

THE PROGRESS OF SURVEY TECHNIQUES IN UNDERWATER SITES: THE CASE STUDY OF CAPE STOBA SHIPWRECK

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Commission II – WGII/9

KEY WORDS: Cultural Heritage, Underwater Archaeology, Survey technique, Photogrammetry, 3D Modelling

ABSTRACT:

The experience on a 10-11th century AD cargo of amphoras of the shipwreck of Cape Stoba, in the island of Mljet, in Croatia could be considered an important example to describe the progress of documentation and survey on a shipwreck. In the first part of the paper, we describe some of the used feasible methods of documentation and their advantages and disadvantages. In the second part, we introduce the three-dimensional reconstruction of the items recovered during the archaeological excavation and how these elements could be integrated to the different types of documentation: bi-dimensional plans, three-dimensional coordinates and multi-image photogrammetry.

3D reconstruction allows to decrease and optimize time and work during the excavation and to obtain a complete range of data for post-excavation study, permitting to better document, represent and investigate the position of the cargo. Furthermore, 3D modelling offers an attractive display for the public, who can better appreciate cultural heritage and archaeological evidence.

1. INTRODUCTION

Documentation and survey of archaeological sites, both underwater and terrestrial, have gone through an evident and clear change in the last two decades (Balletti et al., 2016). Reviewing the evolution of the surveying techniques, three-dimensional surveys and representations of shipwrecks or cargos are very useful in order to better evaluate the volume and the arrangement of a cargo. The 3D documentation allows a better perception of the site, above all in difficult contexts where the archaeological subject is not on the same level or is teeming with details. A simple plan with depths marked on it does not highlight the real appearance of a shipwreck (Drap et al., 2003; Green, 2004).

Underwater, for hyperbaric reasons, diving time is limited by depth and in deep sites, it is more reduced than in shallow water: for example around 40 m, diving time is only 18 minutes and around 28 m it is extended to 35 minutes. In these contexts, the survey and documentation activities have to be fast and precise. The arrangement of accurate documentation, in particular for stratigraphic excavations, is a peculiar and important aspect related to underwater archaeology. Every archaeological site and every different study require a specific technology; first, archaeologists have to analyze the object and the context of excavation, then they have to know the economic possibility and the project timing. After this kind of evaluation it is possible to understand the appropriate recording technology and the appropriate representation and format of the results (Gonizzi et al., 2014).

In this paper, we present and evaluate some of the surveying techniques applied on the same underwater shipwreck during different seasons of excavation. The experience and test filed have been conducted on the *Cape Stoba* shipwreck, excavated by the Department of Underwater Archaeology of the Croatian Conservation Institute, directed by Igor Miholjek, in collaboration, from 2012, with the researchers of Ca' Foscari University of Venice, under the direction of prof. Carlo Beltrame (figure 1) (Beltrame et al., 2018, Zmaic et al., 2016).



Figure 1. The archaeological site at the end of the excavation in 2012 (photo: D. Della Libera).

2. DOCUMENTATION TECHNIQUES

Archaeological site has to be documented in every single phase, in particular during a stratigraphic excavation; different techniques have been known and employed, from direct survey to digital survey techniques, in correlation to the evolution of the know-how and the methodologies. Direct measurement of the items, trilateration, photogrammetry and multi-image photogrammetry are some of the techniques employed on archaeological sites, differently used, according to the context and the characteristics of the site.

In deep sites, restricted diving time entails the choice of the techniques to be used and the technologies have also to comply with the different depths of the cargo and the different years of execution. In *Cape Stoba* shipwreck, the documentation has been carried out from 2009 to 2015, and the applied

technologies have gone through an impressive development from the first to the last year.

