, p.533). The procedure for placing the control points in the desired area is similar to how scale-bars were created. (**Right-click on 3D model > Create Marker – 3x > Create scale-bars – 3x > go to 'View estimated' in reference panel to extract calculated distances**).

Three distances between the points were extracted and transferred to the 3D CAD software *Rhino 3D*, where a triangle was created (*Rhinoceros*). The triangle had no orientation, and for it to get its Z coordinate, depth-measurements had to be imported[23]. Triangle adjustments had created new XYZ coordinates of the three points (corners), and have given the triangle a new position (Fig.16). These new coordinates were used to adjust the 3D model in *PhotoScan/ Metashape* (**in Reference pane – insert new points of the XYZ coordinates in the place of older ones > then click on 'update'**). After all is done, the 3D model is considered to contain geo-referenced data. This procedure will allow extraction of information such as 2D site plans, orthomosaic, Digital Elevation Map (DEM), and others.

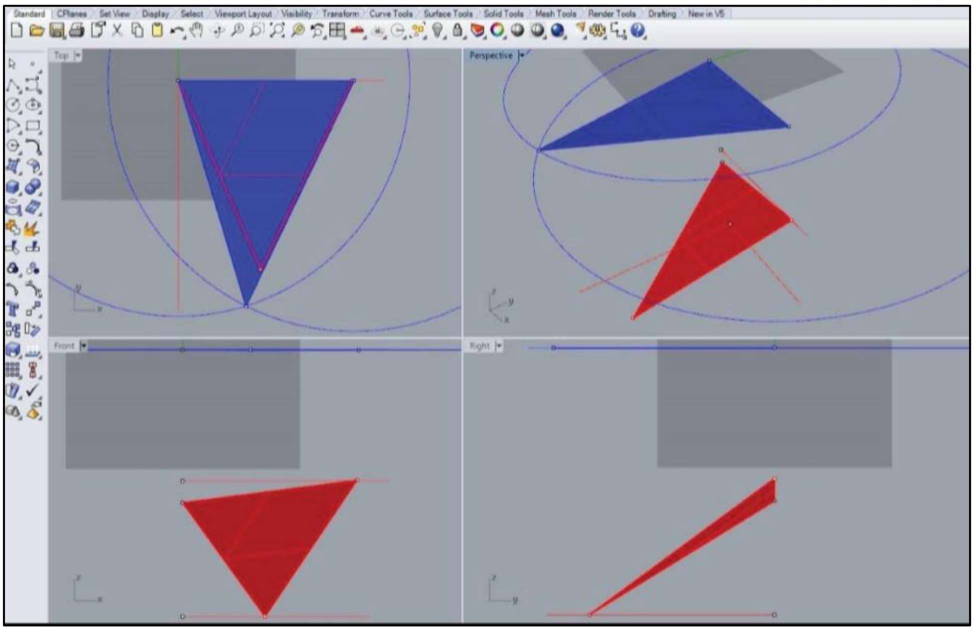


Figure 16. Triangle adjustments in *Rhino 3D*. The blue triangle represents the triangle created by using only distances between the points (XY), and red is after the triangle had been adjusted (XYZ). (Source: K. Yamafune)

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[22] Marked corners of each Scale-bar served as five control points, three out of which were only used for creating XYZ coordinates.

[23] While surveying and recording the site, the depth of each control point (scale-bar) was taken and noted down.

4.3.2 Legacy Data Processing

Legacy data is gradually finding its place inside scientific circles, as a source of datasets archiving information potentially valuable for understanding the site evolution and formation over time. *PhotoScan/ Metashape* was used for processing legacy data, only this time, instead of using the standardized method of multi-image photogrammetry (as in the previous section), video-frame photogrammetry was applied. The idea of these two techniques is identical, and the workflow is similar, but what happens before and after the workflow is where these two processing methods diverge[24]. Before 3D modelling can start, the data preparation (manipulation) procedure needs to be carried out. The data preparation is done through image and video editing software such as *Adobe Photoshop CC, Adobe Lightroom* and *Free Video to JPG Converter*.

Video-Frame Photogrammetry

In several articles, a discussion about video-frame photogrammetry exists, and its use in underwater archaeology, but it mainly deals with datasets created by the researches, professionals, where up till some degree a systematical approach in the recording was applied (Van Damme, 2015, p.40; Torres, 2019). What the author of this dissertation tries to question is the quality of 3D models created by using casual video footage of UCH sites posted online and how relevant and informative the data generated this way could be. This was tested by using the method of extracting still frames from video footage, after which those frame images were uploaded into *PhotoScan/Metashape* for processing.

The positive side of the video-frame photogrammetry use is a wider coverage area and good image overlap. Here, the image overlapping plays an important factor, since every second of video footage contains 24 to 30 still images (Yamafune 2016, p.82). This will prove to be the biggest asset when trying to extract still frames used for the alignment process in *PhotoScan/ Metashape*. Nonetheless, not all 24/30 frames per second can be extracted without consequences (i.e. lower image resolution, loss of original colours, blurriness), that is why a balance needs to be established. The explanation is that the single video footage contains less information than a photo taken by a DLSR (digital single-lens reflex) camera [25], even less if

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[24] In general, it is a Multi-image photogrammetry method derived from video footage.(Yamafune et al.2016)

[25] HD Video footage has 1920x1080 pixels per frame, while a photo made with DLSR camera approximately 6000x4000 pixels.(Yamafune, 2016, p. 87)

the quality of the video is reduced (i.e. 720p). After a thorough inspection of the videos, it is presumed that legacy data footage used for this research was filmed by GoPro cameras.

Before data processing can begin, an important thing to mention is the lack of metadata, and the ambiguity of information overall about the equipment used for filming the videos, as well as the exact date and time. Also, the video footages were posted by the general public, and it is vital to look for any type of information that they might possess. Usually, in the description or the title of a video clip, some details can be found, such as the location, date, camera type, and possibly a short comment about the dive experience. Being able to obtain such information will dictate how fitting and applicable the data may be. Knowing that the final goal and aim of this dissertation is to try to use legacy data to monitor the site over time, presence of date and time on these video footages will play a decisive role in choosing the right material.

Pre-Processing/ Data Preparation

After data has been successfully acquired (date and time, camera settings, etc.) and downloaded, the quality of the final 3D models will rely on how the data was handled and prepared for further use. For that reason, one of the first things would be to edit out the unwanted video sequences in either an online open-source video editor or any standard photo/ video editor installed on every computer. By doing this, all that is left is the video section ready to be manipulated with. A total number of sampled video footages for this research is 15, and they will all be used to test capabilities and the scientific potential of legacy data through photogrammetry. Also, all fifteen videos demonstrated a distortion created from a fish-eye lens most commonly found on GoPro cameras. These types of distortions can be corrected in the *Adobe Photoshop* software.

The entire process of editing video footage was covered in details in the PhD dissertation of Dr Yamafune (2016, pp.90-92). Therefore, the author decided to only apply two adjustments to the video footages, which was to correct the fish-eye lens distortions, as well as, to apply Unsharp Masks filters for sharpening the video (1. before uploading the video file, transfer to the Motion workspace by selecting: 1. **Window > Workspace > Motion > Add Media/** 2. convert video clip to Smart Object by doing: **Filter > Convert for Smart files**/ 3. Image editing: **Filter > Lens Correction Filter, Unsharp Mask filter/** 4. to export the video file: **File > Export > Render Video**). This slightly improved the overall quality of the footage, although, editing tools must not be used extensively, since it can be contra-productive, and it could easily create a negative effect on the video footage quality (**Fig.17**). For clearer demonstration and presentation of the comparative study presented in Chapter V, none of the colour editing options were used. This decision did not affect the validity of the final results, and it was based on the author's personal preferences.

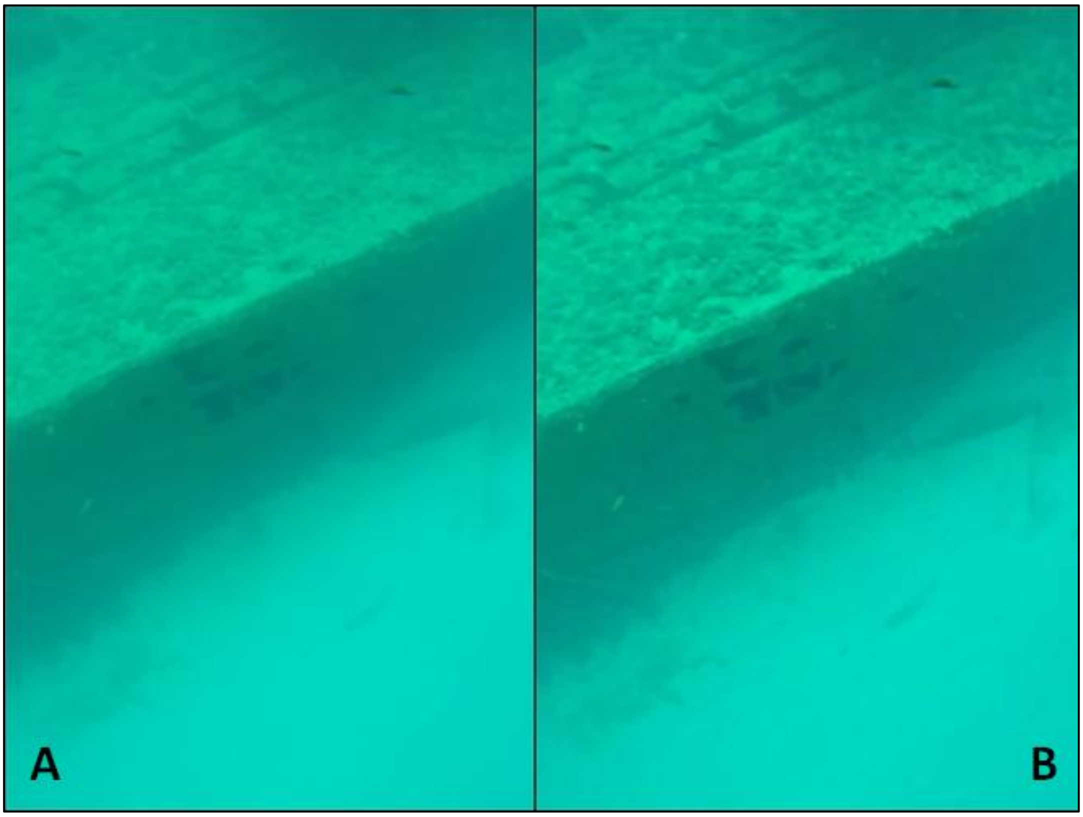

Figure 17. *Adobe Photoshop*: Image before editing **(A)**, Image after editing **(B)**; (Source: Dj.Cvetkovic)

Still Frames Extraction

Still frames extraction from video footage is possible by using either automatic or selective (manual) method. An automatic extraction method was decided to be applied, since selective may demand more time for still frames to be created (Yamafune, 2016, p.82). The extraction could have been done in programs such as Adobe Photoshop, but for this research, an open-source software was used, the *Free Video to JPG Converter* with easy to use software interface. The author was able to extract a certain amount of still images at a controlled frequency, which depended on the type of the video. The frequency or the rate to extract frames can be adjusted in four different ways: **1.** by adjusting the rate of every extracted frame by number (i.e. every 10th frame), **2.** by extracting a certain number of frames per second (i.e. 1 sec/ 2 frames), **3.** by setting the total number of extracted frames for the length of the entire video (i.e. 50 frames from video), **4.** by extracting every possible frame.

A decision was made to use the method of extracting frames by number since this approach gave the control that was necessary for an appropriate amount of image extraction[26]. After uploading a video file (**1.** Add files), and clicking on extract by the number of frames (**2.** entering the number deemed fit), all that was left to do was to choose where to save the extracted images (**3.**) (**Fig.18**). While extracting frames, the images can suffer motion blur which will result in poor pixel information and reduced image sharpness. This might complicate the alignment process in *PhotoScan/ Metashape* since the program will not be able to recognize certain features.

Extract
● Every 08 frame
● Every 05 seconds
○ Total 50 frames from video
● Every frame

Save to: C:\Users\beara\Desktop\

Figure 18. Automated extraction of still frames using *Free Video to JPG Converter*. (Source: DJ. Cvetkovic)

Extracted images should always be checked because sometimes the quality and the total number of extracted frames are not good enough for constructing a 3D model. When this is the case, some re-adjustments should be taken into consideration, such as repeating the extraction with changed settings, or trying to improve the overall quality of videos by editing them in programs similar to *Adobe Photoshop*. Otherwise, if the data is considered to be of good quality, extracted frames can be uploaded to *PhotoScan/ Metashape* as images.

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[26] This way, chances of having images with motion blur would have been reduced to a minimum.

Workflow

Legacy data processing will follow the path of the previously explained workflow in *PhotoScan/Metashape,* with some minor differences regarding the steps and how some adjustments were made to produce the best possible result. Nevertheless, it cannot be said that every attempt to produce a 3D model out of legacy data was successful, by the contrary, only 6 out of 15 videos were usable for being fully processed and geo-referenced. Through the workflow, the overview of the entire process of 3D modelling will be presented, together with examples of a more and less, successful outcome.

PhotoScan/ Metashape provides an opportunity to test the quality of each photo individually, which will help with producing higher quality data. This can be done by using the option to Estimate Image Quality in Photos Pane. It is possible by following the instructions: **Views > Panes > Photos**, then changing the display mode to **Details view**. Next, all images should be selected, and by right-clicking on them, a suggestion box will appear with an option to choose the command to **estimate image quality** (Yamafune, 2016, p.86). Depending from a total number of photos available for one model (the number of LD photos was already limited), the bottom threshold value would change. If the total number of photos was above 50, in that case, every image below 0.75 value would be discarded or deactivated, while if the number was under 50, the bottom value threshold would be at 0.45).

After estimating the image quality, the next step would be to perform masking of photos. This is done manually on each photo, and by doing this, the program will ignore parts which ended up masked and focus entirely on the area that has objects of interest. The masking procedure was done on every 3D model that was created, and overall this produced more reliable results. It was necessary to apply this method since the majority of the videos contained distractions such as scuba divers, the water column in the distance that created blue background noise non-relevant for the research, or letters and symbols digitally edited into a video. To apply this method appropriately, the first thing to do is to open one image at a time and start with the masking procedure (**1.)** Double click on any photo in **Photos Pane** (**2.)** after opening the image, in the toolbar section, there are two options for masking: **'magic wand'** and **'intelligent scissors'**. (**3.)** Afterwards, by using the left click an image can be tailored in the desired way, when all is done, (**4.)** right-click to open suggestion box and choose an option '**Add Selection'**). These steps had to be repeated individually for every image that is being used, for creating a 3D model (**Fig.19, 20**).

