

Meaningful Applications of Photogrammetry on Shipwreck Excavations - Not Just for Recording! Using 3D Data to Understand the Ships -

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ABSTRACT

Photogrammetry has rapidly gained attention in the field of underwater archaeology since around 2011, largely due to significant time constraints associated with underwater excavation. Photogrammetry is a technique that utilizes photographs taken with a digital camera to create precise 3D digital models. It has now become possible to replace some of the manual recording tasks with this technique, which offers both speed and high accuracy. As a result, underwater recording work can now be completed in a fraction of the time it once required, while still maintaining accuracy.

However, the most significant advantage of photogrammetry lies in the flexibility of the data it generates, which subsequently enhances archaeologists' research and facilitates hypothesis formulation. In this paper, the authors present several case studies where photogrammetry is used not only as a recording tool but also as a support for scientific research, specifically to enhance our understanding of historical ships. The case studies to be discussed in this paper include the Fournoi Shipwreck 15 from Greece (5th century A.D.), the Letavica shipwreck from Croatia (1st century B.C), and the Ses Llumetes shipwreck from Spain (1st century A.D.). In the context of these three case studies, the authors will explore the use of photogrammetry as a research and analysis tool in shipwreck studies.

Keywords: Photogrammetry, Shipwreck, GIS, Ship Reconstruction

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1. INTRODUCTION

The topic of this paper fits best within this Session 19. Database, monitoring, non-intrusive documentation techniques and new technologies applied to underwater cultural heritage because this paper will discuss the potential of photogrammetry as an effective tool for the scientific analysis of shipwreck sites. Over the past decade, photogrammetry has become an indispensable tool for maritime archaeology. (McCarthy et al. 2019) This technique allows archaeologists to record underwater archaeological sites quickly, which is particularly beneficial for underwater archaeology, as the underwater environment imposes certain time constraints on work (Yamafune et al. 2017). Photogrammetry, which requires only a digital camera and does not necessitate expensive scanning tools like LiDAR (three dimensional scanners) or total stations often used for terrestrial site recording, is relatively low cost. For these reasons, photogrammetry has emerged as one of the most frequently used tools for recording underwater archaeological sites.

However, the application of photogrammetry and the utilization of the resultant three dimensional (3D) digital models are often limited to producing orthomosaics and two

dimensional site plans. The authors of this paper, however, see greater potential in the use of these 3D photogrammetry models for site analysis, excavation planning, and ultimately, for ship reconstruction to understand the original shapes of the ships. In this paper, the authors present three different shipwreck excavation projects to discuss the more efficient use of photogrammetry for understanding shipwreck sites, beyond just site recording and site plan production. The three archaeological sites where the authors have applied experimental methodologies, and which are discussed in this paper, are the Fournoi Project Shipwreck 15 from Greece (fifth century CE), the Letavica shipwreck from Croatia (first century BCE), and the Ses Llumetes shipwreck from Spain (first century CE).

2. CASE STUDIES

The case studies under consideration are the following shipwreck excavation projects where the authors have applied experimental research methodologies.

The Fournoi Project and The Shipwreck 15 (Greece)

The primary objective of the Fournoi Project is the documentation of the underwater cultural heritage of the Fournoi archipelago in the Aegean Sea. Since 2015, the underwater archaeological survey of the waters around Fournoi has uncovered evidence of fifty-eight (58) shipwrecks spanning a broad timeframe, from the Archaic period to the 20th century. Moreover, a multi-period anchorage site and several individual finds have also been discovered, indicating an area of “high maritime activity” (Campbell and Koutsouflakis 2017, 10-15; Campbell and Koutsouflakis 2021, 281-284). In 2021, the site known as Shipwreck 15, a remarkably well-preserved complex, underwent its first season of excavation.