In the firsts three years, the researchers have used a trilateration to document the position of the amphoras of the cargo. In 2012, we have applied an analogic photogrammetric survey and in 2015 we have used the multi-image photogrammetry and the Structure from Motion technique. At the end of the mission, the obtained data (plan and 3D model) have been compared and integrated to achieve a complete survey of the cargo of the shipwreck. The documentation has oriented in the same reference system thanks to a topographic survey realized by some control points on the site. These mainly belong to the legs of the grid used for the trilateration during the first three years survey, that have remained still for all the campaigns.

2.1 Direct survey: trilateration

Direct measurement and trilateration are simple methods to document a site, usually employed since the beginning of underwater archaeology, both in shallow and deep water (Balletti et al., 2015; Green, 2004). This easy and economic technique needs a meter tape or a double meter stick, but it requires a long time of fulfillment and it has a suitable precision only using short measurements in small sites.

In addition to limited execution, this method can realize only a bi-dimensional documentation: plans, sections and profiles.

In 2009, 2010 and 2011 the bi-dimensional trilateration technique has used to measure xy coordinates on a hypothetical horizontal plane, considering the metal legs of the grid as a fixed datum to divide the site in quadrants; the z coordinate was measured with a double meter stick on the vertical line from the measured grid (figure 2). This technique was employed to reconstruct the plan of the site and the position of the amphoras (figure 3).



Figure 2. Trilateration and measuring of the depth of the amphoras (photo: J. Kwiatkowski).

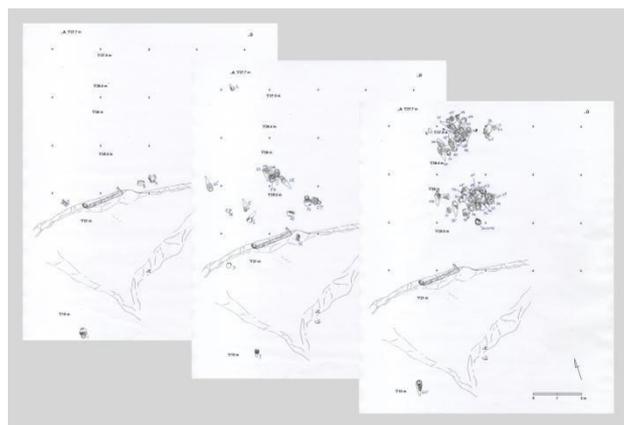


Figure 3. Bi-dimensional maps of the site (drawings: V. Zmaic).

Trilateration has been used for half a century in maritime archaeology, but in the last decades it has been overtaken by three-dimensional techniques and, at this time, it is often used as supporting documentation (Bojakowski et al., 2015).

The three-dimensional trilateration, based on direct measurement of the distances without considering the horizontal plane could be esteemed an evolution of this technique. DSM method (Direct Survey Measurement) is known from '80s when Nick Rule proposed it for the first time on the *Mary Rose* shipwreck (Rule, 1982). In the late '90s, Peter Holt developed the software *Site Surveyor* that is still used in maritime archaeology (Holt, 2003). Another software for trilateration with direct tape measurements, known as *WEB*, has been used by INA from '90s, for the first time on the Turkish shipwrecks as Bozburun (Polzer et al., 2012).

This technique consists in the trilateration of the points on the archaeological site from a number of external control points, using simple tape measurements and a dive computer to acquire the depth. All the measurements are processed by a special 3D software to produce points in space with xyz coordinates, which could be employed to build a model of the objects or to align the control points of a photogrammetric point cloud.

For each point, we need at least four direct measurements and the depth though it is better to measure each point from every others of the net, in order to create a structurally rigid topographic network with redundancy of observations. The divers could take all the linear measurements in different following dives, but all the depths of the targets have to be obtained in the same dive to avoid the feasible errors due to the changing in the level of the tide. The measurements of a numerous net of targets could take many dives in deep contexts as *Cape Stoba* shipwreck where the dive time is around 35 minutes.

Thanks to the progress of survey techniques, fewer targets correctly distributed on the portion documented are sufficient for the photogrammetric survey in order to create a net to rototraslate and check the accuracy of the model (figure 4).