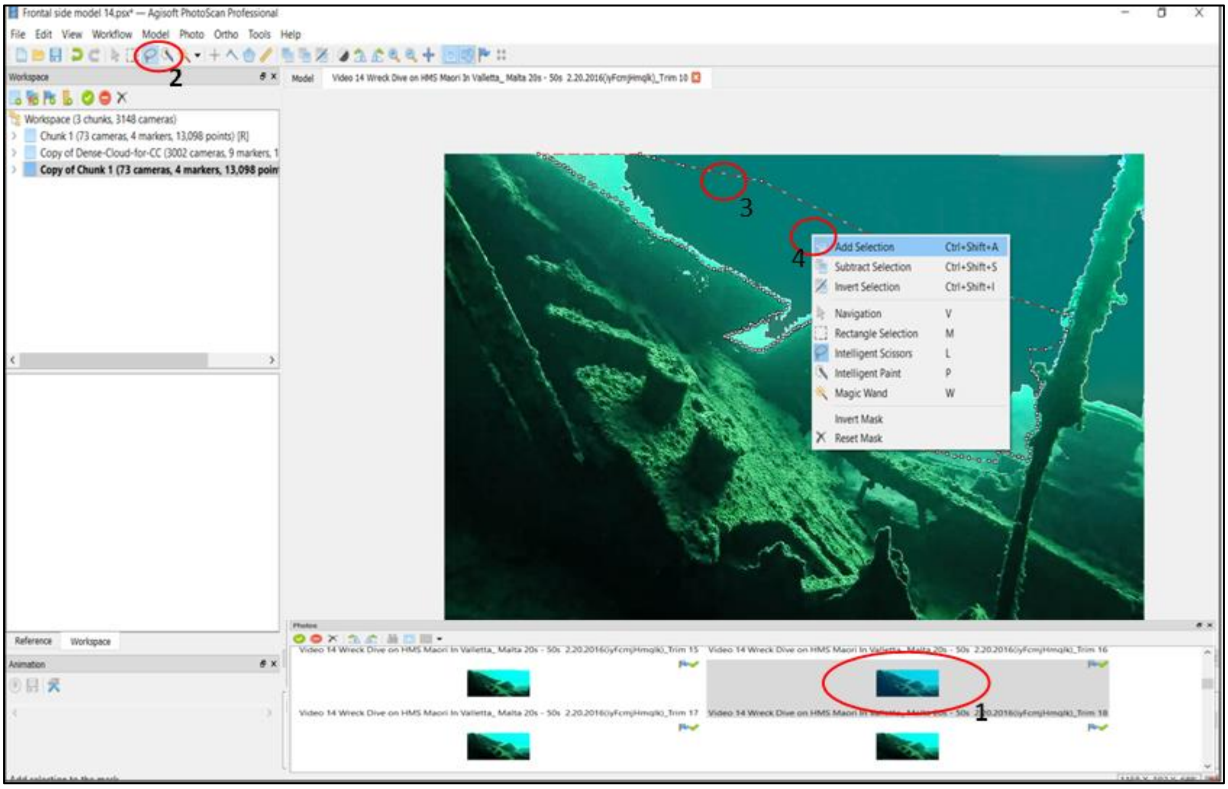

Figure 19. Process of masking photos in 4 steps. (Source: Dj. Cvetkovic)

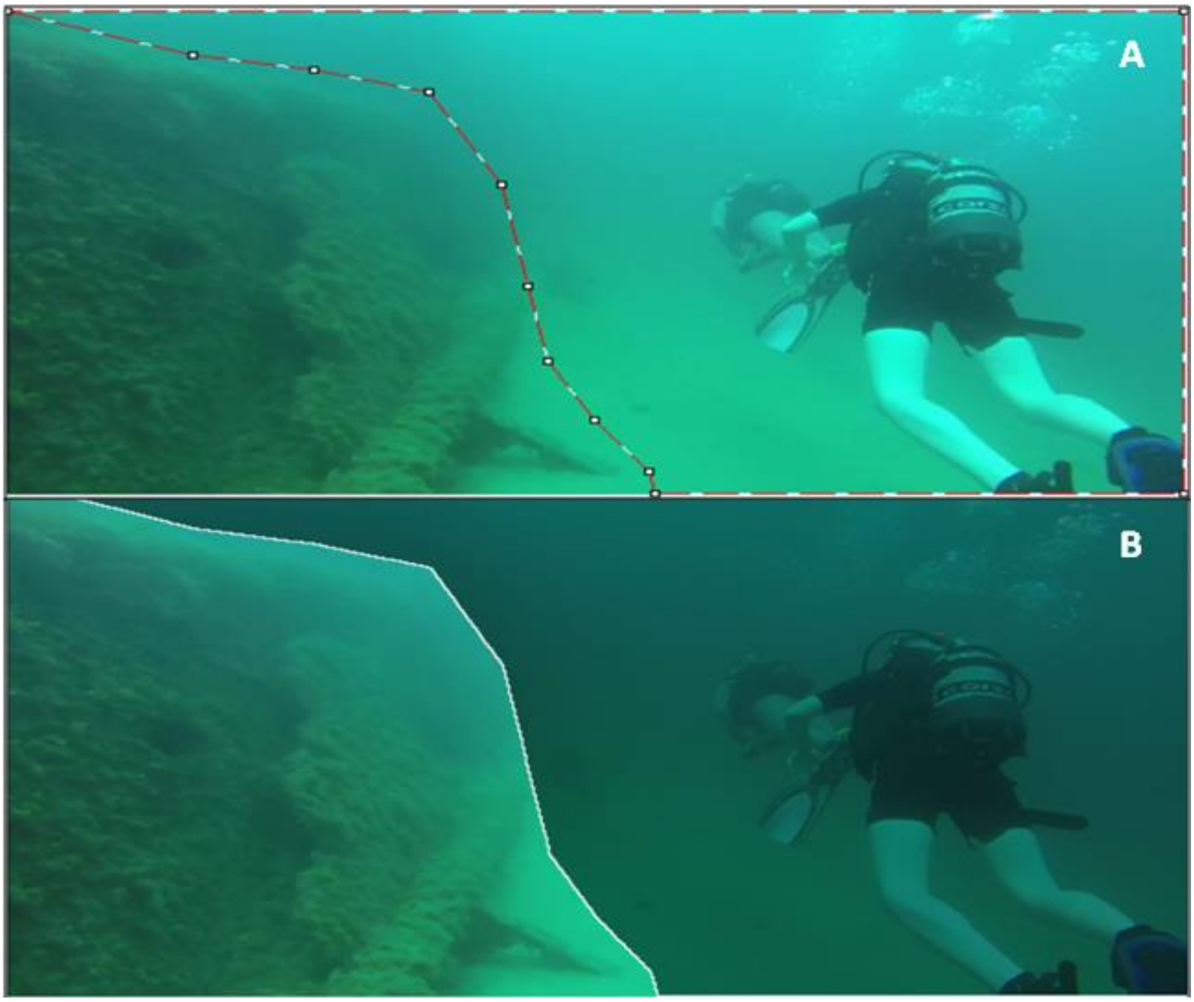

Figure 20. A photo before **(A)** and after **(B)** masking procedure; (Source: Dj. Cvetkovic)

The photo alignment was next in line, and to test the difference of the **sparse point alignment**, all models were generally processed in 'low', 'medium' and 'highest' quality settings. This was done, because it was mentioned in a couple of research papers that, when using lower settings, image alignment would increase, and by having a better image alignment, an overall error would be reduced (Van Damme, 2015, p.45)[27]. That being said and since this dissertation deals with legacy data and video footages which were not created for photogrammetric purposes, the final result proved that 'highest' settings eventually did produce better results.

In the majority of the cases, while producing point cloud with the 'medium' or 'low' accuracy settings, a result was an undefined disperse of points or an average looking model. Also, the number of aligned images was similar, but the quality of the data was noticeably poorer. The reason behind such results might be that image quality was not good enough, and after editing and extracting procedures had finished, it might have influenced the overall image quality (**Fig.21**). Nevertheless, soon after the 'Align photos' phase was completed, it became apparent which model could potentially be used to explore the idea of monitoring through the use of legacy data (**Fig.22, 23**). This does not mean that poor alignment was the main reason for not being able to produce a relevant 3D model, the biggest factor was the angle of the camera while filming, as well as, the complexity of the structure *HMS Maori* has.

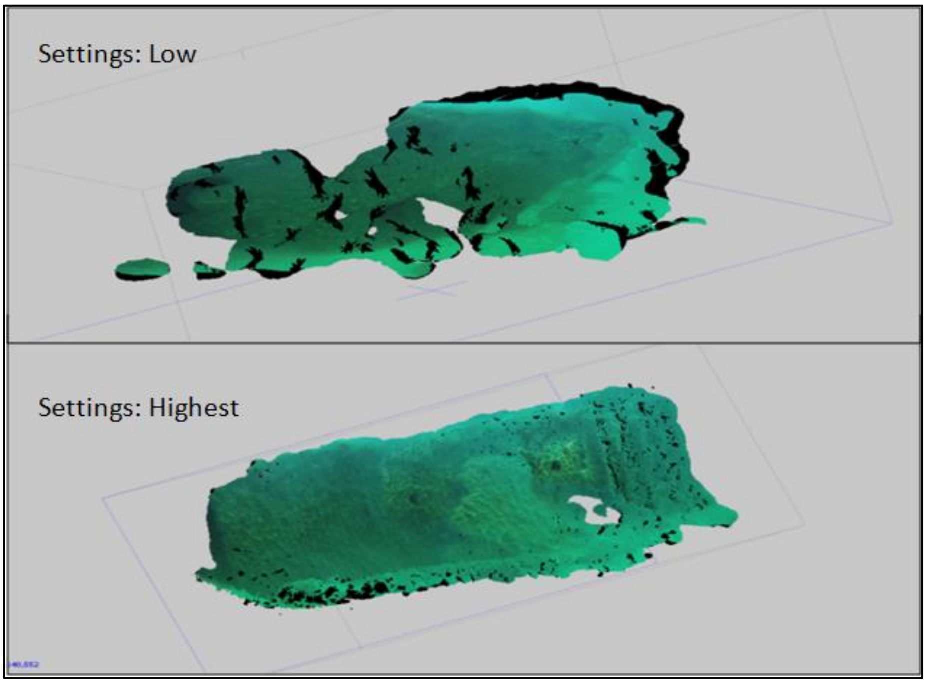

Figure 21. LD model in two different settings adjustments.(Source: Dj.Cvetkovic)

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[27] For the case studies mentioned in a couple of articles, video footages were made to document underwater archaeological sites, or for testing the use of video-frame photogrammetry in underwater surroundings.

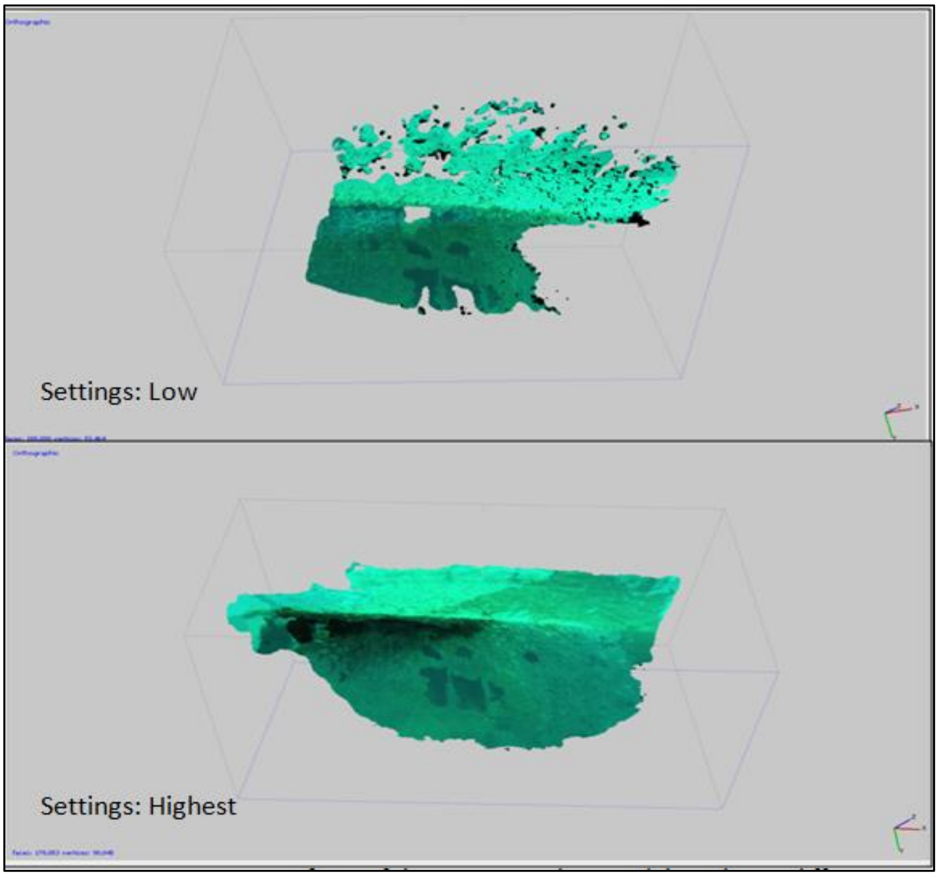

Figure 22. Representation of one of the six textured LD models with two different alignment settings, low and highest. Location: Gunwale (Source:Dj. Cvetkovic)

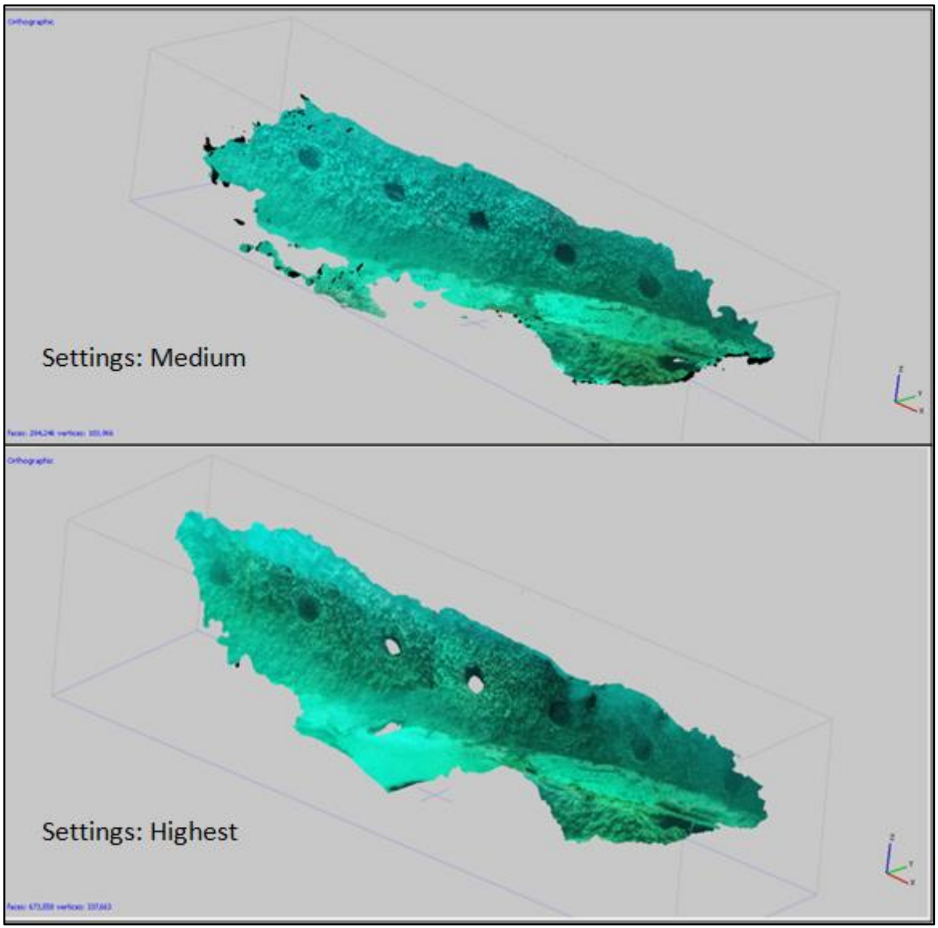

Figure 23. Testing the difference between alignment settings adjusted on medium and highest. Location: lower hull section/ Starboard (Source: Dj.Cvetkovic)

Due to *Maori's* position which is horizontally on the seabed (42m) and vertically (9/15m depth), the camera angle could never be ideally positioned to cover one large area at once, especially with passages, holes and crevasses covering the entire shipwreck. An additional environmental factor which made the alignment process harder at times was low visibility induced by strong currents and poor lighting. Even though some of the processed models were not able to go through the whole procedure and eventually be used for the final analysis, they still carried information valuable for creating an impression of how the site formation has changed over time.

Before continuing with Dense Cloud, like in the previously showed workflow process, a gradual selection needed to be applied. This time, the author decided to use all three stages of gradual selection alongside camera optimization (Projection accuracy**,** Reconstruction uncertainty, Re-projection error), but instead of repeating each step two times, it was reduced to only one repetition. A decision was based on the number of sparse points generated by every legacy data model. This number of points was much lower in comparison with the main model, created by physically recording the site. The danger of repeating the same procedure of gradual selection used for the main model had the risk of losing too many valuable points which could, in return, potentially play a decisive role for the comparative study in Chapter V.

Dense cloud was produced with the 'highest' settings for every 3D model created from legacy data. Even though masking, gradual selection and image quality estimation had been performed, some noise still existed which needed to be taken care of[28]. In this situation, a manual cleaning procedure has to be done, and it may be time-consuming but eventually does improve the overall look and the precision of the model. Aligning and building dense point clouds creates the foundation necessary for the 3D model to be relevant and quantifiable. Mesh and texture were the next step, and the process of creating was similar as in the case of the main model. In the end, the number of successfully created 3D models was six, and the time range they cover is from 2015 to 2017. In total, six legacy data model covered six different parts of the entire wreck of the *HMS Maori*. This provided a reasonable amount of 3D models to allow the monitoring proposition to be tested. One last obstacle to overcome before the comparative study could start was geo-referencing the 3D legacy data models.