Shipwreck 15 was discovered during the 2015 campaign along the eastern front of the Aspros Kavos promontory, a stark, sheer, rocky cliff at the northeastern edge of the central island of Fournoi. The primary deposit lies on a sandy steep sloping seabed at a depth of 43 to 50m. The exploration of the site so far has revealed a heterogeneous, unorthodox cargo, consisting of at least eight different types and variants of amphorae, mainly of Black Sea origin, along with a secondary load of Phocaean Red Slip Ware (LRC). According to the currently available data, the wreck-assemblage should be dated to somewhere between the last quarter of the fifth century and the first quarter of the sixth century CE.

Letavica Shipwreck (Croatia)

In 2018, the well-preserved remains of an ancient sunken ship were discovered near Cape Letavica on the island of Pag. Approximately 400 wine amphorae of the Lamboglia 2 type, dating back to the 1st century BC, rest on the slope of the seabed, outlining the shape of the sunken ship. Judging by the research so far, the bow of the ship points to the northeast. The ship appears to have come to rest on its starboard side, with the keel on the shallower part of the site. The total length of the visible ship's cargo is about 21 m, suggesting it was a merchant ship approximately 25 m long. In 2022, roughly twenty pieces of ceramic and metal vessels from the ship's galley were discovered in the stern part of the ship, and two completely preserved amphorae were raised from the site.

Ses Llumetes Shipwreck (Spain)

Porto Cristo, a small coastal town on the eastern side of the island of Mallorca (Spain), is part of

the municipality of Manacor. The geography of its coastline makes this cove a perfect natural harbor for boats needing to replenish water or carry out repairs during their journey. However, this seemingly ideal anchorage can become a deadly trap for anchored ships when winds blow from the East or Northeast. As evidence of this, there are the five shipwrecks documented by the team of the Balearic Institute of Studies in Maritime Archaeology (IBEAM).

Since 2015, IBEAM has focused its efforts on studying the wreck of Ses Llumetes, a Roman vessel dating back to the 1st century CE. Cargo of the ship consisted of amphorae corresponding to productions from southern Hispania, mainly Dressel 7-11 types, alongside Haltern 70 and Dressel 20 types. The amphorae are complemented by Italian materials, including a representative collection of oil lamps, which give the site its name.

3. RESOURCES

The resources available to conduct the work include digital 3D photogrammetry models created within *Agisoft Metashape Professional Edition* photogrammetry software during the field expeditions of the three above-mentioned projects. The authors primarily applied photogrammetry to record archaeological sites and create 2D site plans of the underwater shipwreck sites. For areas of interest, the team tagged, recorded, and occasionally raised artifacts under the supervision of conservators, anticipating the need for storage and conservation facilities. To record all proveniences of these removed/raised artifacts, the teams applied photogrammetry recording before moving any artifacts. As such, photogrammetry recording was conducted almost every working day, and the 3D photogrammetry models were produced each day.

All the created photogrammetry 3D models were scaled and locally georeferenced. 'Local georeferencing' means that depths and inclinations of the shipwreck sites were determined by depth measurements taken by dive computers. Additionally, archaeological baselines were established by north-south or west-east directions, or the bow-stern direction if the ships' keel orientation was known. All daily created photogrammetry 3D models were aligned/overlaid correctly once created, allowing archaeologists to track the progress of the excavations.

In all these case studies - excavations in Greece, Croatia, and Spain - photogrammetry was used as a primary recording tool and proved its efficiency as a rapid yet accurate recording method. However, the authors sought to explore further potential applications of photogrammetry, using it to understand and analyze shipwreck sites, not just as a recording tool.

4. FRAMEWORK

The research question of this paper is "Can photogrammetry serve as a useful tool for archaeologists to understand shipwreck sites and the original ships, beyond simply recording the site?" The authors conducted various case studies to explore this question."

