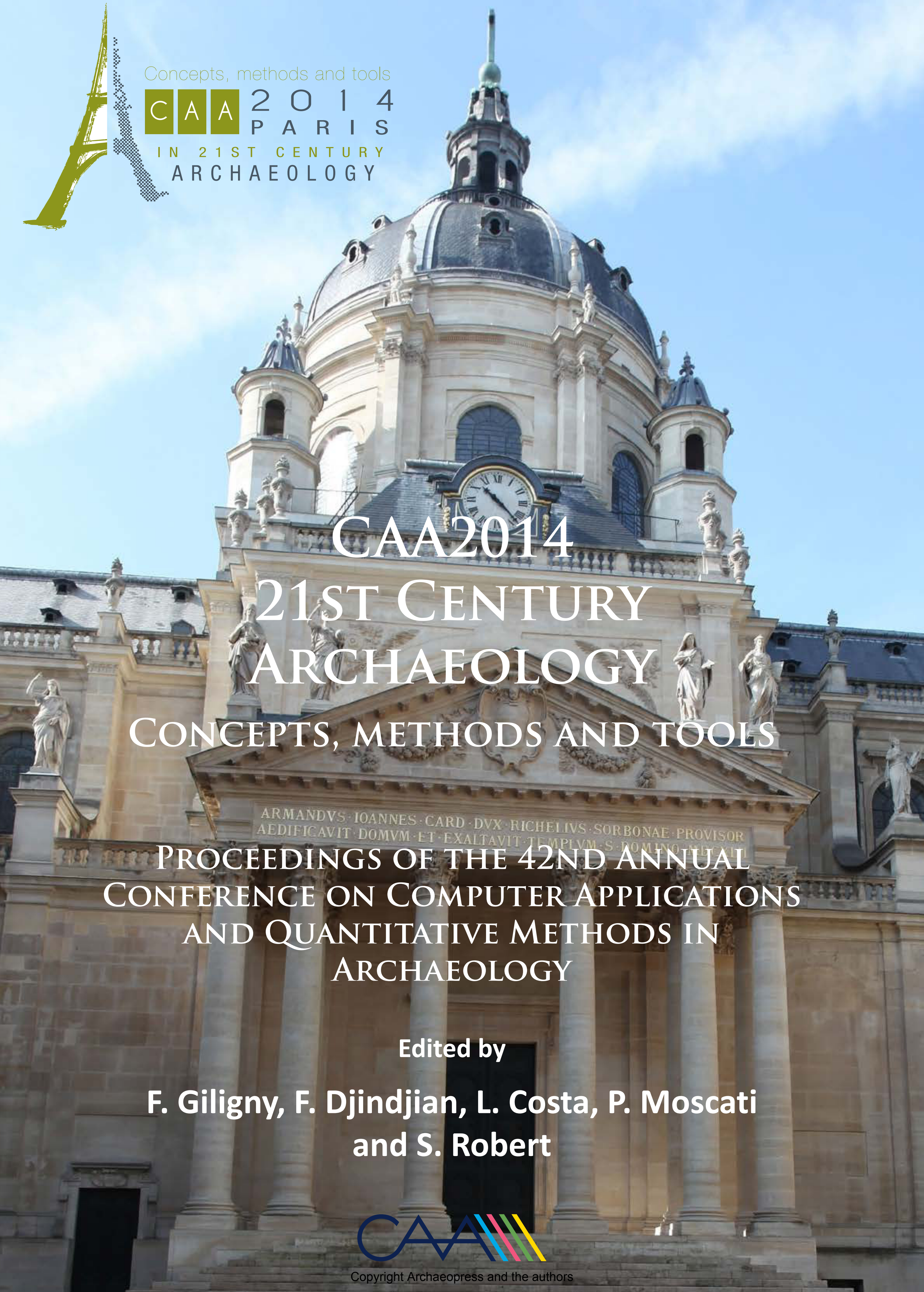

Concepts, methods and tools
CAA 2014 PARIS
IN 21ST CENTURY
ARCHAEOLOGY

CAA2014 21st Century Archaeology

Concepts, methods and tools

Proceedings of the 42nd Annual Conference on Computer Applications and Quantitative Methods in Archaeology

Edited by

F. Giligny, F. Djindjian, L. Costa, P. Moscati and S. Robert

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Foreword

This volume brings together a selection of papers proposed for the Proceedings of the 42th Computer Applications and Quantitative Methods in Archaeology conference (CAA), held in Paris (France) from 22nd to 25th April 2014.