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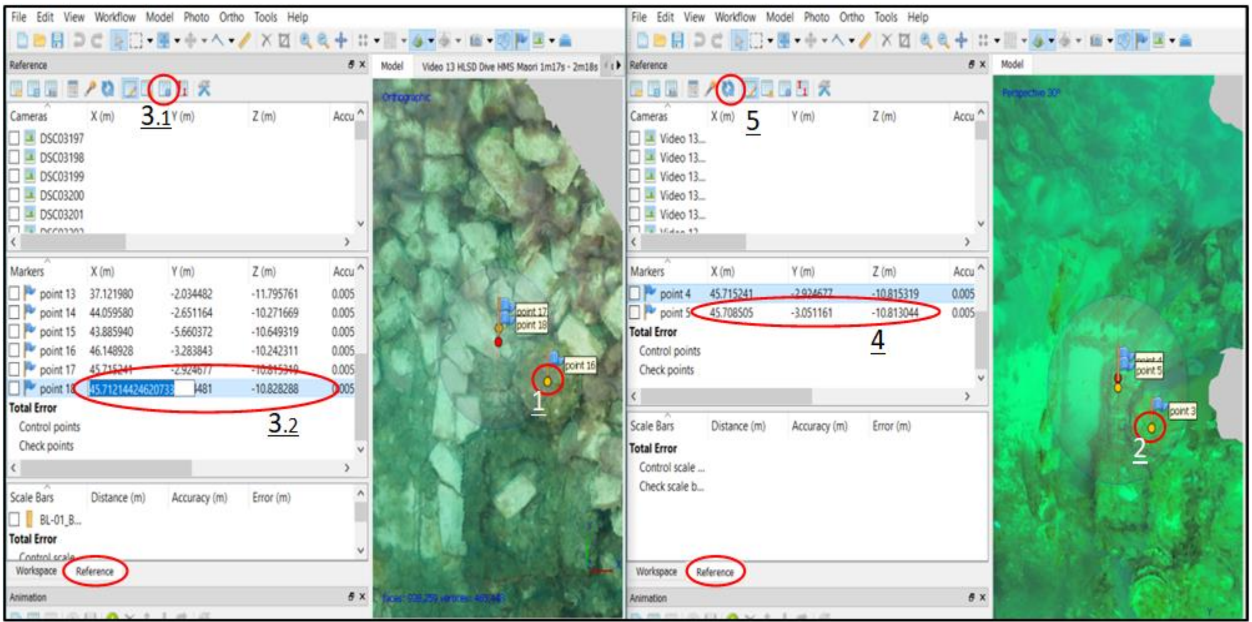
[28] The noise was a product of water and low visibility, which was created by an inadequate camera position (not-perpendicular angle).

Geo-referencing/ Common Points

Video footages used as a source for legacy data left no room for geo-referencing models in the manner demonstrated earlier, by using scale-bars and depth measurements (XYZ coordinates). But that is where the importance of having the main model scaled and geo-referenced contributed the most. This refers to the fact that once a local coordinate system has been developed for the main model, this same coordinate system can be used for geo-referencing and scaling any following photogrammetric model of the same. Dr Yamafune who developed this method of geo-referencing photogrammetric 3D models, tends to call the main model, a "first 1:1 scale constrained geo-referenced 3D model, as a 'Mother Model' and every following 3D models that receives coordinates from the Mother Model as Child Models" (2017, p.534). That is to say, XYZ coordinates can be extracted from the main model, and imported into newly created legacy data 3D models for generating an identical local coordinate system. This is possible by creating markers which would serve as common points between two models after which extracted coordinates from the main model can be transferred onto the legacy data model (Rossi et al., 2019, p.54). It is recommended to have a 3D model with good texture for achieving higher precision in finding common points. One of the first steps after finding a potential common point in the main model would be to '**create marker**' by right-clicking the area deemed fit for the coordinate extraction, and then, in the reference pane to click '**view estimated**' for an exact number. At the same time, if the point in the legacy data model is considered well-positioned, a marker can be created alongside the newly imported coordinates, previously extracted from the main model. A minimum of three such points needs to be established for the model to be fully aligned (trilateration). An overall accuracy will increase with the possibility of extracting more than three common points for every 3D model.

It was clear from the early stages that, due to the severe change which was ongoing at the site and its degradation, finding common points presented a more challenging task than expected. Nevertheless, for each of the six models, a minimum of three common points were established, and in some of them, four or five. It depended on how characteristic and prominent the investigated section was. Also, by having more than three points, a possibility of activating and deactivating certain points existed, which would increase or reduce the total error, by combining them (as long as the minimum three of them were constantly activated). Two models will align after all the coordinates had been imported by clicking the update button in the reference pane (**Fig.24, 25**).



Markers	X (m)	Y (m)	Z (m)	Accu
☐ point 13	37.121980	-2.034482	-11.795761	0.005
☐ point 14	44.059580	-2.651164	-10.271669	0.005
☐ point 15	43.885940	-5.660372	-10.649319	0.005
☐ point 16	46.148928	-3.283843	-10.242311	0.005
☐ point 17	45.715241	-2.924677	-10.815319	0.005
☐ point 18	45.71214424620733	481	-10.828288	0.005
Total Error				
Control points				
Check points				

3.2

Markers	X (m)	Y (m)	Z (m)	Accu
☐ point 4	45.715241	-2.924677	-10.815319	0.005
☐ point 5	45.708505	-3.051161	-10.813044	0.005
Total Error				
Control points				
Check points				

4

Figure 24. Georeferencing/ finding Common points between the main 3D model (2019) and the model created from legacy data (2016). Steps for completing the coordinate's alignment procedure are shown. Location: Forward - Forecastle deck next to the rocky slope (Source: Dj. Cvetkovic)

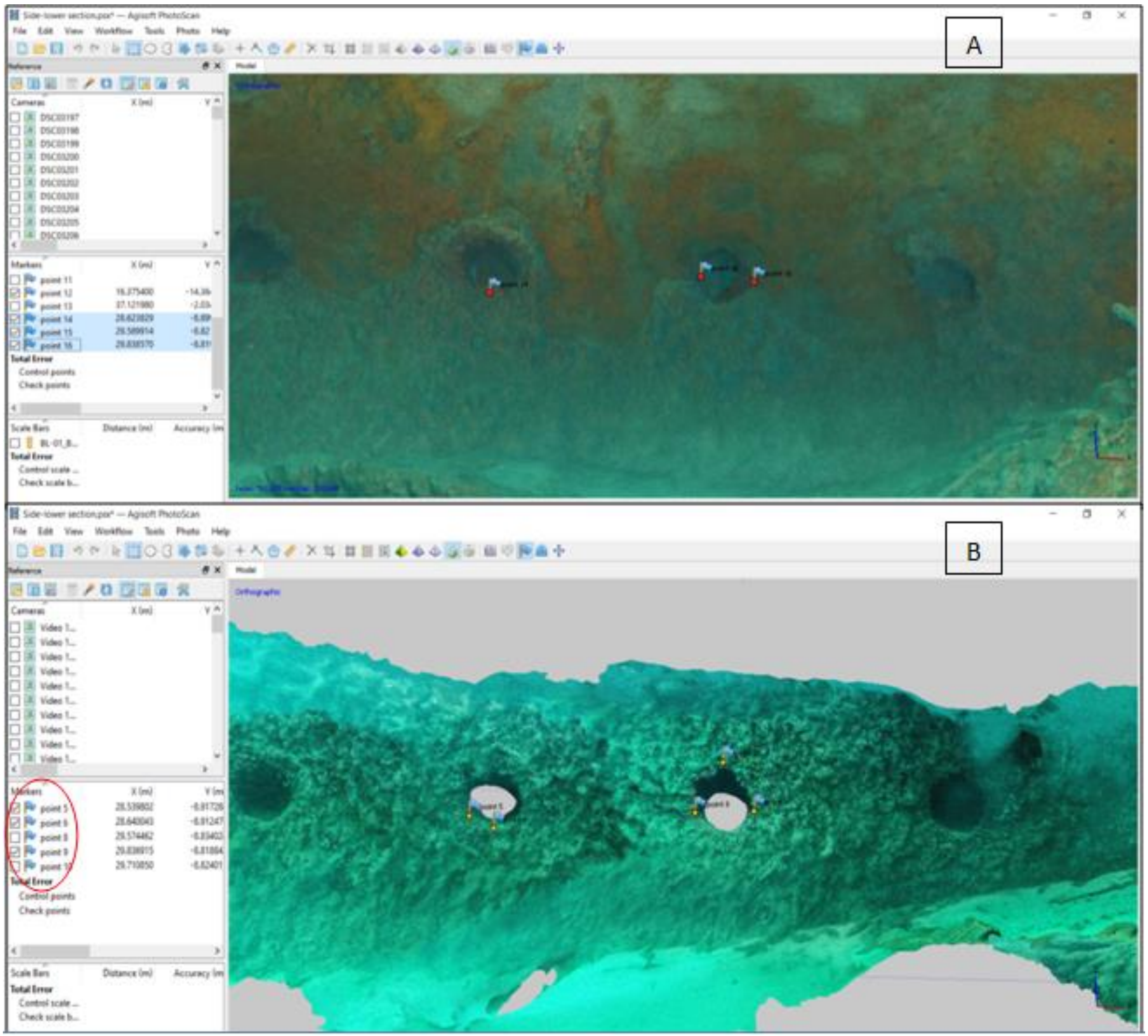


Figure 25. Hull section on the starboard side. In the LD model (B), 5 markers were created, while only three of them are actively used for coordinating the model. (Source: Dj.Cvetkovic)

The last thing to do before analysis could begin was to export dense cloud points from both the main model and from all six legacy data models, as well as, exporting six matching counterparts dissected from the main model. After the geo-referencing has been finished, all exported files should be able to open in their correct position in other software's (**Workspace** > bellow the chunk that was processed, dense cloud layer should be seen > Right-click on the dense cloud and choose the command to **Export Dense cloud >** as **ASTM E57 file.** In this way, the data has been prepared for the final assessment done through a comparative study.

4.3.3 Challenges

The methodology used for both multi-image photogrammetry and video-frame photogrammetry resembled one another. What can be seen from the examples presented in this dissertation was that although the following steps had the same route, their processing procedures differentiated significantly. The positive side of processing photogrammetric data recorded through surveying the site was that it needed no pre-processing because that was all taken care of with the additional equipment and camera adjustments before the recording has begun. On the other hand, legacy data had to undergo some extensive editing and pre-processing procedures for producing higher quality data. The lack of metadata in the extracted images created from video-frame photogrammetry demonstrated one of the biggest hardships when dealing with legacy data. That being said, *PhotoScan* could not use camera calibration for reducing the error in the model by itself, as presented in the main 3D model. Also, every LD model had certain amount of an error within them. This error was calculated per one meter, which meant if a model has an error of 0.5mm, and the length of the LD model is 5 m, total error of a model will be 2.5cm. Overall, this is considered to be acceptable.

The workflow methodology for both multi-image photogrammetry and video-frame photogrammetry have been covered and tested by archaeologists in previous years. Until now, an attempt to explore the potential of legacy data in such a way presented in this research was non-existent, which is why the method of trial and error was noticeable throughout the whole process. The author as an inspiration used the work from much-experienced colleagues, who have been dealing with similar questions for several years (Van Damme, 2015;Yamafune, 2016;Torres, 2019). The majority of 3D models created from video footages covered *Maori's* starboard side except for two models which included sections of the main deck and upper structure (**Table 4**). Each 3D model built from legacy data contained mainly flat surfaces because the geometry of more complex structures was harder to process.

LD 3D Model	Video length (min)	Quality	Extracted frames	Photos aligned	Total error (m)	Date
1. Mounting Gun Base/ Upper structure	0.14	1280/720p, 30f/s	39	37/39	0.0427	Feb 2017
2. Forecastle deck/ Rocky slope	1.01	1280/720p, 25f/s	73	69/73	0.0012	May 2016
3. Forecastle deck/ Starboard side	0.12	1280/720p , 30f/s	73	73/73	0.0434	Feb 2016
4. Gunwale/ Starboard side	0.16	1920/1080p, 30f/s	49	49/49	0.0057	Oct 2015
5. Hull/ Starboard side	1.00	1280/720p, 29f/s	65	62/65	0.0036	Sept 2015
6. Rear Hull section/ Starboard side	1.00	1920/1080p, 30f/s	56	54/56	0.0170	Aug 2015

Table 4. Six LD models successfully created and their most relevant information (Source: Dj.Cvetkovic)

4.4 Discussion

When looking at the overall quality, 3D models created out of videos are usually in an inferior position when compared to the models created through the image-based photogrammetric survey. The author eventually managed to create data that can be considered highly accurate and scientifically relevant. Furthermore, legacy data has in its possession, something which cannot be acquired through the standard photogrammetric survey, and that is the abundance of data from different timelines available for everyone to use and interpret. Still, the type of legacy data covered in this dissertation, because of the way of how it was created, could hardly ever be scientifically relevant on its own. That is why the new approach was implemented, to combine the systematically obtained data through photogrammetric survey and casual video data posted online, to try to understand the change that is constantly happening at the site of the *HMS Maori*.

With the resurgence of computer programs capable of dealing with this type of data (i.e. *PhotoScan/ Metashape*), a rapid expansion in 3D models productivity happened. Underwater archaeologists are now capable of producing a significant number of site plans in a short amount of time, which in return provides a detailed understanding of site formation processes (Yamafune, 2016,p.151).This approach had been used for tracking the excavation procedures, whereby doing so, different layers of the site can be systematically documented (Rossi et al, 2019, p.56). The same idea exists with the legacy data used for this research, through which, by understanding the difference between the main model and created legacy data models, a prediction can be made of the events that could happen in the future. An implementation of new software that deals with the deviation analysis is needed for that difference to become measureable (*Cloud Compare*). Results which this software might produce may serve as inspiration for constructing a potential monitoring and preservation plan.

CHAPTER V:

Analysis: a Comparative study

Chapter IV covered the entire process of collecting data and processing. One other important aspect to highlight in this chapter is the fact that the legacy data tested in this dissertation has proven to be a stable source of viable information. Without such stability, this study would not have been viable. That being said, to fully explore the capacity of both legacy data models and the main 1:1 scale-constrained 3D model, new software called *Cloud Compare* had to be utilised. By using this program, it became possible to compare two different point cloud datasets, which in return would create a representation of differences between the two models (1:1 vs legacy). These changes (calculations) can be presented graphically (colour graphs) or in the form of quantitative data (numbers) (Holst et al., 2017; Rossi et al., 2019). This method will provide much-needed insight into the site formation processes of a modern shipwreck site such as *HMS Maori*.

No two wreck-site formation processes can be identical. This is because of a number of factors such as environmental conditions and the ship's attributes. However, it is essential to note that every wreck-site, by default, goes through at least two of evolutionary phases, and through which it, reaches an equilibrium and becomes one with the environment (Muckelroy, 1978, p.157; Martin, 2014, p.48). The first stage is the anthropogenic factor (wrecking), the second is more dynamic, where intense interaction between the wreck and its environmental surroundings occurs. What comes next can be considered as a phase in which the archaeological site might continue its rapid degradation, or these processes slow down (degradation is still present just at a slower rate). By conducting a comparative study on *HMS Maori*, it would be possible to observe how stable that final stage truly is. Given that this metal hulk is located in relatively shallow waters, easily accessible and in a so-called high energy zone, makes this site ideal for tracking changes and for testing the method of the deviation (deformation) analysis.

The primary focus of this chapter is to demonstrate how *Cloud Compare* can be used for conducting such an analysis. It will also explore how one will be to portray the final results of the comparative study. From there on, data derived from such analysis will be inspected, and an attempt will be made to try to interpret its reliability and trustworthiness.

5.1 Point-Based Deviation Analysis

The term of monitoring can sometimes have, depending on the scientific discipline more than one precise interpretation. For the purpose of this dissertation, the definition can be formulated in one sentence: monitoring is the detection of any kind of systematic change that happens to the object of observation (Heunecke et al., 2013). After successfully scaling and geo-referencing previously created models, those measurements (as exported dense point clouds of the main and LD models) can be used as a reference to calculate any significant geometrical changes that happened to the wreck-site. Any displacement or a minor change that occurred in the interval between two measurements is something that should be detectable (Schroeder and Klonowski, 2019). In underwater archaeology, the use of this method is almost non-existent, and had been used in only one project so far (Rossi et al., 2019, p.58). In Croatia, while excavating the Gnalic shipwreck site, the deviation analysis method had been used to track the progress of the excavation (Yamafune, 2016, p.152). By doing this, detailed stratigraphic documentation can be conducted, something that is more common in terrestrial than in maritime archaeology. This differentiation between terrestrial and marine context also exists in deviation analysis, and to find any type of research concerning the submerged environment is rare. It is most commonly used for analysing the deformation and change in superstructures such as bridges, towers, dams, tunnels, etc. (Neuner et al., 2016). Here, a terrestrial laser scanner is commonly used, since it produces 3D point cloud with higher density. Nevertheless, as presented in two case studies, as well as, in this dissertation, photogrammetry is more than capable of creating 3D point cloud necessary for conducting reliable deformation analysis (Holst et al., 2017).

Before any attempt is made to interpret results, it is crucial to understand the context and geometry of the wreck. That knowledge will inform the researcher of potential deformations that may occur on the object, and if a specific distortion produces a pattern when comparing two point clouds. Changes that can be seen are rigid body movement and shape deformation. Also, the direction of deformation can be recorded, such as in-plane or out-of-plane movement (Holst et al., 2017). Nevertheless, the deviation analysis is capable of representing only absolute numbers without clear indication if these deformations are positive (accretions) or negative (erosion). Here, the experience of the person interpreting these results is of key importance. Whichever the case, awareness of the processes to which *HMS Maori* is regularly exposed, and by knowing exactly what type of results this analysis can produce, the chances for creating erroneous interpretations are drastically reduced.