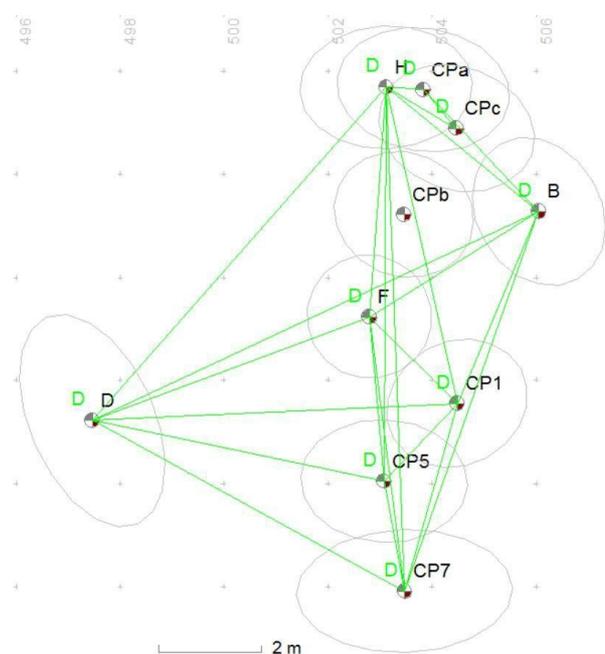


Figure 4. Processing of the measurements of DSM with *Site Recorder* software.

Particular attention has been paid to the essential aspect of the topographical survey of the shipwreck through the network of control points located in the site and the DSM could be considered the principal technique to create the local reference system for the site.

During the stratigraphic excavation in 2015, we fixed some targets inside the cargo between the amphoras, in a steady position for all the different layers. These targets and some of the external metal legs of the grid were still on the site and have been measured to create the same reference system from 2009 to 2015, in order to align all the results of the surveys.

2.2 Photogrammetry: geometric approach

Photogrammetry, from the first application in 1963 on an underwater site by G. Bass (Bass, 1970; Polzer et al., 2012), allows to obtain 3D coordinates of the objects and their precise position in space through the calculation of the parallax equations on couples of measurable images (Green, 2004). One of the principal advantages of this technique is the possibility to obtain a 3D model without a direct interaction with the object. Stereo-photogrammetry usually employs single metric cameras or double metric camera fixed at pre-set distance, but the evolution of the technique has permitted to reduce the use of a standard scheme with an established fixed grid and to acquire the images from casual position, maintaining the rules of overlapping between the images. On *Cape Stoba* shipwreck, the metal grid on the site has been used as a measured base for photogrammetry. The depth of the targets on the site and the horizontal level of the grid has been calculated with a spirit level.

The rules and the know-how on nadiral photogrammetry, acquired from 2001 on the brick Mercurio excavation by Ca' Foscari University, where a camera run on a measured rail on a metal grid (Beltrame et al., 2012), have been applied to the photogrammetric process in the 2012 mission on Cape Stoba. "Not nadiral" images has been conformed to this technique with an analogical and geometric approach:

- first, the images have been corrected from the radial distortion of the 20 mm grandangular lens and have been rectified using some measured control points located on the grid. This allowed us to "normalize the shot", producing an image with the axis of the camera perpendicular to the grid plane, in accordance with the physiological conditions required for stereo-vision of parallel optical axes (Drap, 2012).
- then, camera's projection centers were recovered by finding the point of intersection of the vectorized lines between the image coordinates of the targets on the images and the real coordinates measured on the site (figure 5).
- the images were scaled and arranged in the right position bearing to the metal grid and to the position of the targets (figure 6).
- photogrammetric restitution was realized obtaining the bundle adjustment solution between the projection center and the homologous points in the overlapping areas of the photograms.