Fournoi Project Shipwreck 15: GIS-Based Cargo Analysis Using Geo-Referenced Orthomosaics and Photogrammetry-Based Site Plans

The authors managed to produce geo-referenced photogrammetry 3D models every working day and also developed geo-referenced orthomosaics each evening based on these 3D models. Once created, these orthomosaics were imported into GIS software. The primary goal of a GIS

database in a shipwreck context is the intra-site spatial analysis – determining spatial relations among archaeological remains, which aids in reconstructing the site and understanding the assembly as a unit. Furthermore, this tool facilitates archiving, management, and monitoring of every archaeological task undertaken at a wreck site, thereby aiding both fieldwork and data analysis (Bartoli et al. 2012, E3; Theofanous 2017, 32-33, 38).

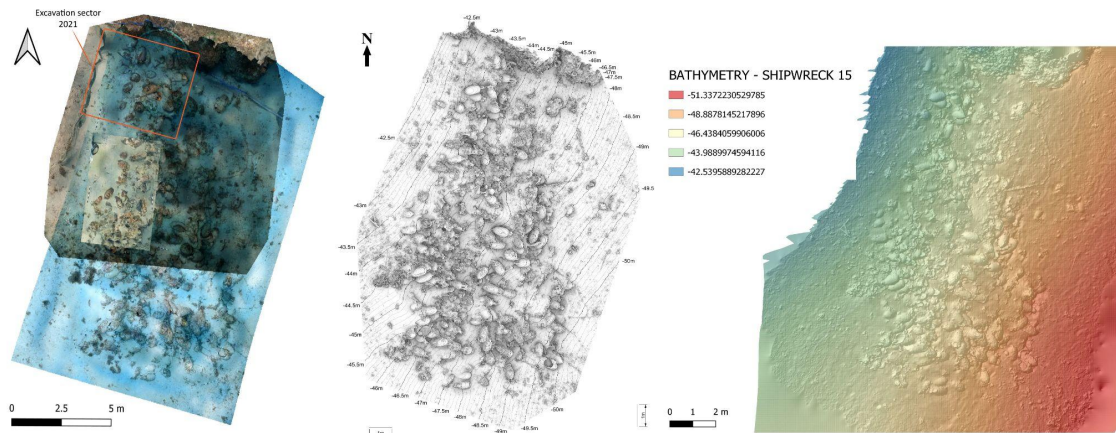


Figure 1. Fournoi shipwreck 15's QGIS baselines: georeferenced orthomages, site plan with isobaths and DEM Model. (Image: K. Yamafune and D. Voutyrea).

For the Fournoi Project Shipwreck 15 case study, the authors used QGIS, a free, open-source desktop software. The database was constructed based on a satellite map, multiple geo-referenced orthomosaics, black-and-white-rendered 2D site plans, and Digital Elevation Models (DEMs). (Fig. 1) Vector datasets were created from multiple orthomosaics, which provided temporal data to identify what came earlier and what came later. To examine the arrangement of the heterogeneous containers and make preliminary interpretations of the shipwreck's findings, the authors used color-coding indicative of various amphora types and other artifacts (Voutyrea 2022). (Fig. 2) Each amphora was outlined by a polygon feature of a specific color, corresponding to a particular type. A separate point layer was designed to track the positioning of wooden remains and fine ware. All necessary information for every individual object (e.g., material, typology, recovery date) was added in the attribute table categories.

This process resulted in a multi-layered geodatabase, providing different kinds of archaeological and spatial information. The archaeologists can track, observe, and compare data from numerous perspectives and ask distinct questions of the database, such as "which amphorae belong to the X type?" or "which finds were raised on the X date?" The database's digital environment can be updated regularly to accommodate, organize, and handle new archaeological data as the excavation progresses. The authors anticipate adding new data categories in the future, such as the conservation status of raised finds and sampling of amphorae for archaeometrical analysis. The ultimate goal is to combine the GIS database with other open-source tools, like *CloudCompare*, to manage workflows, compare, and visualize results in an integrated manner.