5.2 *Cloud Compare* (v2.10-alpha)

Cloud Compare is open-source editing software capable of producing 3D point cloud deviation analysis. Standard file formats that can be used both in *Cloud Compare* and in *PhotoScan/Metashape* are ASTM E57 (.e57) and ASPRS (.las) (Yamafune, 2016, p.151). In the case of this research, dense point clouds were exported in E57 format. Since every 3D model created for this dissertation has been geo-referenced, the exported cloud points should open in their correct position fully scaled. The total amount of exported dense cloud models is thirteen (six belonged to LD models, and seven were exported from the main model). The primary purpose of this method is to test to what extent the production of reliable information is possible, for multi-year site monitoring to be feasible.

After downloading the software, only two dense point clouds datasets from different dates can be compared at the same time (Cloud Compare, 2020). One of the two will always represent the main 3D model created in 2019 since the goal is to test every legacy dataset created in the years that preceded 2019. The span of years that legacy data covers for this research is 2015, 2016 and 2017. Besides standard cloud to cloud distance comparison (C2C) which this program is capable of doing, also, it can perform cloud to mesh (C2M) distance calculations if deemed necessary. The application can be considered user-friendly, and if instructions are to be followed as presented in subsequent case studies, the deviation analysis should be created without any complications.

The first thing to do in *Cloud Compare* is to upload two .e57 files representing the same area of the wreck from two different timelines (i.e. 2017 and 2019). They should be seen in the DB Tree pane (left) and ready to use. Two scan files are to be checked (activated) and marked, after which in the main toolbar an option to perform '**cloud to cloud distance comparison**' should be selected (**Fig.26**). Before the analysis can continue, a decision has to be made as to which of the two will serve as a reference point for producing the final analysis (**Fig.27**). Asking the right question, such as to find out what can no longer be found on the site (what has changed from the year of 2017 to 2019?) will create the analysis that represents what had happened to the wreck in between that interval. This is so because it uses older (legacy data) point cloud as a reference for tracking the degradation that happened over time. Also, when using an older point cloud dataset as a reference point, *Cloud Compare* is capable of monitoring both rigid body movement and shape deformations. If the question is asked vice versa, and if the main model from 2019 is used as a reference point, the software will be able to compute the older point cloud data and to track the shape deformations between the two, only this time graphical representation will appear slightly different. Although this might seem confusing, depending on the aims and objectives, the final analysis will show two different results.

As already mentioned, a legacy data point cloud was used as a reference point in the majority of the cases (in the situations where LD models were not used as a reference point, an explanation will be given why). The next thing was to set the distance computation, where, in general parameters, only one box should be checked (multi-threaded) before clicking the compute button (**Fig.28**). A compared object should be created and ready to be tailored. In the properties panel, the display appearance can be adjusted for providing appropriate information, such as the colour scale, display parameters, cloud point size, etc. Here, the colour scale should be turned on, after which all necessary information should be displayed about the computed deviation analysis. The final results are fully scaled and in proper position with their differences presented graphically in colours alongside their numerical values (**Fig.29**).

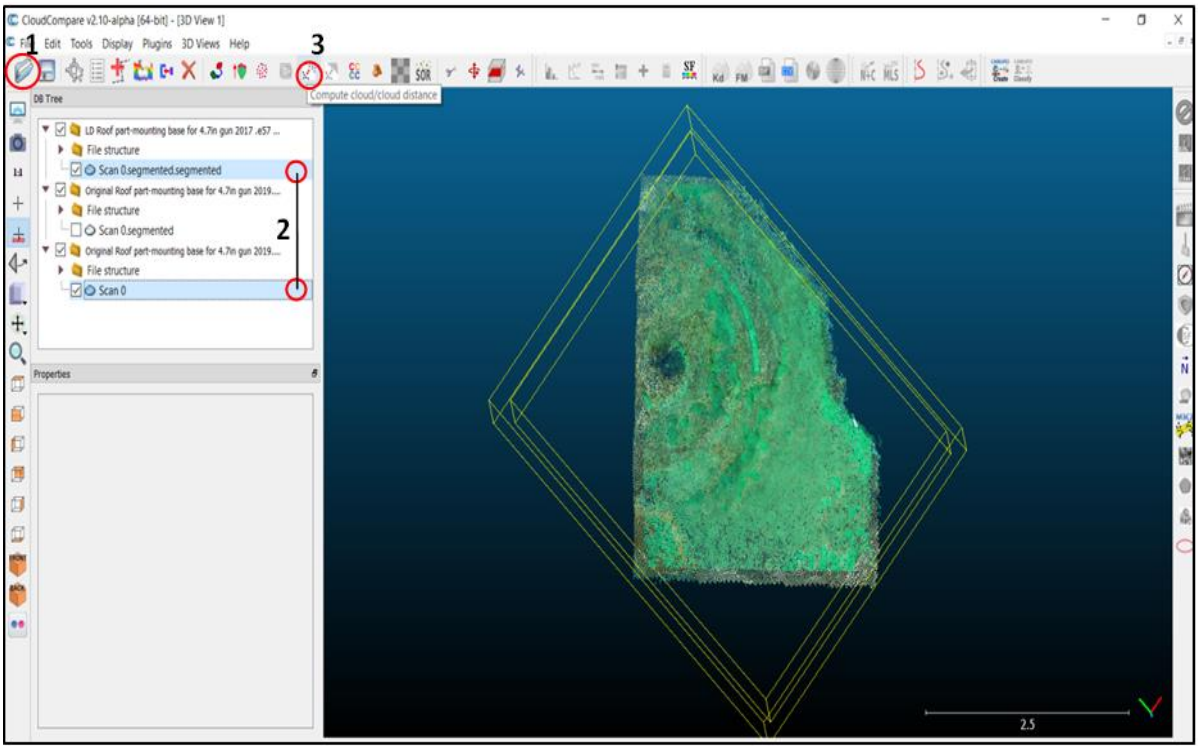
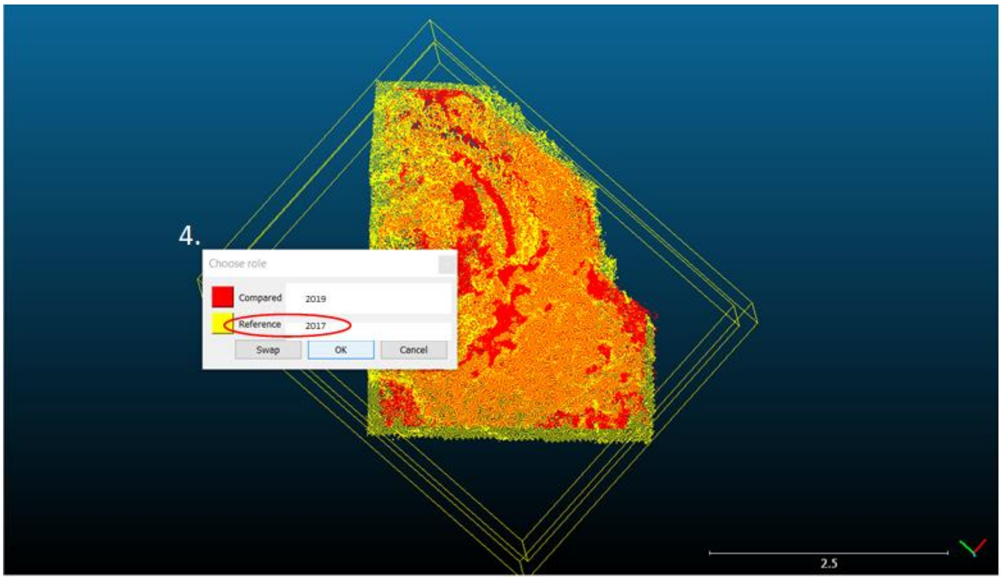


Figure 26. Importing and starting C2C distance analysis (step 1 to 3). Mounting base for 4.7in gun (Source: Dj.Cvetkovic)

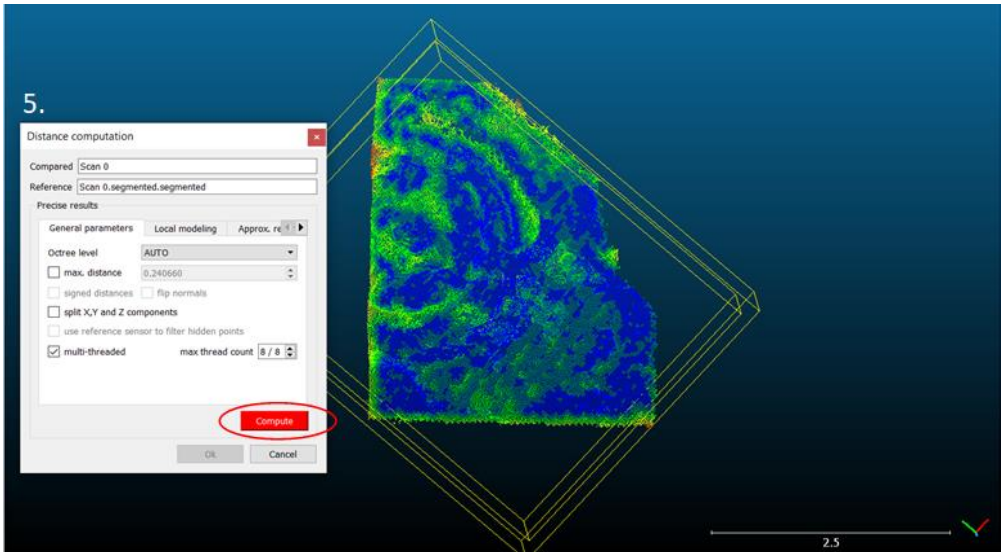

4.

Choose role

Compared 2019

Reference 2017

Figure 27. Step 4 - Choosing which point cloud will serve as a reference point. Yellow (LD 2017), Red (Main Model 2019) (Source: Dj.Cvetkovic)


5.

Distance computation

Compared: Scan 0

Reference: Scan 0.segmented.segmented

Precise results

General parameters | Local modeling | Approx. re

Octree level: AUTO

☐ max. distance 0.240660

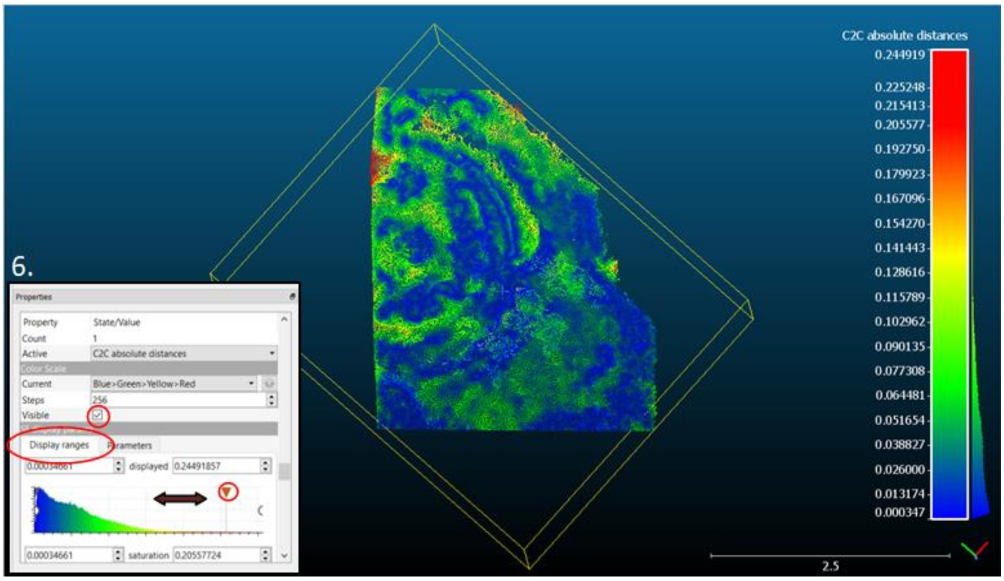
☐ signed distances ☐ flip normals

☐ split X,Y and Z components

☐ use reference sensor to filter hidden points

☑ multi-threaded max thread count 8 / 8

Figure 28. Step 5 – When distance computation finishes the Deviation analysis is completed (Source: Dj.Cvetkovic)


6.

Properties

Property	State/Value
Count	1
Active	C2C absolute distances
Color Scale	
Current	Blue>Green>Yellow>Red
Steps	256
Visible	☑

Display ranges | Parameters

0.00034661 displayed 0.24491857

0.00034661 saturation 0.20557724

Figure 29. Step 6 – Adjusting colour scale and display parameters. Results are presented graphically with absolute distances (Source: Dj.Cvetkovic)

5.3 Results and Interpretation

Six deviation analysis have been successfully created, and the author will here discuss what they represent and how can they provide new insight into the current condition of the wreck-site (Appendix A). Being able to dive on the site, learn about the ship through literary sources and to apply a comprehensive methodology to eventually test the probability of creating a monitoring scheme based on empirical evidence, forms a solid basis for constructing an authentic interpretation.

5.3.1 The Wreck-Site of *HMS Maori*

Firstly, before any comparison and interpretation can be attempted, it is essential to give an overview of the site and how it looks today, as well as, to point out the sections of the wreck that will be possible to analyse (**Fig.30**). The difference between the main model and legacy data models can clearly be seen since neither of the LD video footage had gone through colour correction procedures (apparent distinction between two different datasets). What can be noticed in figure 30, is the concentration of the successfully created LD 3D models on the starboard side with two 3D models at the forecastle deck and one at the mounting gun base (‘B’ position). All six of them are covering mainly flat surfaces because the circumstances in which these models (based on videos) were created left no possibility for any other outcome.

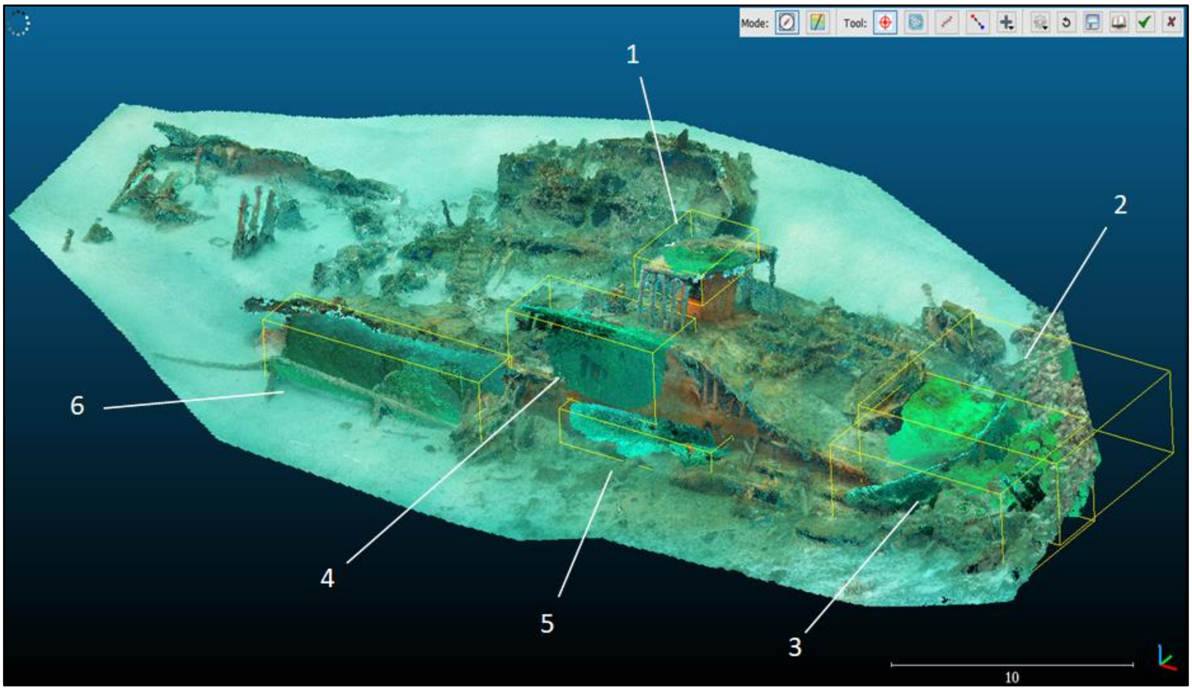


Figure 30. The main model alongside six LD models (inside yellow boxes) was uploaded into *Cloud Compare*, and since they were all properly geo-referenced their position was automatically aligned (Source: Dj.Cvetkovic)

Example 1: Mounting Gun Base (2017/ 2019)

The only successfully created model that belonged to the upper structure (bridge) area of the wreck was the mounting gun base, position 'B'. This is also the last free-standing section of the wreck that can be easily recognised. Nevertheless, since it has been heavily worn out over time, her finite appearance made her 3D recording hard to capture, especially when using LD for a source (full of holes, thin poles, bad lighting). It was possible to recreate a slightly more than half of the top view, which would eventually be compared and analysed (**Fig.31**).