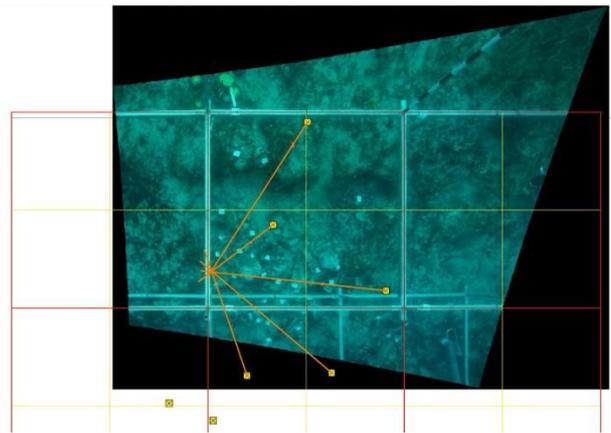


Figure 5. Identification of the camera projection center on the rectified image (data processing: S. Caressa).

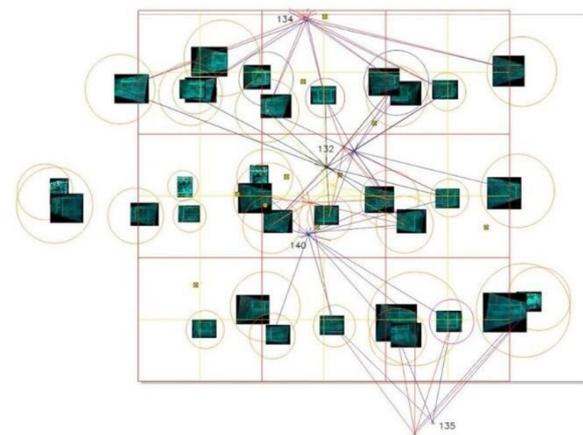


Figure 6. Disposition of the scaled images on the drawing grid (data processing: S. Caressa).

Time consuming during post processing phase and data processing – both elaboration of the images and recognition of the coordinates of the points – can only take place once the acquisition phase is completely finished are the limits of this procedure (De Reu et al., 2013).

This process has been used to compare analogical photogrammetric method to new techniques that has widely employed on underwater archaeological site, as the photogrammetric elaboration through different software. This comparison permit to acquire a better know-how on analytical and analogical solution and on methods of newly software for multi-image photogrammetry. The same images have been processed also with *Photoscan* software and the model has been rototraslated with the same coordinates of the targets and the metal grid; comparing the two models obtained by the different techniques, the average of the error on the targets and on the principal points of the amphoras is calculated around 0.0024 m (figure 7).

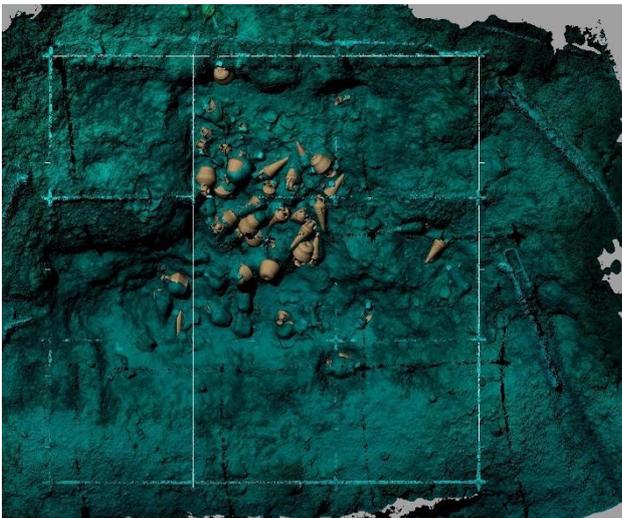


Figure 7. Comparing of the models obtained by the two different photogrammetric techniques.