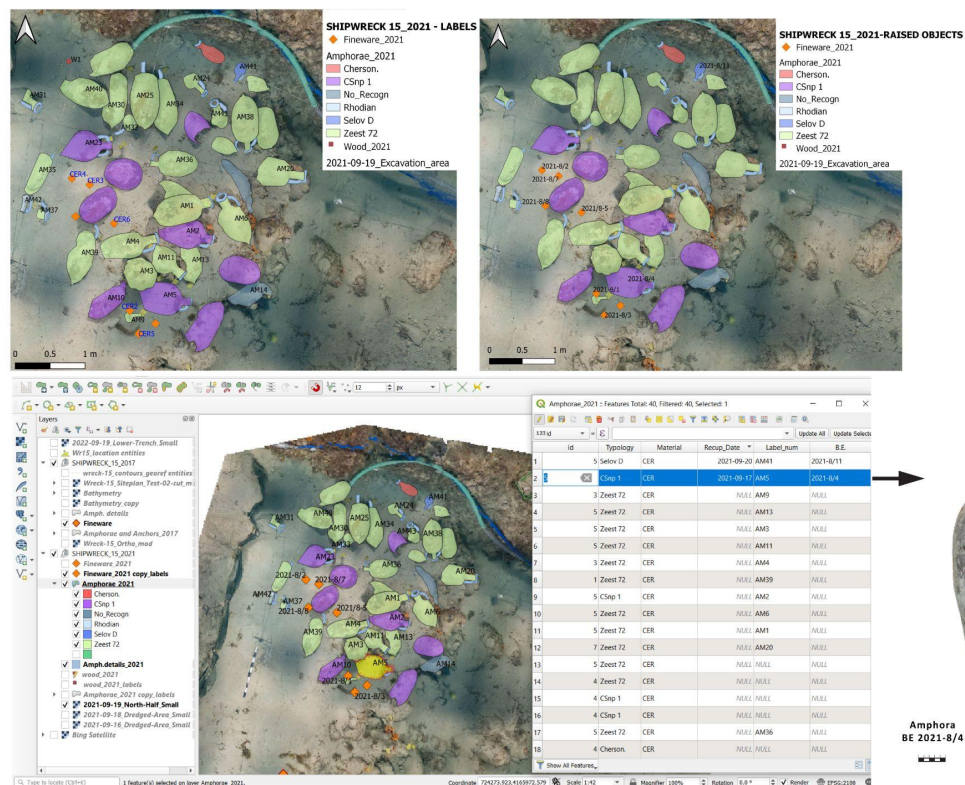


Figure 2. Fournoi shipwreck 15's QGIS database at the end of 2021 fieldwork. The archaeological objects are featured by a color - coding. The different layers are providing various information about every single artefact (Typology, Label number, Inventory number - raised finds etc.). (Image: D. Voutyrea)

Letavica Shipwreck: Understanding Unexcavated Ship's Size and Positions of Wooden Structures

The Letavica shipwreck site has only been partially excavated, but the information gathered, and subsequent analysis provide clear insights into the original ship's size and the locations of wooden structures, even those that are still buried. (Fig. 3) During the 2022 field expedition, the team focused on the portside in the bow area and the starboard in the stern area. The bow section excavation measured approximately 2m x 6m, reaching the bedrock at a depth of 1m from the surface sediments. The stern area, around 2m x 8m in size, reached the bedrock at a depth of 1.5m. Beneath the amphorae in the bow area, segments of hull planks were discovered, featuring distinct pegged mortice-and-tenon joinery. The stern area yielded a variety of pottery, including oil lamps and cooking pots.