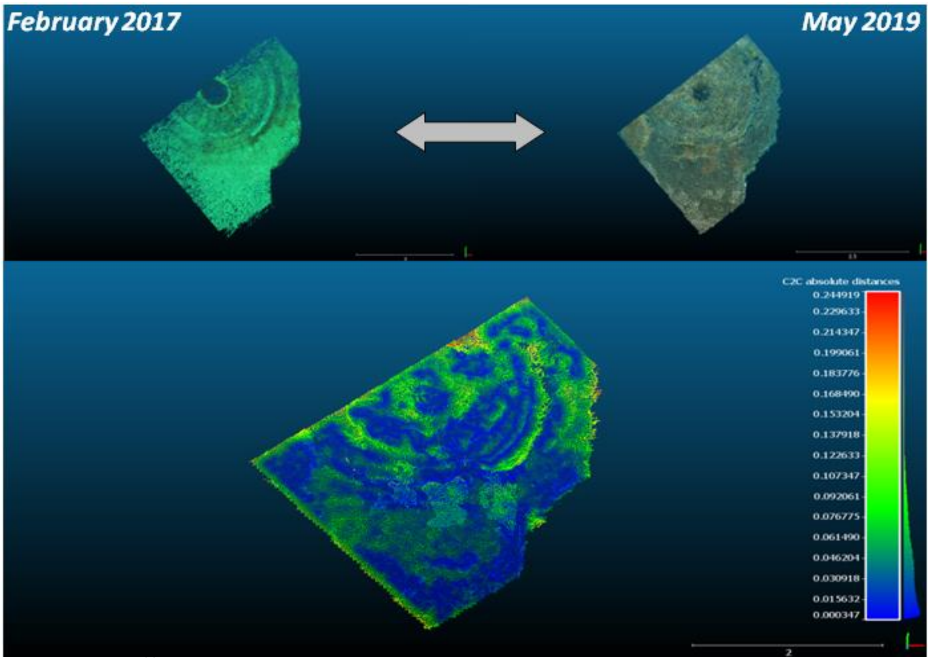


Figure 31. Differences between the two datasets displayed graphically in colours and in numbers (Source: Dj.Cvetkovic)

The colours represent the intensity of change, followed by an absolute number. As shown in Table 4, total error per one meter for this LD 3D model was 4cm, which means that if the model stretches 2.5 m in length, a potential error may increases up to 10 cm in total. Furthermore, if the absolute distance (deformation) that *Cloud Compare* calculated was 24 cm, the only thing that author had to do in this situation was to subtract 10cm out of 24cm. By doing so, final result can be calculated, and that result would be 14cm of deformation. Blue marks the minimal change that happened, while green, yellow and red intensify as the deformation gradually increases, which means that shape deformation happened to some degree (**Fig.32**). Although this might not be the best possible example, it forms an idea of how this method can be used in the situations where small margin for error exist. Visual inspection also needs to be taken into consideration, and what can be seen in this example is that the marine growth is significantly more abundant in the LD model, while signs of corrosion are more evident in the model from 2019.

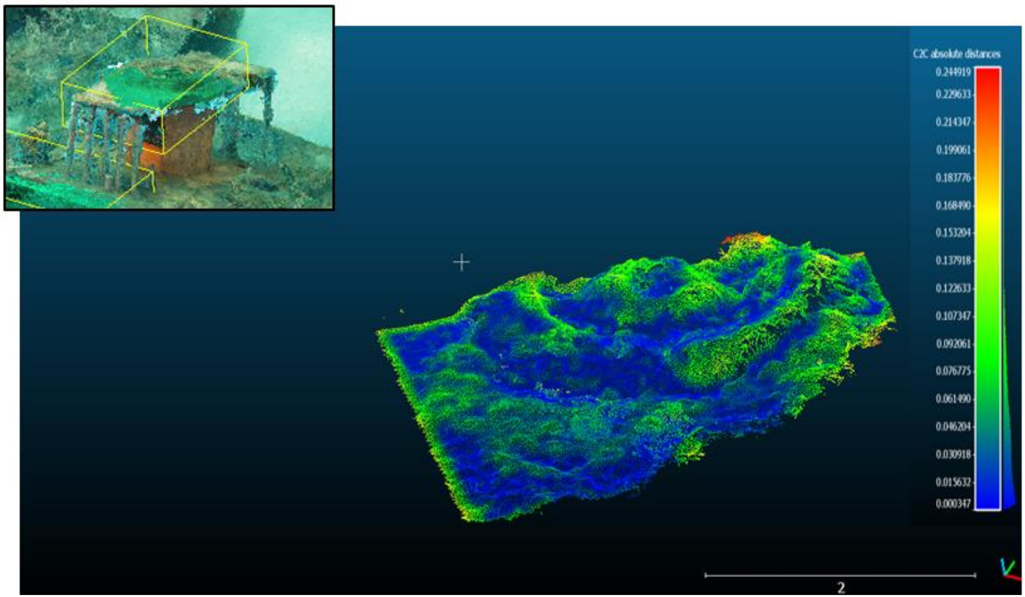


Figure 32. Signs of Out of Plane shape deformation (Source: Dj.Cvetkovic)

Example 2: Forecastle Deck/ Rocky slope (2016/ 2019)

A LD 3D model (2016) that covers the largest surface area created for this research is located in the forward part (the forecastle deck), leaning onto the rocky slope (**Fig.33**). It includes the anchor windlass, breakwater, and reaches the place where mounting gun base position 'A' starts. The total error of the LD model was around 1 mm, which creates almost a perfect basis for further analysis. The fact that this location can be considered as one of the most active ones on the entire wreck-site (wave action, strong currents, rocky slope), provides the possibility for collecting some of the most substantial indications on the occurrence of site formation processes on this site.

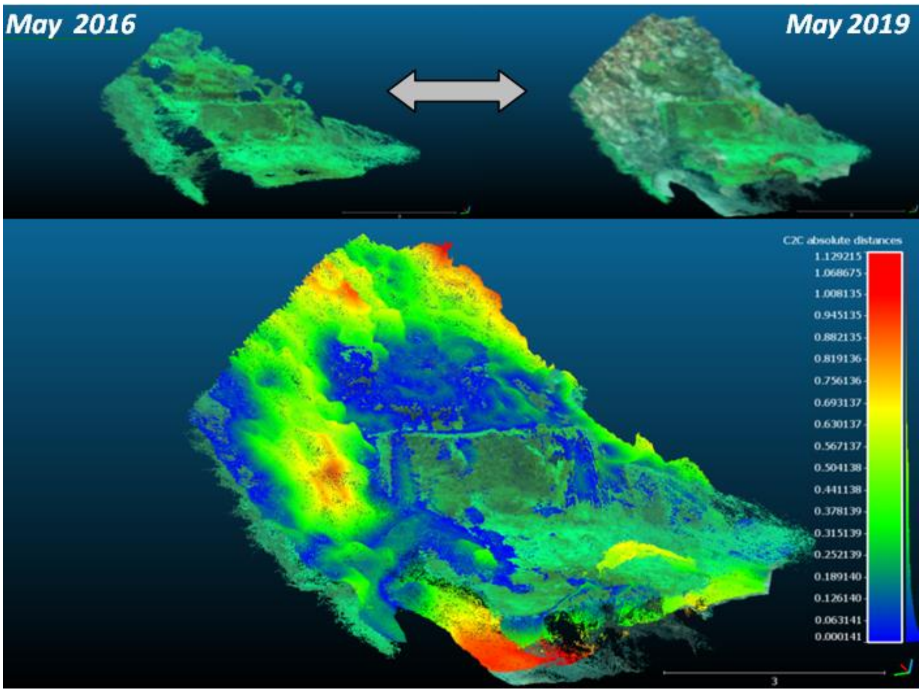


Figure 33. An angle from which it can be seen how the rocky slope is covering the forecastle deck (green and red) (Source: Dj.Cvetkovic)

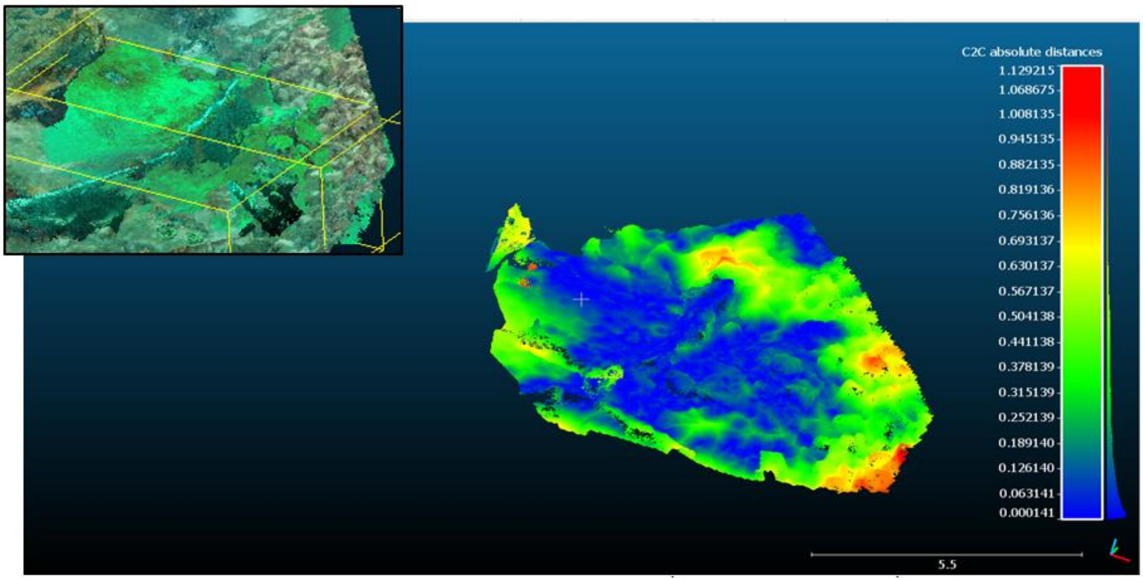


Figure 34. Out of plane shape deformation - Forecastle deck (Source: Dj.Cvetkovic)

The first thing worth mentioning is that the absolute distance is measured at 1.12 m. Blue marks where some minor changes can be noticed on the wreck (from 0 to 10 cm), while the green, yellow and red colour covers the surrounding area (from 10 cm to 112 cm) (**Fig.34**). The wreck itself can be seen to be positioned lower than how it was in 2016, and some of the materials had been stripped off (the surface of the breakwater). Also, one side of the mounting gun base ('A') can be seen only in the 3D model made in 2019, although one may easily miss this detail. This indicates that it broke off at some point and is now slightly above the floor surface of the deck. One of the most prominent things that can be undoubtedly demonstrated is the pilling of rocks on top of the wreck. In the LD model, the anchor windlass is visible, as well as is the small patch of sand marking the area between the wreck and the rocks. In the 2019 model, a sandy patch of the seabed is no longer present, while only the top part of the anchor windlass appears to be emerging from the rock pile. The deviation analysis clearly shows signs that *HMS Maori* had suffered shape deformation. It simultaneously underwent some rigid body movement probably caused by the rocks that are crumbling from the slope onto the site. The author has concluded that significant changes happened to the forepart of the wreck for the time interval demonstrated in the deviation analysis (2016/19). A presumption can be made on how this all came to be, on the basis of the evidence showed in figure 33 and 34. It can be safely stated that natural elements played a significant role that changed the *HMS Maori* into what can be seen today. Strong currents and turbulent water in the area around the site are strong, and the shape of the rocky slope tends to direct all that power towards the fragile structure of the *HMS Maori*.

Example 3: Forecastle deck/ Starboard side (2016/ 2019)

A continuation of the previous example can be seen here. Recordings from February 2016 present an opportunity to analyse the frontal section in its entirety. This area covers the forecastle deck, including the starboard side where traces of impact from the harsh environmental conditions can also be noticed (i.e. collapsing of the deck, corrosion, metal debris on the seabed). Some of the more prominent characteristics in the LD model are the two mooring bollards and the structure ribs and beams of the starboard side. These features can no longer be seen in the 3D model from 2019, and that made finding common points difficult, thus hampering the process of geo-referencing the LD. Despite this, the task of geo-referencing can be considered successful as the total error was reduced to 4cm. As in the previously discussed example of the mounting gun base, the error will change with the size of the site. This means that it might impact the final results in small percentages. The absolute distance calculated that the differentiation between the two was 1.75 m. If not for the breakwater and its distinctive shape, the model would be hard to recognise and position properly (**Fig.35**). Blue represents a significant change up to 20 cm, while green and yellow reach 1m in length. Something drastic had happened, and these numbers are good indicators for making such a statement.

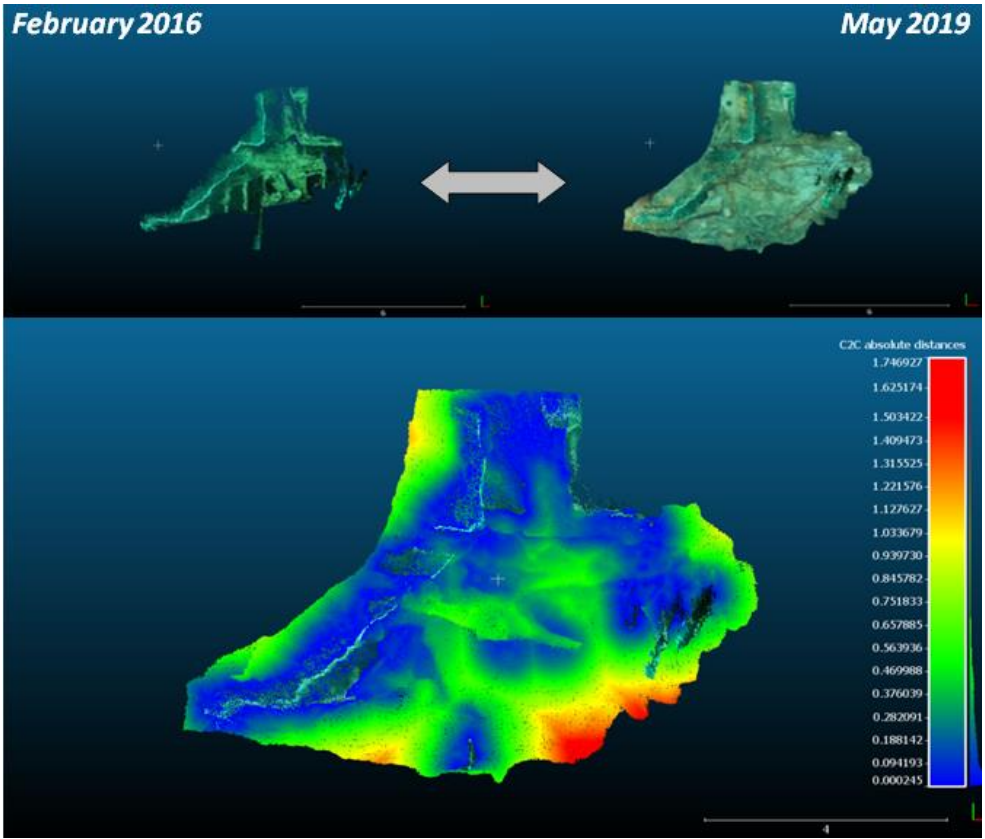


Figure 35. Presence of both In and Out of plane shape deformation, Forecastle deck - starboard side (Source:Dj.Cvetkovic)

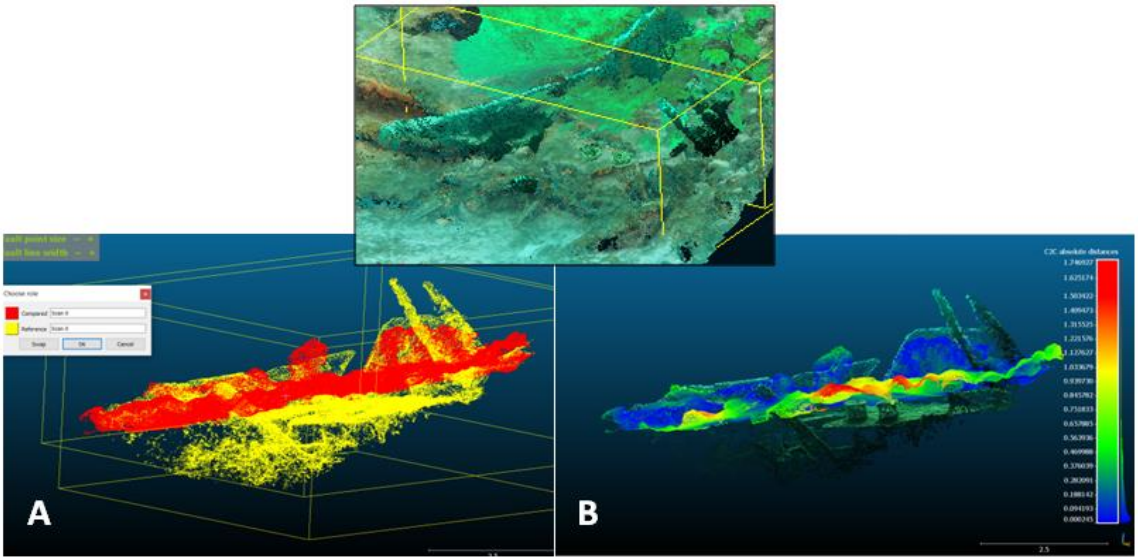


Figure 36. Demonstrating the change in different colours Red (2019) and Yellow (2016) (**A**), comparing LD and created deviation analysis (**B**); Clear signs that the forecastle deck did collapsed (Source: Dj.Cvetkovic)

When looked at from another angle, a definite argument can be made in favour of the theory that the upper structure collapsed at one point in the last three years (**Fig.36**). What was once a recognisable section of the wreck now lies in a broken pile of metal, mixed with rocks and sand. This can explain the breaking of the mounting gun base shown in the previous example. Also, a similar deformation of the breakwater can be measured, which points to an error of 4cm but which has no significant influence on the final results. Although not in their original place, beams, ribs and a pair of mooring bollards can be seen in the 3D model from 2019, albeit dispersed on the seabed. This can be interpreted as further evidence for the claim that environmental conditions are one of the most damaging factors documented at the wreck-site. The LD model used for the analysis was created out of a 12 seconds long video. The fact that information was 'extractable' demonstrates the potential of using such a methodology.