2.3 Photogrammetry: SfM approach

First phase of the process of photogrammetry is the image acquisition on field; the photographs have to follow a regular geometric network, with 60% overlap between images and 20% between the strips. Differently from traditional photogrammetry, the advantages of this new method are a fast and semi-automatic data processing and the direct elaboration of a continuous textured model. Many commercial application and photogrammetric software employ algorithm for matching images, as *3DF Zephir Aerial*, *Pix4D*, *SURE*, *MicMac* and *Agisoft Photoscan*. It is possible to directly process the images acquired at a low resolution with a laptop right after the survey to check the entire network geometry before removing the next layers of amphoras. In archaeology, this is an important revolution for researchers, as it allows keeping track of every layer of the stratigraphic excavation, permitting a complete documentation of the site. The photogrammetric models obtained have been merged in the same reference system using the xyz coordinates achieved with trilateration topographic survey of the targets.

Once the first results had been evaluated and after the acquisition phase was completed, the images have been processed at "Ultra High resolution" to be aligned and to create a sparse point cloud. After the alignment of the images that recognizes the disposition of the camera shooting, three other phases of photogrammetric process have been realized: creation of a dense point cloud, of a mesh and application of the texture. The process to obtain the 3D model is fully automated (De Reu et al., 2013, Michieletti et al., 2015), but we have to pay attention to every step, changing the parameters to achieve the best results in our context. We have realized a photogrammetric block of nadiral images, as in aerial photogrammetry, combined with radial images around the amphoras to cover the portions hidden in the nadiral views.

As shown in figure 10, images have been taken from the same distance from the subject, in a parallel way from the sea bottom, as demonstrated also by surveys on others shipwrecks (Diamanti et al., 2015, Demesticha et al., 2012). This conformation of the camera shooting has been used to maintain the same pixel resolution of the images and, consequently, of the virtual model. To follow a good "dive-profile", due to the conformation of the depth of the site from 20 m to 28 m, the diver had to take photos by strips at decreasing depths, moving from the bottom to the upper part of the site.

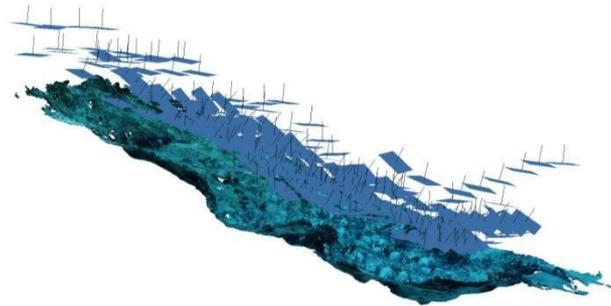


Figure 8. Disposition of the camera shooting.

Images of the three layers were acquired with two full frame cameras, Nikon D700 and Nikon D610, with a 20 mm lens. The different dimensions of the images acquired by the two cameras (Nikon 610: 6016 x 4016 and Nikon D700: 4256 x 2832) entail a different dimension of the pixel (Nikon D610: 5.9 micron and Nikon D700: 8.4 micron).

Shooting at a regular distance of about 1.7 m with Nikon D700 and at 1 m with Nikon D610 and complying with the proportion:

$$C \text{ (lens focal length)} : dm \text{ (medium distance from the subject)} = \\ = \\ 1 \text{ (sensor size in pixel)} : L \text{ (coverage in pixel)}$$

it is possible to calculate the dimension of the real pixel of 0.7 and 0.3 mm, reaching a resolution of about 1:4 with Nikon D700 and almost 1:1 with Nikon D610. In the following image, we can see the same portion of the shipwreck and it is difficult to observe which is the real image and which is the model (figure 9).