Utilizing photogrammetry 3D models of the entire site, the authors conducted a detailed analysis to develop a hypothesis regarding the original ship's size and its final resting position on the seabed. The initial step involved creating a photogrammetry 3D model of a raised and preserved amphora from the 2018 field expedition. This model was duplicated, color-coded based on size (in red and blue), and overlaid on the photogrammetry 3D models of the Letavica shipwreck site. The authors deduced from the positions and inclinations of the amphorae that the ship had tilted to the starboard side and that most amphorae had also fallen on that side. Further analysis of the amphorae's arrangement and the height of the piles, coupled with the reconstructed bedrock topography based on the excavated areas' depths, allowed for the reconstruction of the original stacking pattern of amphorae in the ship's cargo hold. The pattern appeared to form 3 or

4 layers. Considering the dispersion pattern of the amphorae pile, the length and width of the original cargo hold were estimated, which in turn helped determine the ship's original dimensions. Based on these measurements, it was hypothesized that the ship was 24m in length and 5m in width, and was carrying approximately 920 amphorae when it sank. The reconstructed hypothetical ship and its cargo provide archaeologists with a clearer vision for future excavation planning.

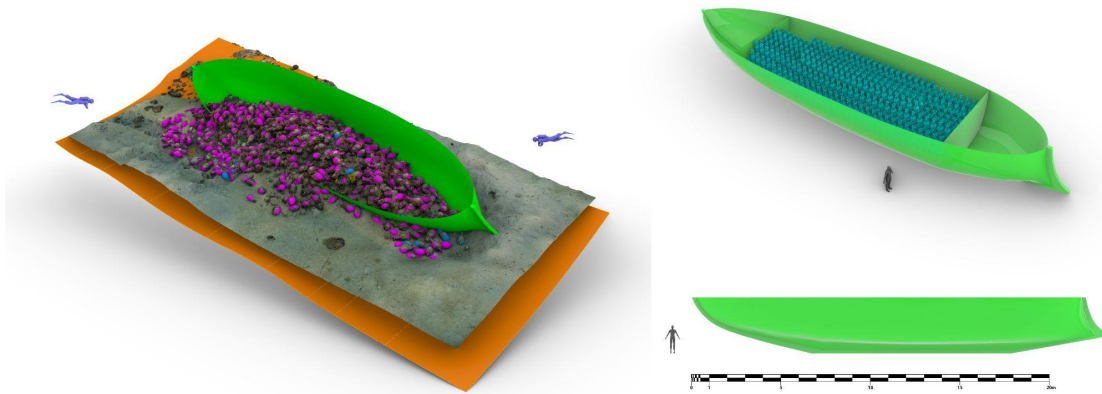


Figure 3. Hypothetical shape of the Letavica shipwreck. This reconstructed shape of the hull is primarily based on data derived from 3D photogrammetry. (Image: K. Yamafune)

Ses Llumetes: Reconstruction of Hull Lines from Excavated Ship Structures/Fragments

Different from above two shipwreck sites, 95% of its preserved hull structures of Ses Llumetes shipwreck site has been excavated. Unfortunately, only forward half of the portside structure survived, and the entire starboard structures and the aft half of the portside was not preserved (it must be noted that there is a possibility that the preserved area is starboard of the stern). In 2022 field expedition, the team removed ceiling planking, and all survived frames and hull planking were recorded *in situ* using photogrammetry. Using this 3D photogrammetry model of Ses Llumetes from 2022 field expedition, the authors experimentally reconstructed the original shape of the ship. (Fig. 4)