<u>Example 4. Gunwale/ Starboard side (2015)</u>

So far, each deviation analysis has proved extensive degradation of the wreck-site. Similar evidence can also be seen here, at a corner section of an upper hull area (gunwale). Right bellow the gunwale, a top row of portholes can be seen (starboard side). These portholes were used earlier for geo-referencing the model in *PhotoScan/Metashape*. Although the surface which this deviation analysis covers is not extensive, it still gives enough information for assessing the change that happened over time. Two deviation analysis of the upper hull section have been done and are presented, one that used the LD model from 2015 as a reference, and for the second one, the 3D model from 2019 served as the reference point (**Fig.37**). It was performed this way because when there is a section that is missing, a graphical representation is much more precise when newer models are being used as a reference. The total error of the LD model was 6mm, which makes these results highly accurate. The first analysis with LD as reference source had an absolute distance deformation of 36 cm. The second one used the main 3D model from 2019 as a reference point, with a total distance of 2.26 m. This demonstrates that when using the model from 2019, the deformation is more extensive, as it includes in its analysis the part that is missing today.

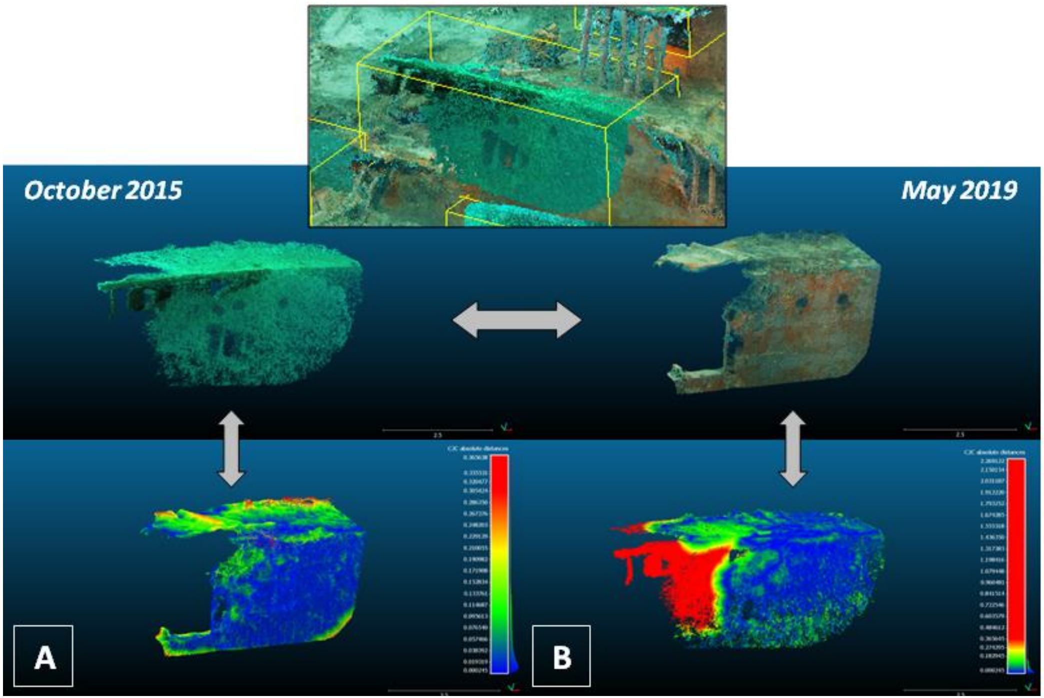


Figure 37. Both sources used as a reference for the analysis **A** and **B** (showing the difference in results); Clear evidence for Out of plane rigid body movement (**B**); (Source: Dj.Cvetkovic)

What both results have in common is that the deformation is evident, and to test if the numbers were matching in the deviation analysis where the 3D model from 2019 was used, the colour scale was reduced to 36cm (as in LD model), which then showed almost identical colour arrangement (degradation rate). Regarding the condition, this section of the ship had gone through severe deformation. Since objects can be measured directly in *Cloud Compare*, the missing part of the gunwale encompasses almost 6.5 m² of the surface. It broke off at its weakest point, and if LD model is carefully checked, portholes and one other large hole can be seen at the same spot of the breakage. With the help of deviation analysis, it may be possible to trace back some of the metal debris to this place (explained in more details in example 6). The section that broke off is positioned in the area which is unprotected, and the currents that are coming from the port side had most likely (alongside corrosion) gradually eroded this section of the upper structure and propelled the broken piece onto the starboard side. Learning more about the breaking does show which part of the ship is currently under the largest stress induced by the natural habitat.

Example 5. Hull/ Starboard side (2015)

Not far from the previously analysed section of the ship, right beneath it to be precise is the area which will be discussed in this example. It can be considered as the lower hull section (starboard side) where the wreck meets the sandy bottom. It is easily recognisable due to the long row of portholes stretching across (the second-row line from the top). Those portholes also served for geo-referencing the LD model, with the total error measured at 3 mm. Changes such as shape deformation can also be seen here. The deviation analysis confirms this with the absolute distance measured of 59 cm being the maximum deformation (**Fig.38**).

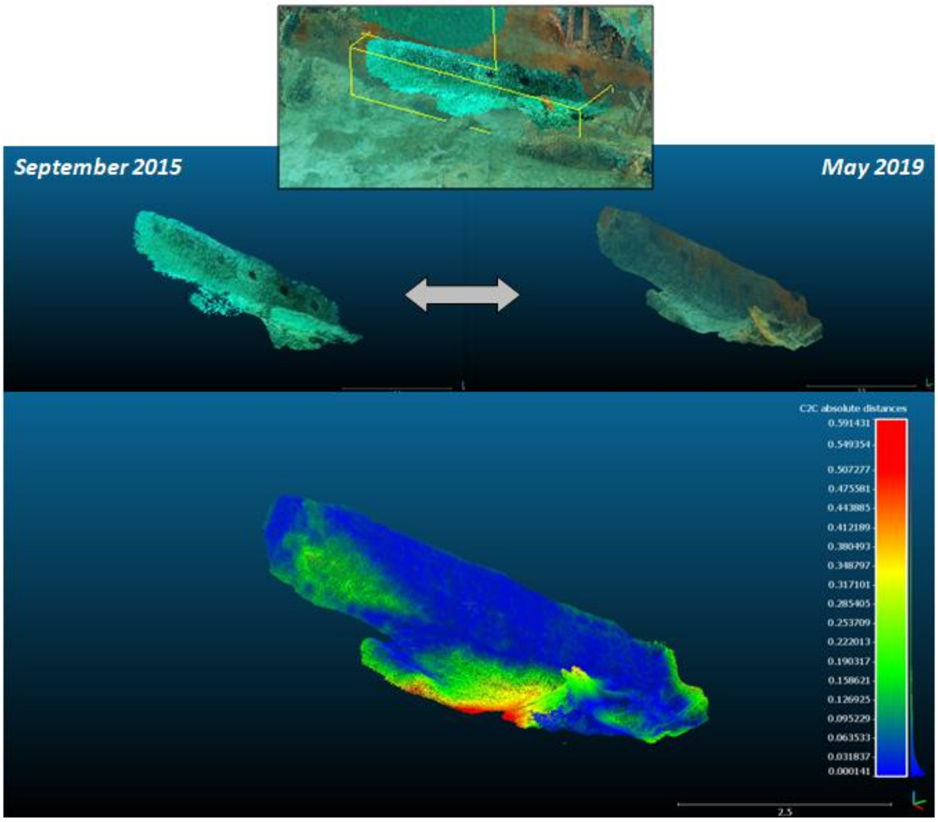


Figure 38. Starboard side, the hull is more exposed; Out of plane shape deformation (Source: Dj.Cvetkovc)

Deformation of between 0 and 10cm can be seen on the majority of the surface area (blue), while the rest is covered in green with small traces of yellow and red (12 to 59cm). A large segment of green and red indicates that the seabed has eroded and is now much lower. An observation can be made pointing to the fact that in 2019, the bow section was more exposed than in 2015. This exposure level might also be due to the collapse of the upper structure. In the aftermath of this collapse, the wreck was forced to lean more onto its port side, and by doing so, the starboard side became more exposed. Although it is hard to confirm with utmost certainty that this was the course of events that took place, one visible detail supports the idea of collapse. The metal debris is scattered across the seabed on the starboard side of the wreck. A small portion of this was successfully detected in the analysis. This confirms the extent of deformations which *HMS Maori* is continuously subjected to, and it also demonstrates that there are no areas which have not been somehow impacted by natural elements.

Example 6. Rear-Hull/ Starboard side (2015)

For the last deviation analysis, the area of interest will be the after section of what has remained of the ship's hull (**Fig.39**). This comparison is based on the oldest 3D model used in this study (August 2015). Portholes can also be seen, the second-row line from the gunwale, alongside the metal debris that originates from an unknown part of the ship. The first impression, after a thorough visual inspection, was that the LD model (2015) surface was covered entirely with green weed. On the other hand, the 2019 model clearly shows the surface of the hull that is entirely devoid of any traces of marine life. In addition to that, corrosion of the metal is more evident in the later model. These changes can be interpreted as reliable indicators for the rapid degradation that is on-going at the wreck-site.

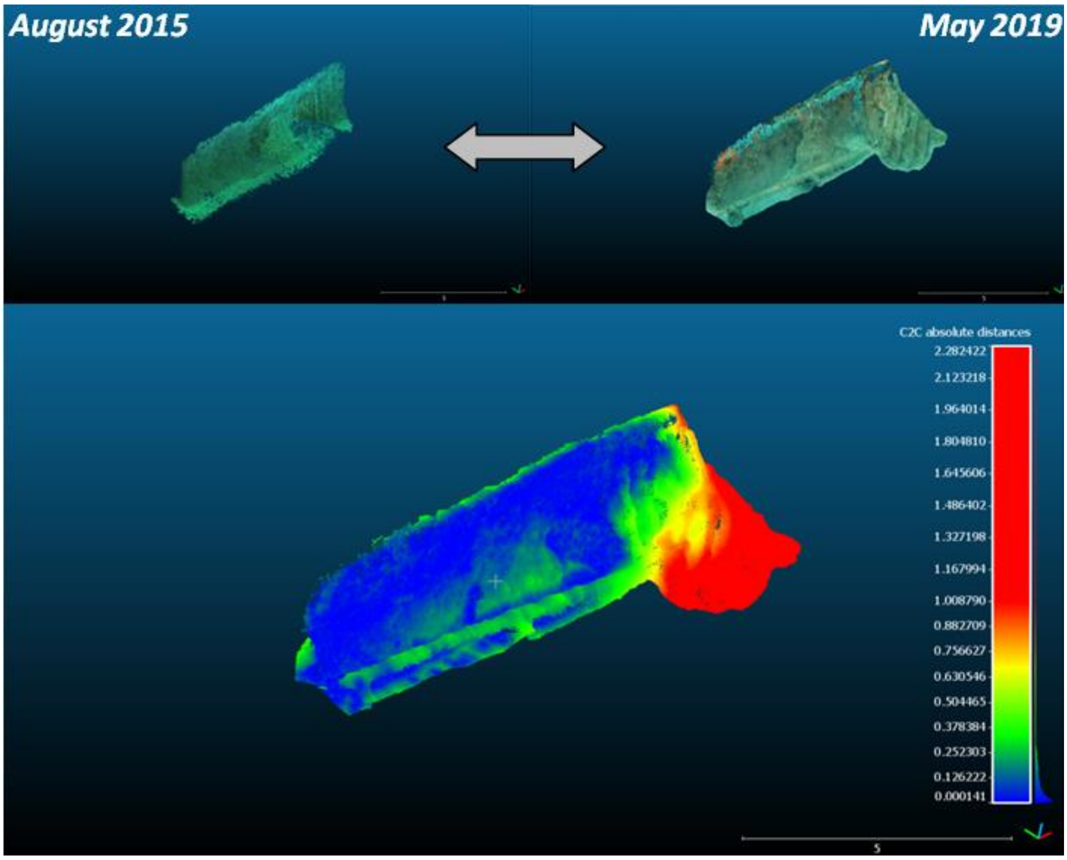


Figure 39. The red colour indicates the metal debris. For that reason, the colour scale was adjusted to represent this change more clearly (Source: Dj.Cvetkovic)

The level of degradation can be empirically tested only through deviation analysis. The total error of the LD model was 1.7cm, which allows for highly accurate analysis. The program calculated an absolute distance of 2.28m. This number is larger than it should probably be, but the reason behind such a high number was the presence of a large metal fragment that is now leaning on the side of the hull. Knowing that in the third example (gunwale) one section of the hull broke and fell onto the starboard side, it became possible to measure the metal fragment and compare this with the missing piece from the gunwale. After measuring the size of the broken off metal piece, the surface area turned out to be 6 m², which resembled the missing part that was measured at the gunwale (6.5 m²). This demonstrates that the deviation analysis software is capable of tracking potentially lost (fragmented) sections of the site, and giving them a more contextualised story of how they ended up there. A palette of options exists in *Cloud Compare* for the researcher to manipulate and extract a specific information needed for one to conduct its investigation (i.e. measure distances, cropping, export coordinates, etc.). The absolute distance analysis confirms that minor changes did happen in the more substantial part of the 3D model (0 to 15cm - blue), while green and yellow represent more extensive deformations between 20 and 80cm (**Fig.40**). As shown in other examples, a specific type of degradation also exists here. In addition to that, more prominent signs of corrosion were noticed. These should not be ignored.

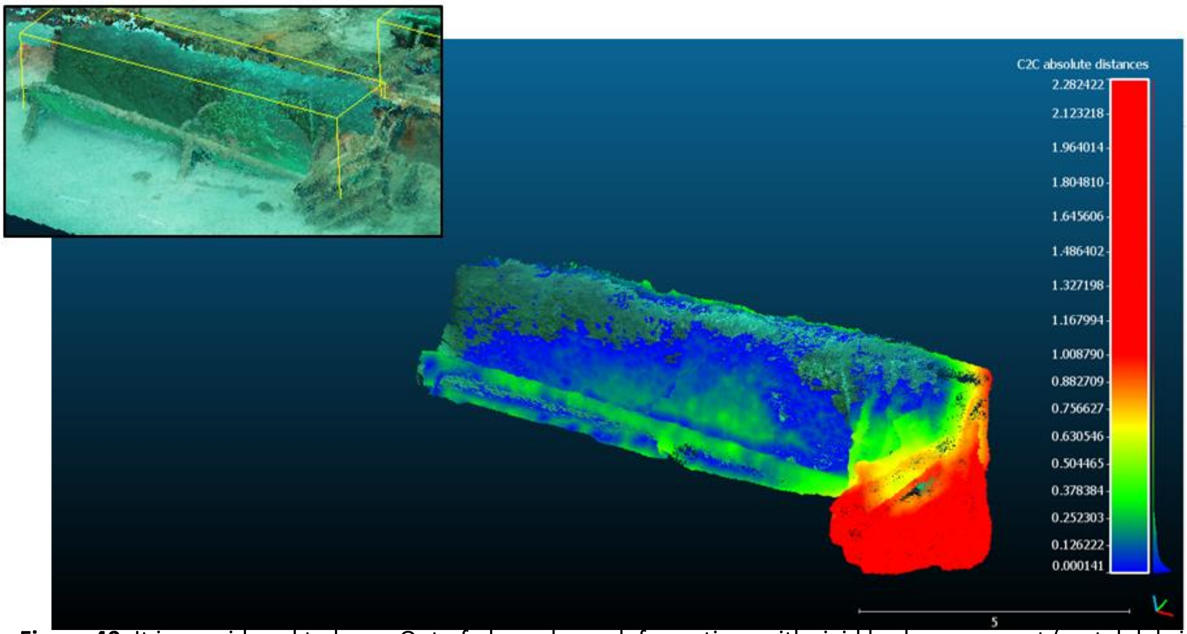


Figure 40. It is considered to be an Out of plane shape deformation, with rigid body movement (metal debris) (Source: Dj.Cvetkovic)

5.3.2 Closing Observations

Site formation processes are sometimes difficult to perceive. In situations where some traces and clues can be found about the site, the chances of scientifically extracting information can prove to be very difficult. Nevertheless, awareness of how the site could develop over time exists, and the goal of the analysis presented in this chapter was to explore the idea of measuring the level of changes *HMS Maori* underwent in the last four and a half years. Results of six deviation analysis created in the different parts of the same wreck-site produced good area coverage. This, in return, provided empirical evidence that could be used for forming the final interpretation, which will then be used for constructing a suitable management plan. The comparative study provided essential information about the site, and it allowed the author to build a more informative interpretation of the course of events that happened over time. This also confirmed that the methodology used for this research created a good platform for investigating and learning more about underwater site formation processes.