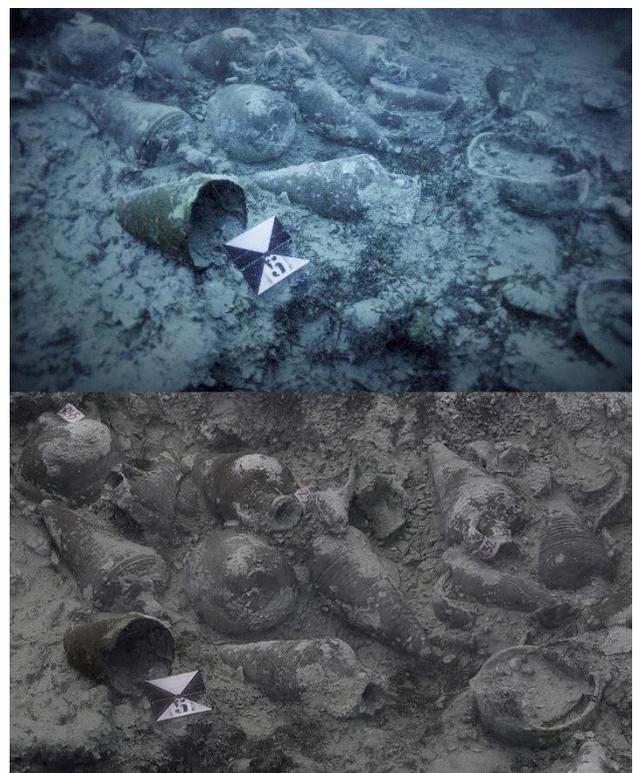


Figure 9. Same portion of the shipwreck: above, underwater image and, below, 3D model.

From the photogrammetric textured model we were able to extract some orthophotos, in order to vectorize in a CAD software the object of the survey and realize a plan, that could be overlapped with ancient maps of previous excavations. These are only one type of the results that could be derived from a 3D photogrammetric survey. Therefore, various aspect of the study could be investigated through the different results of the survey: measuring, conservation, preservation, reconstruction of the missing part, etc. (Gonizzi et al., 2013). We have realized four different models, following the stratigraphic excavation, obtaining different orthophotos of the plan of the site (figure 10).

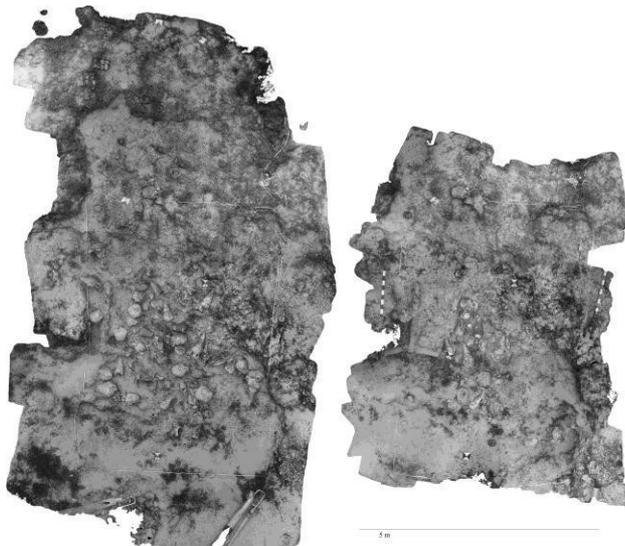


Figure 10. Orthophotos of the layer 1 and layer 2 of the shipwreck, 2015.

3. 3D MODELLING

One of the final aims of the survey is the analysis and the interpretation of the site through 3D modelling, simplifying the objects by lines and geometrical surfaces, and the realization of a virtual 3D database, where there are as many layers as the number of amphoras, divided according to their years of recovery and their different typologies. This documentation could be employed by researchers to study the disposition of the site and the arrangement of the cargo from a complete point of view (figure 11).