The conference venue was Paris 1 Panthéon-Sorbonne University, in the main building next to the Panthéon. Workshops were held at the Institute of Art and Archaeology and the EHESS School. This was the first time in 42 years that the CAA had come to France, and we are proud to have hosted this important scientific event in Paris.

CAA2014 welcomed 477 participants from 39 countries. Altogether 397 papers were presented in 26 different sessions. The 5 round tables and 12 workshops also contributed to the success of the conference.

The program was divided into different themes and this structure has been maintained in the arrangement of articles in the various chapters of this book.

We are grateful to the following institutions which made the conference possible and supported it financially. Paris 1 Panthéon-Sorbonne University, the *Mairie* of Paris, the CNRS, the EHESS – Ecole des Hautes Etudes en Sciences Sociales, the INRAP – Institut national de Recherches Archéologiques Préventives, the research laboratories from the Maison de l'archéologie et de l'ethnologie, Nanterre – UMR Trajectoires & UMR Arscan. We would also like to thank the staff of the university and the student volunteers.

We hope that the congress participants, the contributors and all people interested in computing in archaeology will enjoy these proceedings.

Potentialities of 3D Reconstruction in Maritime Archaeology

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Abstract

During excavation and documentation of a site many factors affect the choice of the type of technical documentation: features of the evidence, soil properties and the depth of the shipwreck. We describe three research projects to show how 3D reconstruction can be the final step of different types of documentations: 3D photogrammetry, 2D drawings, and 3D trilateration.

3D reconstruction is the best type of documentation, because it allows us to optimize time and work during the excavation, and to obtain complete data for post-excavation study. We have to evaluate the potential for innovation, and new prospects for research and study of this methodology for technical documentation. Furthermore, the 3D model allows us to better record and represent the position of the cargo or the wooden hull; and at the same time it offers an attractive display for the public, who can better appreciate the archaeological evidence.

Keywords: Maritime Archaeology, Photogrammetry, 3D Reconstruction, Survey

Introduction

In the field of maritime archaeology, experimentation of various techniques of surveying and documentation is developing rapidly. The aim of this paper is to compare these techniques, and in particular, the three-dimensional survey used for the documentation of underwater archaeological shipwrecks. In some sites, in particular where the topography presents an extensive vertical component, such as a rocky slope, some form of three-dimensional measurement is required (Green, 2004). Difficulties in using underwater technologies normally used in land archaeology, such as total-stations and laser scanners, have oriented the research mainly toward the photographic method (Drap, 2012a; McCarthy, Benjamin, 2014). Integrating this method with a technical survey and measurements is the best solution for obtaining a complete, exhaustive and precise study.

In planning the documentation, there are several factors which influence the choice of the particular underwater survey technology: the characteristics of the various archaeological contexts, that are the subject to be documented, the morphology of the seabed, the condition of the water, and the depth of the site (which determines the dive time limits).

The team of the Department of Studi Umanistici of the Ca' Foscari University, under the direction of Carlo Beltrame, has been experimenting various techniques in their underwater investigation project. We have examined the results of the use of these techniques to identify the most suitable one for each situation. All the technical methods employed for the study of the archaeological site are focused on three-dimensional documentation. The 3D model is the final product of processing which can be developed from a three-dimensional survey (such as triangulation or photogrammetry), from two-dimensional documentation (such as a simple map and sections), or directly from the measurement of each single find.

The technique of trilateration with linear measurements was first used to produce 3D plans for the excavation of the Mary Rose shipwreck in 1982 (Rule, 1982). Nick Rule at that time proposed the Direct Survey Method (DSM) technique (Rule, 1989). In the late 1990s, Peter Holt developed a software, which is now the most popular documentation technique in underwater archaeology (Holt, 2003). This technique consists in trilateration by measuring the points of the archaeological site from a number of external control points, using simple tape measures and a dive computer to measure the depth. All the readings are processed by a special 3D software to produce points in space with x, y and z coordinates. Those points can be employed to build a model of the objects documented, or to link a points cloud model produced by the photogrammetric technique.