The wreck-site of *HMS Maori* has changed in the past few years, and this can be seen through the various types of deformation documented through the meticulous comparison presented. The deviation analysis is capable of providing only the absolute measurements, and tells nothing about the cause behind such drastic change. This is where the knowledge and the experience of the person that is interpreting these results play a key role. That being said, environmental conditions are believed to be the main factor behind continued degradation of the site. Some of the conditions such as human interference or water pollution do exist, but judging by the results produced through the deviation analysis, the high energy zone is what the author believes to be behind such a rapid rate of the site deterioration. Its position underwater (9 to 15m deep) and above (entrance to the harbour) forms an environment that can be considered neither safe nor stable. The detection of less marine life growth is another indicator that points to the high energy level of site corrosion. In almost every analysis hull plates or parts of the upper structure such as the gun bridge or the forecastle deck show severe signs of deterioration due to corrosion. This makes the ship structure more fragile and easier to brake. However, the presence of strong currents and wave action is what has altered the appearance of the wreck-site. This can be seen just by looking at the position of the wreck, where the port side cannot be detected due to sand deposition. On the other hand, the starboard side is more exposed. Due to its proximity alongside the slope, one may observe the forecastle deck where rocks from the slope slide downwards and fall onto the deck.

Closer to the bow, the upper structure collapsed slightly towards its starboard side, most likely during the heavy storms of February 2019 (Times of Malta, 2019). All of the metal debris has fallen on the same side, right next to the wreck. This can be indicative as to from which side the currents and the waves are creating the strongest pressure. There is no debris on the port side, but what can be found is a car that was washed into the sea during a heavy storm in 2016 (Divewise, 2020). An unknown metal construction can also be seen at the port side in the aft section of the wreck-site (**Fig.41**). Additional observation and visual inspection of the LD models that were not used for the final analysis can still be informative for the overall interpretation (Appendix B). For some models, the impossibility of finishing processing method made them unusable. Other LD models (i.e. from 2014, 2015, etc.), that reached the texture build phase represented the section of the wreck which no longer existed in 2019. Due to this, geo-referencing through common points was not an option. For the final interpretation of the site, quantitative data provided the core of the research.

Given that, a comprehensive approach is desirable for constructing an appropriate management plan, any available information should be taken into account. As presented in this chapter, analysis shows that monitoring is possible when using legacy data models combined with a fully scaled 1:1 photogrammetric 3D model. This confirmation opens up the possibility to a better understanding of site degradation processes through the use of past records in an attempt to predict possible future events.

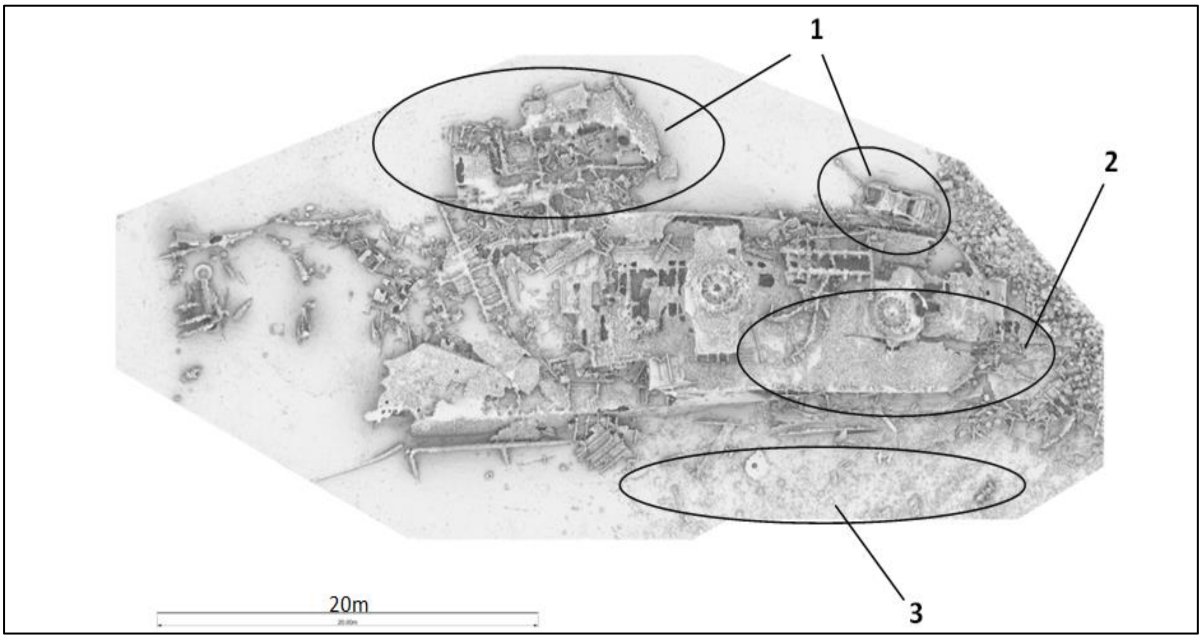


Figure 41. Site plan of the wreck site (Source: K.Yamafune); Important factors providing information about the site formation processes: Port side of the wreck is clean of debris, and has an unknown metal construction and a car leaning to one side (**1**), a large portion of the forecastle deck collapsed toward the starboard side (**2**), a significant amount of debris is lying on top of the sediment on the starboard side (**3**). The rocky slope located at the bow is in an elbow shape (corner) which most likely impacts the activity of the water.

CHAPTER VI:

General Discussion

Shipwreck sites present valuable records of human history, telling grandiose stories and achievements of ordinary men, which have always captivated the public's curiosity. For these and many other reasons, an ambition to find new ways to record and preserve historically significant sites for the generations to come is undoubtedly justified. Archaeological communities worldwide try to focus their attention on developing new methods for proper conservation and management of underwater cultural heritage sites (Manders et al., 2008; Atkins et al., 2019). World War shipwrecks are highly complex sites and diverse in their size, construction and location of sinking, which implies that every submarine, battleship or aircraft goes through different site formation processes. Since there are a vast number of such wreck-sites, it is physically impossible to record and document each of them individually and systematically in a manner as has been done so far. The next best solution is to implement citizen science, or as in this case, legacy data (video footage). This data allowed testing the idea of monitoring a modern shipwreck site and understanding better the changes the wreck-site of *HMS Maori* had gone through.

6.1 Final Assessment

One of the initial goals was through the use of desk-based research, to make sure that the importance was given to the role which *HMS Maori* had in the past and to describe her resting place today in one of the main Maltese harbours. Besides covering factual information related to *Maori*, the intention was to emphasise its historical and cultural significance. Potential research value also existed, and this was crucial for creating a solid foundation for everything that followed afterwards. The wrecking process is the first step in site formation evolution and is vital. Three years after sinking, she was scuttled in 1945 and moved to the place where different environmental conditions were present. It is important to mention this because, besides the change of the environment, the ship broke in two. This abrupt change affected the ship's integrity (which was already severely compromised when sunk) and its degradation, restarting the process of site formation. In its new location, at the entrance to the Marsamxmett Harbour, *Maori* found herself in a habitat diametrically opposite to the one in Valletta Harbor. Alongside the rocky slope she stood for 78 years and became an artificial reef abundant with marine life but at the same time a popular site for scuba diving. Her relatively shallow position underwater (9-15m) made the wreck a favourite with recreational divers. Still, that depth also represented a potential danger for the safety of the site. However, given the possibility of rapid changes brought about by a highly active environment, this situation also provided an opportunity. For these reasons, *HMS Maori* was a perfect candidate to test the methodology presented in this dissertation.

The use of 3D photogrammetry in underwater archaeology had evolved in recent times (McCarthy et al., 2019, p.3). With rapid technological development in the past few years, the process of documenting sites located underwater is now more pragmatic and more efficient. Indeed, one of the objectives of this dissertation was to test how useful and credible photogrammetry can be in preserving large-scale UCH sites. Regarding this, the wreck-site was successfully documented, a 3D model processed, scaled and geo-referenced. When combined with everything previously mentioned such as the desk-based research, a broader understanding of the history of the site was formed. The methodology of collecting and processing used for this research followed the footsteps developed by experienced practitioners, with some minor but essential adjustments done by the author. After creating a 1:1 scaled 3D representation of the site, and learning more about its current state, the next task was to test the usability and dependability of legacy data.

It was confirmed that the main 3D model of the shipwreck could be used as a reference for the smaller 3D models created out of old video footage (legacy data). But before the geo-referencing of legacy data was done, processing and collecting of LD had to be performed first. A total of six LD 3D models were created and subsequently used for the analysis. Processing amateur video footages demanded more image editing since the data had to be adjusted for it to be used in *PhotoScan/Metashape*. The process of geo-referencing proved possible, with the best evidence for such a claim being the overall low error demonstrated in every LD model. Having a highly accurate data made the analysis and results acquired through the comparative study more reliable.

As seen in the previous chapter (V), deviation analysis was capable of producing quantitative data. These results demonstrated the level of change that happened, but it also proved to be a reliable source of information which helped with identifying the possible cause behind such significant degradation of the site. By examining the LD 3D models which represented how parts of the site looked in 2015, 2016, 2017, the author was able to recognise certain features that can no longer be found in 2019 or had undergone some severe deformation. Deviations represented in the analysis could result from movement of the ship structure due to progressive failure, movement of the wreck as a result of currents, waves, terrain collapse, marine growth, dumping or removal of material. As it was said previously, the knowledge and experience of the person dealing with these results plays an important role when it comes to interpreting the origin of any deformation. In addition to that, any potential image processing error was excluded, due to the high accuracy level of created 3D models. Without doubt, the comparative study displayed everything that was needed for constructing a realistic site formation interpretation of the modern shipwreck site of *HMS Maori*.

Consequently, the most integral part was to show how this newly gained information can be used for creating an appropriate management plan for preserving and protecting the wreck-site. The aforementioned plan presents a monitoring scheme which confirms how unstable the wreck-site is and gives an insight into all of the disruptive factors that negatively influence its overall condition. The next step would be to use that knowledge and to try to predict the course of future events and the ways of how further degradation can be slowed down. Knowing the extent of the severe change that happened in the past four years, similar, or worse outcome can be expected to occur in the future. Eventually, the author had come to several possible solutions in an attempt to prevent any further deterioration of the site.

6.2 Future Recommendations

After learning how environmental conditions present the most influential deterioration factor recorded at the wreck site of *HMS Maori*, ideas for solving such a problem were sought from different case studies worldwide, which were dealing with similar issues (Oxley, 1998; MacLeod et al., 2011; Jeffery, 2017). Malta is well known as a popular destination for wreck diving which brings financial rewards from tourism. Also, because of the importance of the site for the diving community, options such as reburial or any other method of covering the wreck would be un-practical and most likely undesired by the Maltese authorities. Potentially, the site’s authenticity, historical value, as well as the cultural value could be lost. Since the objective should be the long-term conservation of the wreck, some of the additional analysis can be performed to learn more about the level of corrosion. Such analysis could potentially be used for building an adequate management plan for site stabilization while trying not to lose the significance it has in today’s society.

The recommendations for monitoring and preserving the site of HMS Maori:

- To perform an On-site Conservation Survey, so more details about the structural integrity of the wreck and the dynamics of the natural habitat could be collected
- Public engagement (citizen science) of monitoring the site for a more extended period
- Actions should be taken, such as cleaning the site from modern trash and most importantly finding the best solution for reducing the impact of currents, rocky slope erosion and sediment deposition.

The On-site Conservation Survey

The on-site conservation survey should be performed as soon as possible. Through this survey, the corrosion rate can be empirically calculated, as well as, the amount of the concretions found on the wreck, which would in return provide precise information about the *Maori's* structural integrity (Richards and McKinnon, 2009, p.66; MacLeod, 2013). Besides tracking the corrosion potential, the presence of oxygen in the water column that surrounds the wreck can be measured, as well as, salinity, turbidity and others (MacLeod, 1992, p.47). These results (after obtaining them), should be able to confirm or deny the claim of high energy zone environment (MacLeod et al., 2004). This survey can also be part of a monitoring scheme, where after taking specific actions to protect the wreck, their efficiency can be observed over time with repetition of the same survey method. It all comes down to preserving the site in situ, and to find an ideal solution to create a calm and stable environment (to reach equilibrium) (Yonge, 2009, p.36). The best solution might be to install sacrificial anodes on the wreck site (cathodic protection), but this will depend on the results created through the on-site conservation survey (MacLeod, 1992, p.46; MacLeod and Harvey, 2014).

Citizen Science Monitoring

The limited capacity of experts in the field, and the shortage of the financial resources to record (document), protect and manage UCH sites such as *HMS Maori*, creates a need for forming a new type of public engagement, also called citizen science (Viduka, 2017, p.77). Dive clubs should be informed about the danger that is threatening not just in the case of *Maori*, but also to the rest of the wrecks found in a similar situation. The method would be for dive clubs and their instructors or a specific volunteer association to record the site with a regular underwater camera such as GoPro, in the way previously explained by a maritime archaeologist (Raoult et al., 2016). This way, a platform could be created where such video footage could be shared and later used for monitoring the wreck. As long as there is one 3D model that was geo-referenced, as shown in this dissertation, every subsequent legacy data model should be able to align after which the deviation analysis can be performed. Divers who are operating the camera and recording the site should be informed on how to execute a proper dive path for covering a larger surface area or even a whole site if possible. These surveys could be done periodically (i.e. once a year). All this would be sufficient to monitor and to analyse the site in the same manner, as shown in Chapter V (Maarleveld et al., 2013, p.214).

Possible Interventions

Probably the most important decision is to find a way of somehow reducing the on-going rapid deterioration of the site and a better understanding of the water turbulence which is causing extensive sand deposition, rock erosion and construction distortion. That being said, the marine life should not be affected, and the role that *Maori* has as an artificial reef needs to be preserved. Every option for establishing a calmer natural environment should be explored and discussed in details so as to reach the most appropriate solution. By enhancing the protection through community awareness, dive-clubs could be appointed to take care of the wreck-site. The clubs would work on cleaning the modern waste brought by the currents and waves. Moreover, a clear set of rules for tourists should be established when diving on a historically significant wreck-site (Maarleveld et al., 2013, p.53).

Besides attempting to undertake conservation of the site through the use of a sacrificial anode (to slow down the corrosion rate), the next thing could be to find out if there is a way of reducing the dynamic activity of the water in its environment. More attention should be given to understanding the impact that slope has on the way currents are generated across the site. This knowledge will eventually provide archaeologists with more substantial pieces of evidence about what should or should not be done at the site, in the near future. Doing nothing is also an option, but awareness should exist about the probable outcome for the wreck if such action is taken. In the end, every decision should be made whilst consciously following the rules of local heritage authorities.

6.3 Dissemination and Promotion

HMS Maori should be actively managed over the years to come, because if not, the danger of losing the site (along with its archaeo-historical significance), as well as, its current role as a popular dive site may happen. Besides *Maori*, there are probably more wrecks on the seabed around the Maltese shorelines in a similar situation, and the monitoring of these sites would be highly preferable. A good example for the proposed initiative is a platform built by the Maltese government, where as a part of Heritage Malta an Underwater Cultural Heritage Unit (UCHU) was formed, with a desire to manage, protect and promote UCH sites (Heritage Malta, 2020). Nevertheless, this dissertation focuses on the *HMS Maori*, and the results demonstrated here can also serve for dissemination to the public in various forms. 3D models can be used for creating virtual museums or tour animations while sharing them online is not new and has become a standard practice done by archaeologists. It can be done through a platform such as Sketchfab, where models can be uploaded with detailed explanations of detectable features. Promoting UCH through online platforms can be one of the alternative approaches to presenting and bringing maritime cultural heritage to the audience. It could be seen as cost-effective since diving is not necessary for one to fully experience the uniqueness of a submerged site (Maarleveld et al., 2013, p.54; Cohn and Dennis, 2014, p.1055). One additional advantage that can be used possibly in the future by dive clubs is the option to have 3D models of the wreck-sites used for preparing recreational divers for what they are about to see. This can be good visual assistance and more informative approach in an attempt to represent the connection between the local history and the submerged shipwreck sites.