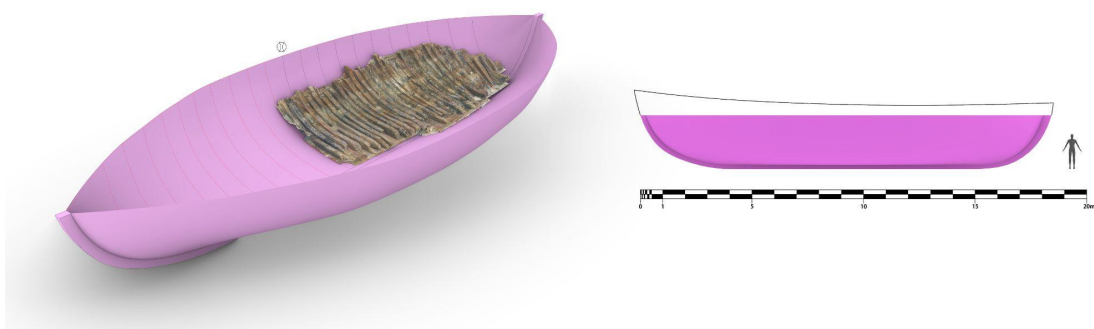


Figure 4. Hypothetical shape of the Ses Llumetes shipwreck. This reconstructed shape of the hull is primarily based on the curvatures of frames extracted from the photogrammetry 3D model of the Ses Llumetes shipwreck site. (Image: K. Yamafune)

Research methodology that reconstructs original shapes of the shipwreck is called ‘Ship Reconstruction.’ Traditionally, ship reconstruction had done by archaeologists using manual recordings. First, curvatures of exterior face of each frame, positions of each frames, positions of fastenings has to be carefully recorded. Using all those archaeological information from the shipwrecks site, archaeologists can reconstruct ‘hull lines’ that represents ships’ original shape with series of curvatures. Hull lines are 2D plans composed with three different orthogonal vies/plans, namely sheer plan, half breadth plan, and body plan. From this reconstructed representation of the ship shapes, or hull lines, archaeologists also can understand, cargo capacity, sailing abilities, and other characteristics of the ship.

For Ses Llumetes shipwreck, the authors used the photogrammetry 3D model instead of manual recording to do Ship Reconstruction. First, completed photogrammetry 3D model of Ses Llumetes is exported to Rhinoceros 3D CAD software. In Rhinoceros, the wooden structures of Ses Llumetes were re-oriented based on keel and angle of frames according to its entering angle to the keel in the body plan, or section profiles. In other words, the ship structures are re-positioned as if it is on plans of hull lines. Then using Rhino’s commands, curvatures, or section profile of the ship structures are extracted. Then from these curvatures, the authors find out the most broad curvature, and this curvature must be the external shape of the master frame. Master frame is the key component of the ship designs, and the most cases it is placed in the widest points of the full. And in ancient shipbuilding, master frames can be found in the amidship area. Henceforward, the authors duplicate curvatures of the forward frame and mirrored those to the aft parts of the master frame. Although, the stern half of Ses Llumetes was not preserved, the author made curvatures of stern-half slightly narrower and higher based on many other ship examples. Once all curvatures, or section profiles, of the portside was created, the author also created horizontal curvatures which pass through the frame curvatures, or section profile curvatures, at the same height. These horizontal curvatures are called water lines. Initially water lines were not smooth because the wooden structures of shipwrecks, including its frames, were distorted while its was pressed by cargos and buried nearly 2000 years under the seabed. The angles of frame curvature have to be re-angled and modified observing conditions of frames from photogrammetry 3D models of Ses Llumetes. This adjustment process of the water line and the frame curvatures is called ‘Fairing.’ After this fairing process is completed, all curvatures of the portside are, finally, duplicated and mirrored to the starboard side to form complete hull lines. Furthermore, the authors created surface, or digital 3D model, by connecting those curvatures of hull lines; and from this digital 3D model, characteristics of the Ses Llumetes can be calculated inside the software. (Fig. 4)

5. RESULT

The authors believe the most significant advantage of using photogrammetry 3D data for analysis lies in its repeatability. Once the 3D models are created, archaeologists can extract measurements and information from the 3D models, rather than directly from the underwater shipwreck site. These measurements, obtained from the digital 3D models, are uniform, meaning the data available for analysis and research remains consistent over time. Consequently, the research and analysis are repeatable, and the results reliable. This repeatability is crucial for archaeologists to conduct scientific research.

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