Photogrammetry is of two types: the classical one, which consists of the production of a series of overlapping photographs following a regular scheme from a square grid; that is at a defined and constant distance from the subject. In this way, the camera is always orientated and perpendicular to the object that is being documented (Green, 2004). The other type consists of photographing from free positions without the use of a fixed grid, and without positioned targets in the site, as is necessary in the first type. These photographs must be made both from the

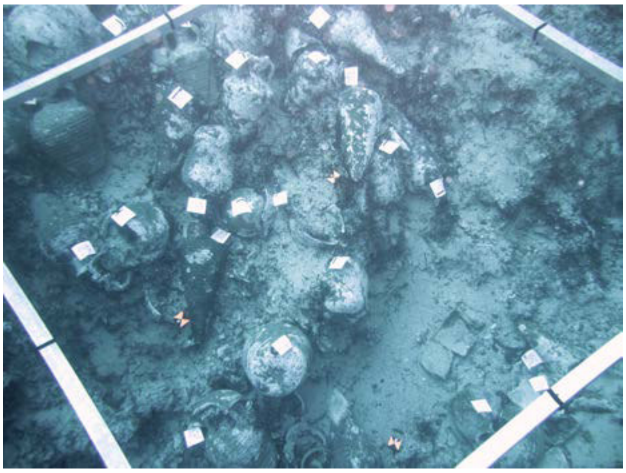


Figure 1: Cape Stoba (Isle of Mljet, Croatia) shipwreck (photo: S. Caressa).

top and from a 45 degree position to determine the lateral angles of the objects (Green, 2004; Skarlatos, Demesticha, Kiparissi, 2012). The photographs must be taken with a considerable overlap; in fact, the key factor of this method is redundancy: each point of measured space must be seen in at least three photographs (Drap, 2012 a; McCarthy, Benjamin, 2014).

We present three case studies of research projects which the Department of Studi Umanistici has carried out in the last two years on different archaeological and environmental situations.

The first one is a cargo of amphoras belonging to the Cape Stoba shipwreck, sunk in the 10-11th century AD off the Isle of Mljet in Croatia, and which is the object of an excavation carried out in collaboration with the Conservation Institute of Zagreb (Zmaic & Miholjek, 2012). This is quite a complex case study because the amphoras lay on a slope at depths from 20 to 28 m (Fig. 1). The 3D documentation appeared useful in allowing a much better perception of the site, which was not obvious from a simple plan with depths marked on it, but where the depths were not visually emphasized.