The research presented here should be available to the rest of the scientific community since the way how this dissertation was written, had for a goal to make every section of the work easily accessible and understandable by other scholars (as a guideline). Not only that but also, anyone who is interested in testing different ideas of monitoring the UCH with the use of photogrammetry will be able to use this research as a reference for their personal aspirations. A field of maritime archaeology and especially photogrammetry is continuously evolving, and every scientific paper that gets published is in one way an upgraded version of research done by scholars in previous years. For this reason, the author believes that this type of monitoring of the modern shipwreck sites with the use of legacy data makes a worthy contribution in the global race toward the protection of the underwater cultural heritage.

CHAPTER VII:

Conclusion

HMS Maori, as a modern shipwreck site, gave a number of possibilities for creating a comprehensive research study. The background of the wreck-site has been successfully documented first, through detailed desk-based research. Therefore, its historical role as one of the active participants of the Second World War and its current cultural/economic significance of the vessel as a popular dive site argued the case for potential future preservation. The management plan depended on the methodology and its use in creating an adequate monitoring scheme.

With the help of 3D photogrammetry, recording and monitoring of underwater archaeological sites have never been more practical. Conducting a non-intrusive survey can be cost-effective, and time-efficient (as presented in this dissertation) and demonstrates the rapid technological advancement currently underway in the world of underwater archaeology.

Archaeologists will probably explore the potential use of legacy data in the years to come. LD has proven to be a viable source for archaeological research when trying to use data from previous studies (i.e. photo documentation and videos) for creating 3D models (1:1 scale) or producing photomosaics (Van Damme, 2015; Yamafune, 2016; Green, 2019). That being said, *HMS Maori* has never been systematically documented or researched before. Thus the only available source of LD was videos posted online by the general public. With this approach (using amateur video footage), the chances for expanding the scope of research increased significantly. Also, *PhotoScan/Metashape* has proven to be more than capable of processing image sequences derived from video footage captured without photogrammetry in mind.

A proper monitoring scheme was developed with the help of the deviation analysis software. It presents one of the first attempts to actively track the site formation process based on empirical evidence collected from a standard photogrammetric survey and LD. The comparative study demonstrated the current state of the site, as well as, the extensive change *HMS Maori* has gone through. Thus, the final assessment and interpretation of the wreck-site have provided the right direction for constructing an appropriate management plan that could potentially slow down the rapid change recorded at the site, and monitor further deterioration in the years to come.

The biggest advantage and disadvantage (limitation) of the methodology represented in this dissertation lie in legacy data itself. A large amount of data exists online, but at the same time, the quality of the data is poor. This leaves little room for manoeuvre, and can easily determine how plausible it is to conduct the research entirely. Therefore, three factors are crucial for the results to be made scientifically relevant, the amount of data, quality of the data, and the experience of the person who conducts the research. An additional difficulty was the application of the software that produces deviation analysis (*Cloud Compare*). Since it has never been used in underwater surroundings, many aspects of this programme are left unexplored. This research uncovered some of them, but the author believes that there are many more left to be discovered. Everything aforementioned demonstrates how technically demanding it was to combine different methodologies and approaches. Nevertheless, the purpose was to bridge the gap which existed and to pave the way for any future researcher interested for monitoring of underwater archaeological sites.

To conclude, the results presented in this dissertation are the product of a broader approach, which try to encompass the past, present and future of the wreck-site *HMS Maori*. Research had to be conducted in such a way because the concept of monitoring through LD is actually monitoring of the site in reverse. By understanding the site formation processes that happened over time, a chance for predicting future events increased.

Rediscovering new ways of protecting underwater cultural heritage is probably a constant inspiration for researchers working as maritime archaeologists worldwide. As one of the most affordable and reliable methods of monitoring UCH, the author is assuming that in the following years, a considerable number of case studies will be published on this topic. This dissertation hopefully presents a small but significant contribution to the vast research discipline of maritime archaeology.

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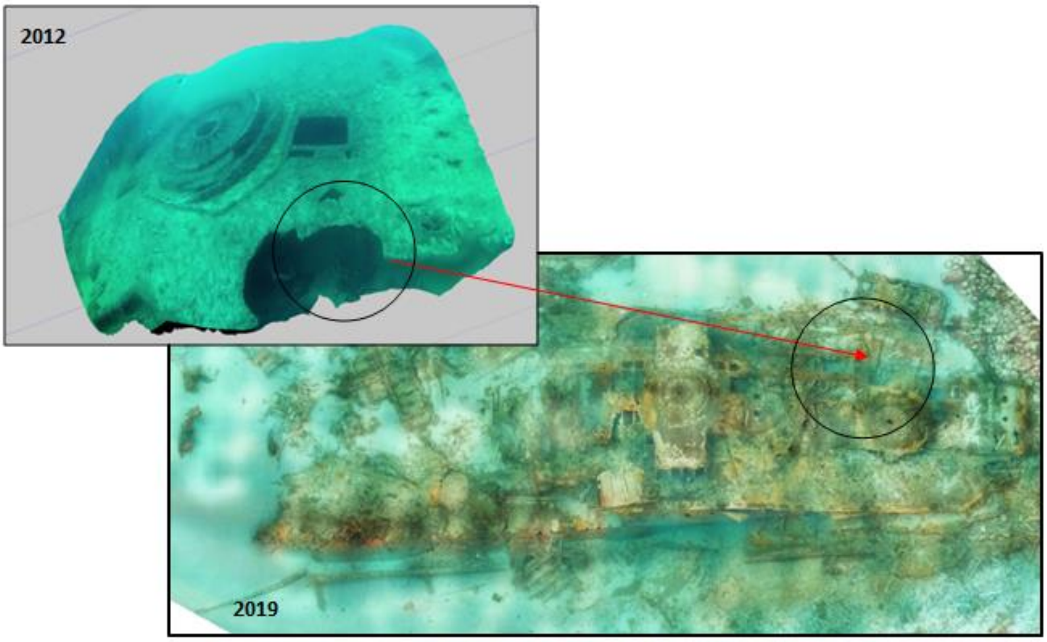
Appendix A – *YouTube* Sources

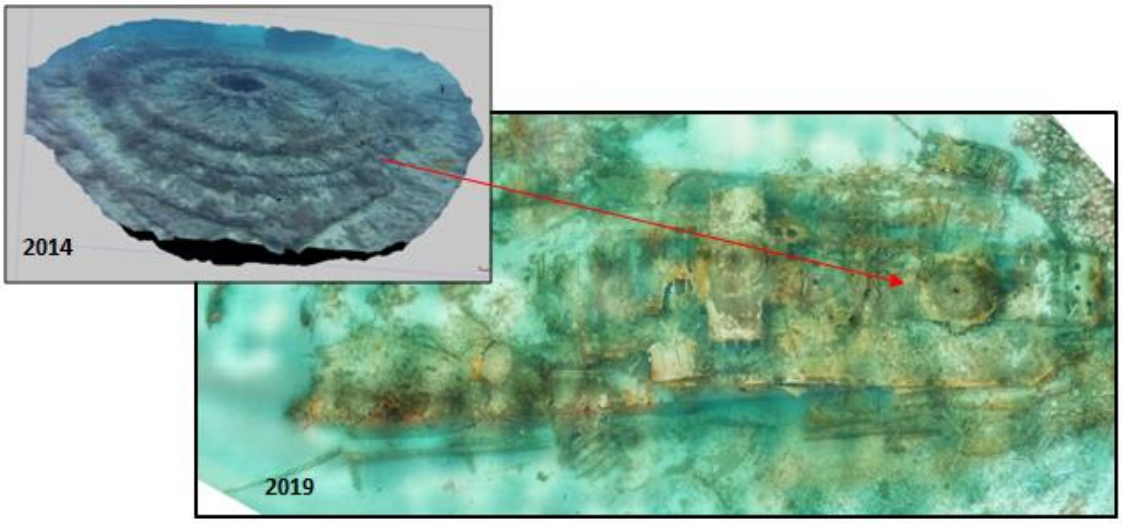
LD 3D Model	**Source (*YouTube*)**
1. Mounting Gun Base/ Upper Structure	https://www.youtube.com/watch?v=ORU6HRUDvnE
2. Forecastle deck/ Rocky slope	https://www.youtube.com/watch?v=0JCv6QHB2V0&t=232s
3. Forecastle deck/ Starboard side	https://www.youtube.com/watch?v=iyFcmjHmqlk
4. Gunwale/ Starboard side	https://www.youtube.com/watch?v=LB8H4JYH2os
5. Hull/ Starboard side	https://www.youtube.com/watch?v=y1jCuiqtswc
6. Rear Hull section/ Starboard side	https://www.youtube.com/watch?v=tQCHrBjrNho&t=151s

Note: Representing sources for six LD 3D models (only the ones that were used for the final analysis).

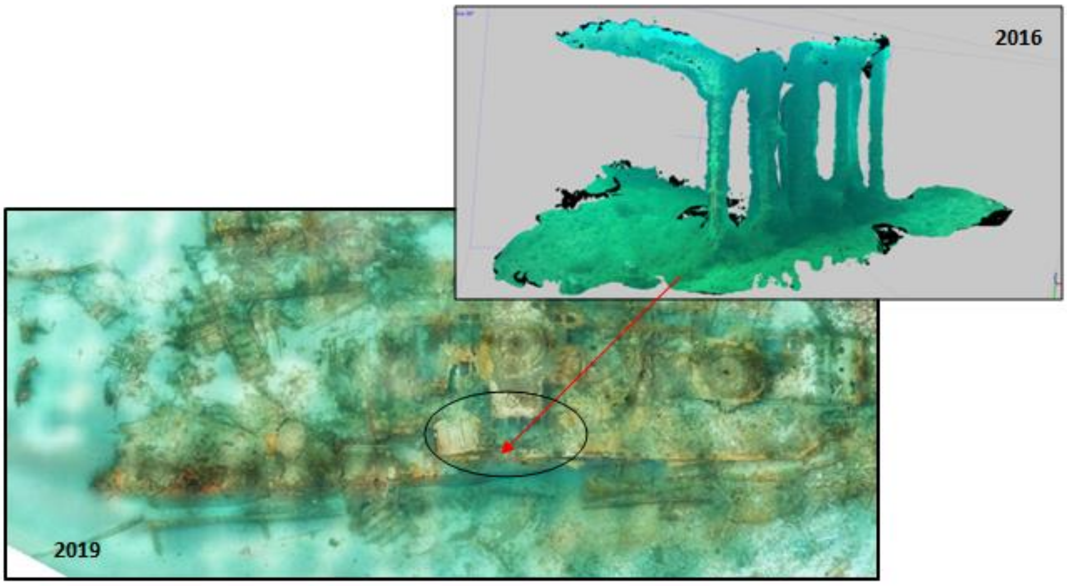
Appendix B – Unsuccessful Legacy Data 3D Models



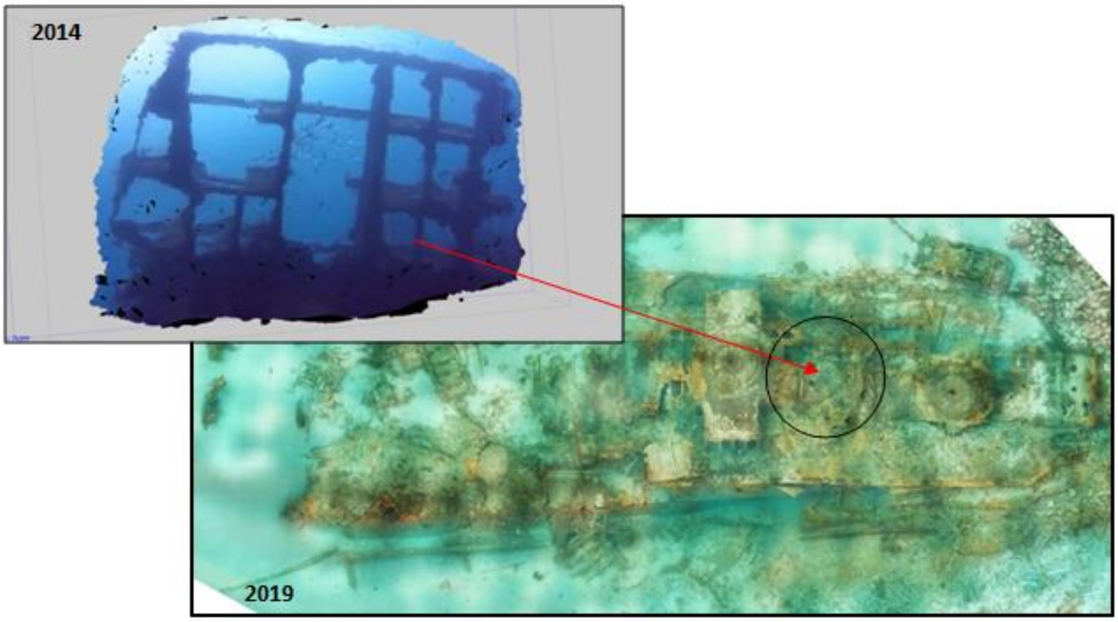
Note: After visually inspecting LD model from 2012, it was noticed that at the time, the forecastle deck was still in a relatively good condition.. An entry point can be seen in LD model. Bad angle of camera did not allowed for this model to develop properly.



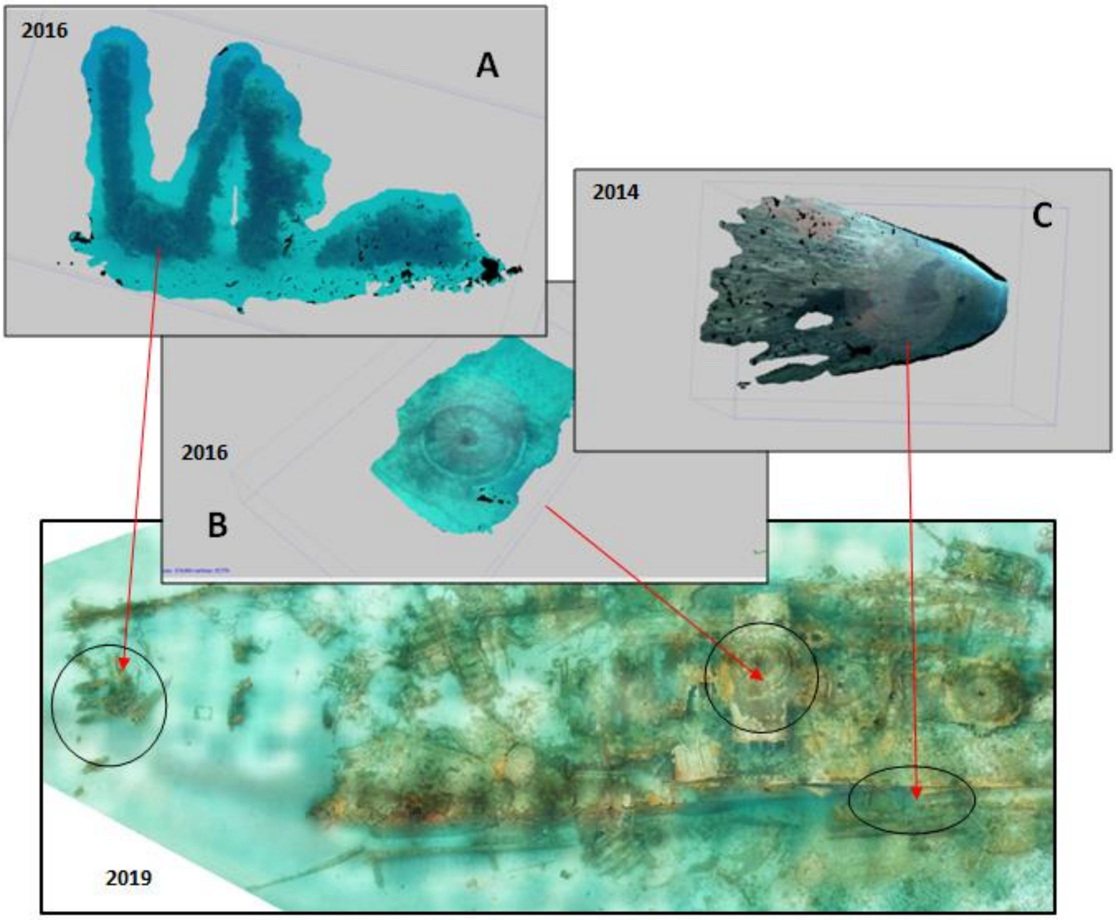
Note: Mounting gun base 'A' is visible, camera was not held perpendicularly, hence the model was never used for the analysis (2014). Forecastle deck



Note: LD 3D model (2016) was created properly, but geo-referencing through common points was not feasible due to impossibility to find any intertwining characteristic sections in the legacy data model. Upper structure - Gunwale



Note: LD model from 2014 shows a section of the ship that is no longer standing today. It represents a ‘blast shield’, which was located between 4.7in Guns ‘A’ and ‘B’. Also, bad camera angle did not allowed for this model to be fully developed.



Note: None of the three shown LD models were used. The main reason was the bad camera position while filming, also, there was not enough surface coverage for 3D models to be completed. The last two LD models that remained were not good enough for procedure to be finished in *PhotoScan/Metashape*.