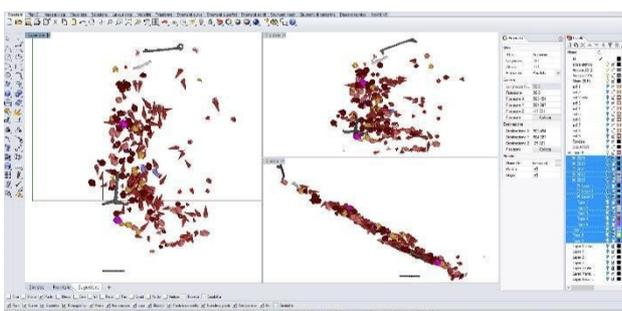


Figure 11. Virtual 3D database of the cargo.

The virtual model has required the creation of 3D theoretical polygonal models of the ten types of amphoras in a 1:1 scale (Drap et al., 2003; Drap et al., 2007).

The drawings of the items are based on the vectorization of the archaeological drawings of the amphoras, on the realization of 3D theoretical models following the geometry of the types and creating the solid wire-frame (Green, 2004) and on modification and cutting of the fragmented items according to the photographs of the real objects (Costa et al., 2015).

The amphoras were scaled and arranged in the original position according to the different documentation obtained by the surveys during the excavations.

For 2009, 2010 and 2011 data sets, we have matched each model with the existing plan, positioning xy coordinates on the drawings and z coordinate accordingly to the value of the depth signed on the plan and reading into the overlapping drawings of the amphoras (figure 12).

In 2012, we have applied a roto-translation and have arranged every model according to the 3D coordinates of the remarkable zones of the amphoras (neck, foot and handle) obtained from the photogrammetric survey (figure 13).

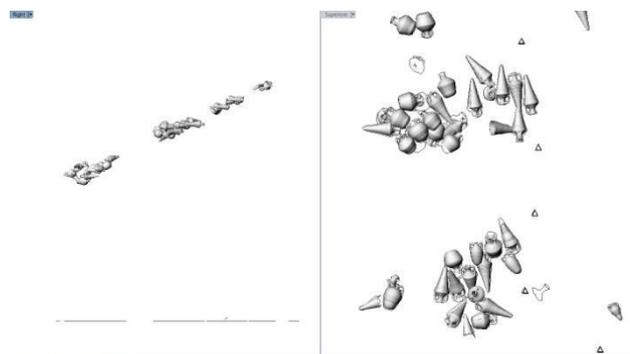


Figure 12. 2009-11 documentation: trilateration.

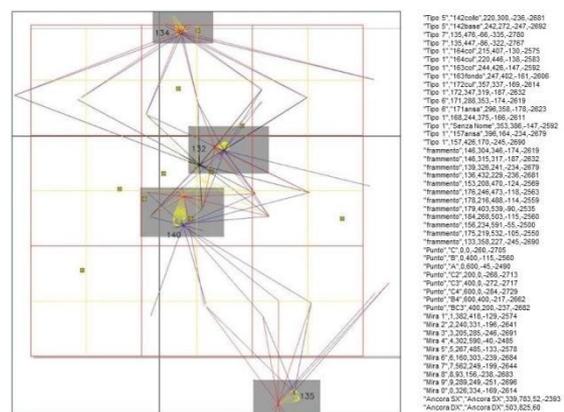


Figure 13. 2012 documentation: photogrammetry.

In 2015, differently from the other survey techniques, with multi-image photogrammetry we obtained the original surface of the objects, reaching a better accuracy of the shape of the amphoras. Despite the fact that this method had realized 3D models of the site directly from the survey, these have been imported in Rhinoceros as a reference on which we could insert the reconstruction of each amphora (figure 14), to simplify the objects and to conform this documentation to the previous ones.

Once concluded the arrangement of the model of the cargo in the same reference system, we have rendered all the surfaces with the application of photographic textures that reproduced a general color of clay. At a later stage, from the bathymetric survey obtained by photogrammetry, we have produced the model of the seabed, a rocky ridge (figure 15).