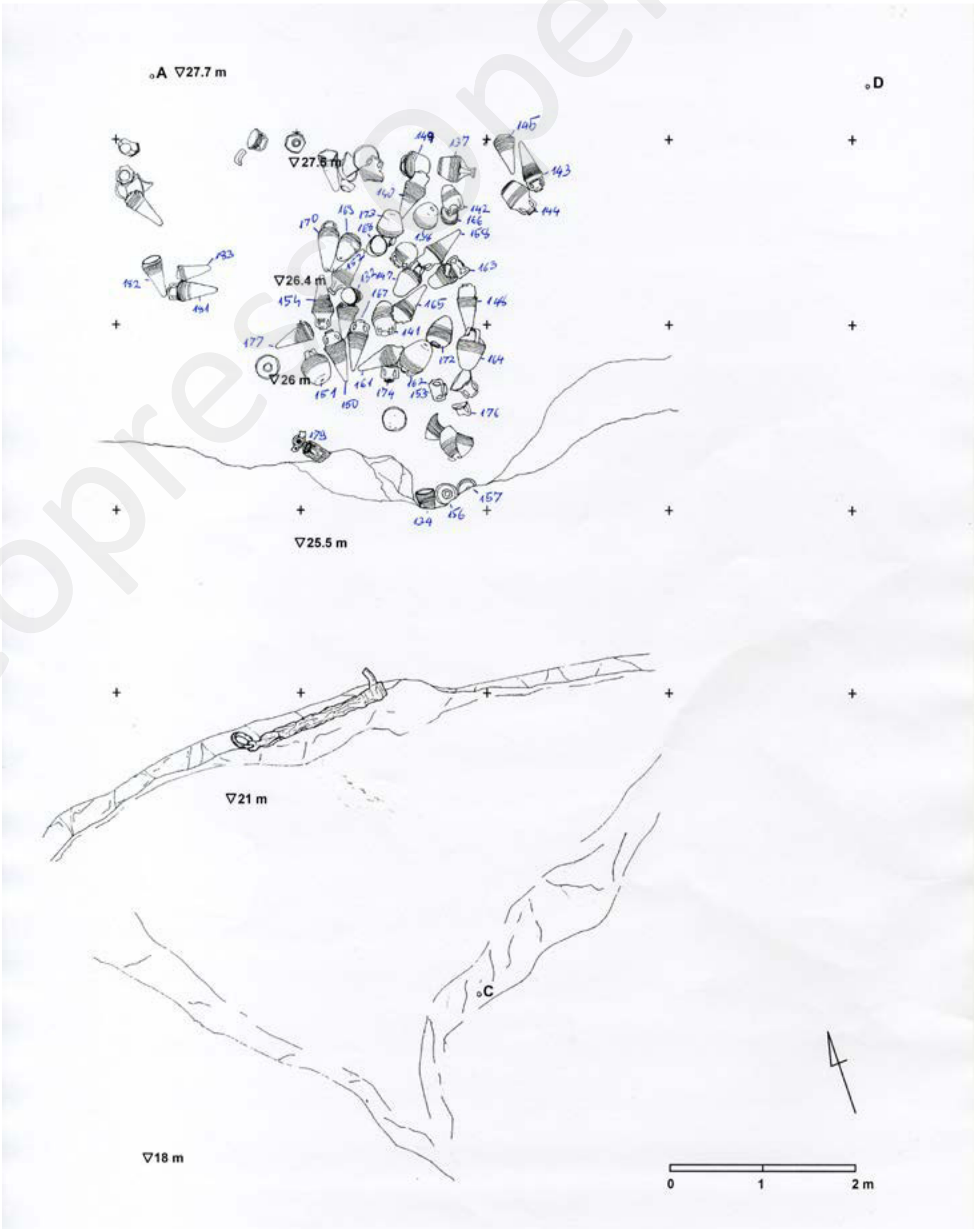


Figure 2: Plan of Cape Stoba wreck, documentation of the 2011 season (drawings: V. Zmaic).

Figure 3: Some of the 3D models of the amphoras (reconstruction: E. Costa).

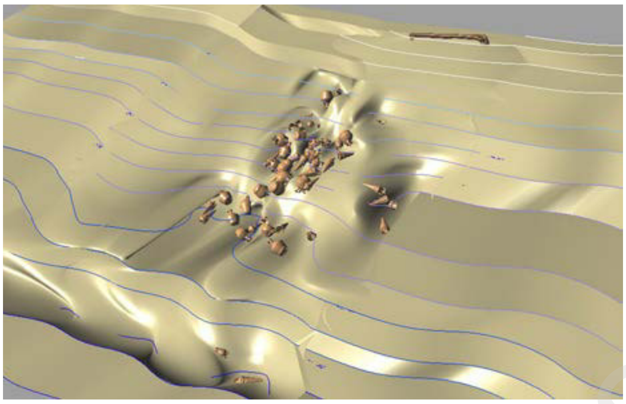


Figure 4: Some of the 3D model of the amphoras (reconstruction: E. Costa, S. Caressa).

Figures 5 and 6: 3D model of the central part of the cargo from two different perspective. (reconstruction: E. Costa, S. Caressa).

The seasons of excavation from 2009 to 2011, coordinated by the Conservation Institute of Zagreb, had produced detailed excavation plans of the cargo, which did not show the variation of the depth of the cargo, which was indicated only randomly on the plans (Fig. 2). At the end of the excavation, in 2012, we decided, therefore, to produce a three-dimensional documentation of the wreck, to show the complexity of the cargo layout in detail. In this situation, we decided to produce the 3D model using photogrammetry from free positions. This type of documentation produces measurable photography, that allows the calculation of the three-dimensional coordinates of each element, and consequently its precise position in space.

This documentation is based on three phases of survey:

- the measurement of the amphoras made in the laboratory after the excavation;
- the theoretical model of the amphoras, the geometry necessary for the graphic representation of the objects;
- the photogrammetric survey based on underwater photography (Drap, 2012 b).

From the two-dimensional drawings of the different types of amphora, we produced the 3D model, both of intact and fragmented amphoras recovered in the site,

Figure 7: Sveti Pavao (Isle of Mljet, Croatia) shipwreck (photo: D. Della Libera).

producing the outline of the object, which was rotated around the vertical axes of the amphora to create the solid wire-frame (Fig. 3) (Green, 2004). For this we used the software Rhinoceros, an application used to create solid figure, to which is possible to apply photographic textures. After the modeling according to the real dimensions, all the amphoras were scaled and positioned in space by the spatial coordinates obtained from photogrammetry. At a later stage, from the bathymetric survey, which was also obtained by photogrammetry , we produced the model of the seabed, a rocky ridge (Fig. 4).

To finish the model, all the surfaces created were rendered by the application of photographic textures that reproduced the colors and features of the original elements (Figs. 5, 6).

Because before the beginning of the Italian-Croatian collaboration on this site, the documentation was only two-dimensional, we are now working on the plans and the depths indicated on these to produce a 3D model of the entire site.

In this way, the 3D model of the entire cargo and of the morphology of the seabed allowed us to illustrate realistic views of the context from different points of view. This type of representation provided more detailed information than the conventional archaeological site plan (Green, 2004).

The second case study is a late 16th century AD Venetian shipwreck, armed with bronze artillery, with a cargo of Iznik pottery, which was discovered at the bottom of the so called Sveti Pavao cliff at the isle of Mljet (Beltrame, Gelichi & Miholjek, 2014). During the 2010 and 2011 seasons, the Croatian and Italian mission decided to excavate and document a section of a hull, preserved at 42 m, to study its construction technique (Fig. 7).

Due to the depth, beyond sport-diving limits, which, although the divers used Nitrox, did not allow more that 18 minutes' bottom-time, we had to use a very fast technique for the documentation. At the same time, this technique had to be precise due to the particular subject, that is a section of wooden hull where each small detail is important for understanding the technique of connection of each element, and where the edges of wooden element were not clearly visible.

Firstly, we decided to carry out photogrammetry from free positions and, secondly, to make a 3D model which could allow a better study of the construction details, also giving the possibility of obtaining measurements of the various elements directly from it. The depth of the hull and the perishability of the wood did not allow us, indeed, to leave the hull uncovered for future investigation, but required immediate covering, with no chance of returning to the site for further measurements.

For the production of the 3D model, made with the Rhinoceros software, the available documentation was only the two-dimensional drawings produced by the photogrammetry, one plan and three cross-sections (Fig. 8), photographs of details of each wooden element and some measurements. Transverse sections were made on only three of the ten frames individuated (Alfonso, 2014). Considering that the thickness of the other frames and of the longitudinal elements as keelson, maststep and *cosce* were not shown, to recreate the correct shape and position of these absent elements, we needed to use, in addition to the two-dimensional drawings, the photographic