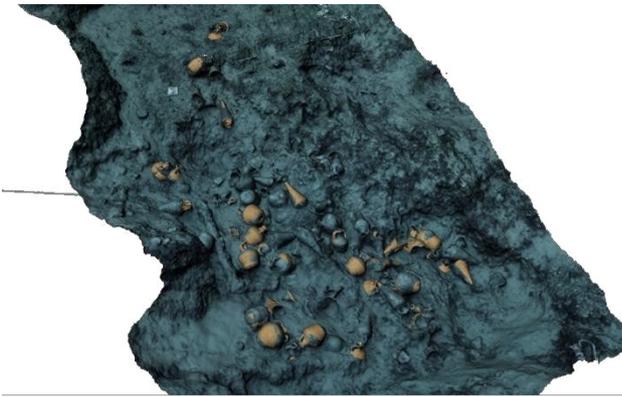


Figure 14. 2015 documentation: multi-image photogrammetry.



Figure 15. Textured polygonal model.

4. CONSIDERATION

This project could represent an important example of integration and correlation of different techniques of documentation to create a modern, innovative and interactive model of a cargo of a shipwreck. The development of the techniques of the last decade is accurately analyzed and employed to give a new life to ancient map of underwater archaeological sites, integrating these with the multi-image photogrammetric survey through digital modelling and virtual reality.

Three-dimensional surveying techniques are widely employed in archaeology to document Cultural Heritage. Properties of digital technologies are accuracy, portability, low cost and fast acquisition (Remondino et al., 2010) and each one of these characteristics is essential in archaeological sites, especially for shipwrecks with a cargo of amphoras. Multi-image photogrammetry can be a very useful tool for archaeology: the high speed and simplicity of acquisition allow to use this method of documentation in situations where slower or unwieldy technology would be inappropriate (McCarthy, 2014). From an archaeological point of view, digital techniques are essential and important to recreate a virtual model with a centimetric accuracy and the geometric accuracy ensures reliable visualization outputs (Quattrini et al., 2016). With this method, we can obtain a very precise documentation from the technical aspect, but, at the same time, it is very fast during the operations on field. In extreme situations, as deep underwater sites, we have only half an hour to collect the essential images to realize a complete and precise documentation. The 3D virtual model has been used to solve the problem of the documentation

of a multi-stratified mound of amphoras; 2D documentation indeed would not have allowed a clear comprehension of the volume of the shipwreck.

One of the aspect on which we want to pay more attention is the topographical aspect used as a fundamentals of all the survey techniques. The determination of a unique reference system for all the years of excavation has given the possibility to accurately obtain a complete model of the whole site; on the contrary, it would have been more complicated without a topographic survey realized during the stratigraphic excavation.

Furthermore, the virtual model has been employed to explore the inaccessible shipwreck with a stereoscopic display system such as virtual reality headset, promoting knowledge of underwater cultural heritage to a wide public. The case study of the Byzantine shipwreck is an interesting project for virtual reality because the cargo is characterized by different layers of amphoras that could be navigated following the stratigraphic excavation (figure 16).

Hence, the capability to create public interpretive deliverables to be implemented in museum's environments allows sharing knowledge about archaeological sites.

Our experience wants to highlight that the correct approach to Cultural Heritage 3D documentation has to use and integrate multiple technologies (photogrammetry and direct survey as trilateration) taking advantage from the intrinsic potentials of each method and has to employ different techniques as a complete dataset of information for both scientific and dissemination purposes.



Figure 16. Virtual reality of Cape Stoba.

ACKNOWLEDGEMENTS

The excavations on the *Cape Stoba* shipwreck have been organized by the Croatian Conservation Institute of Zagreb, with the collaboration of the Università Ca' Foscari, and has been financed by Regione del Veneto, by Ministero degli Affari Esteri and by funds of the same University., of Dipartimento di Studi Umanistici. We want to thank the directors of the project, Igor Miholjek and Carlo Beltrame, and Stefano Caressa for the data processing of 2012 photogrammetric survey.

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