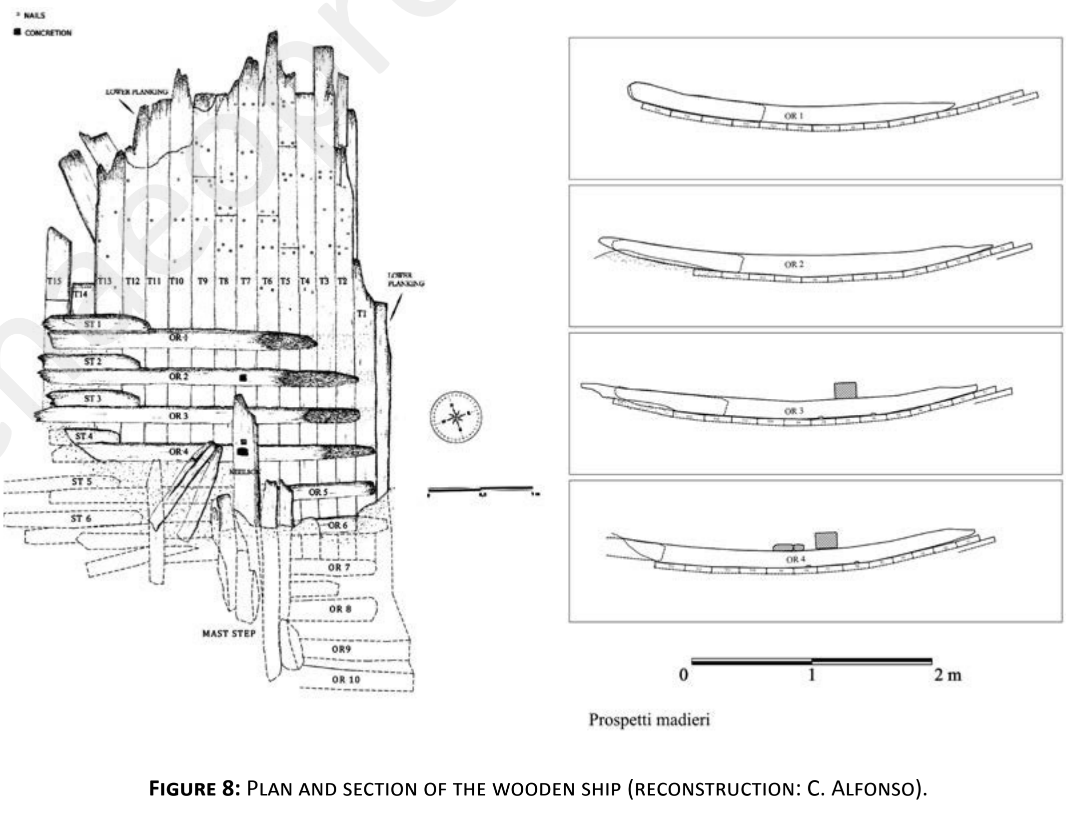


Figure 8: Plan and section of the wooden ship (reconstruction: C. Alfonso).

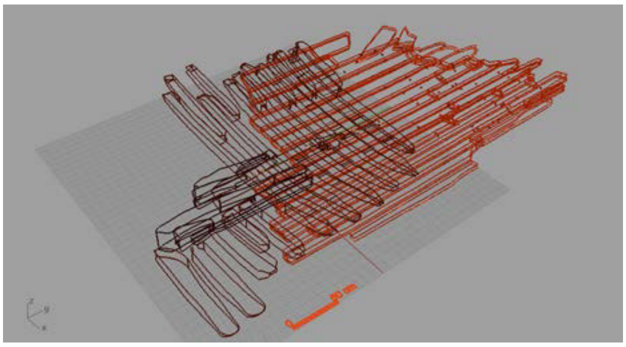


Figure 9: 3D reconstruction of the wooden ship, wireframe (reconstruction: E. Costa).

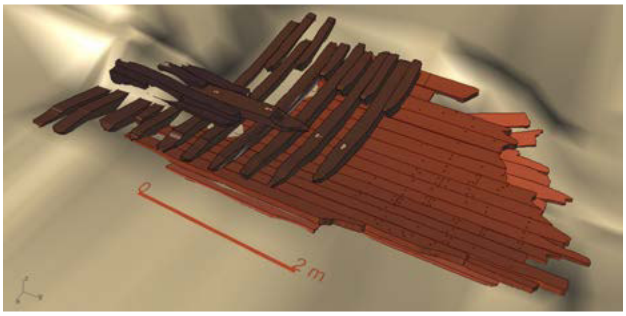


Figure 10: 3D reconstruction of the wooden ship, surfaces (reconstruction: E. Costa).

Figures 11 and 12: 3D reconstruction of the wooden ship, textures (reconstruction: E. Costa).

Figure 13: Punta Scifo D (Crotone, Italy) Roman shipwreck (photo: D. Della Libera).

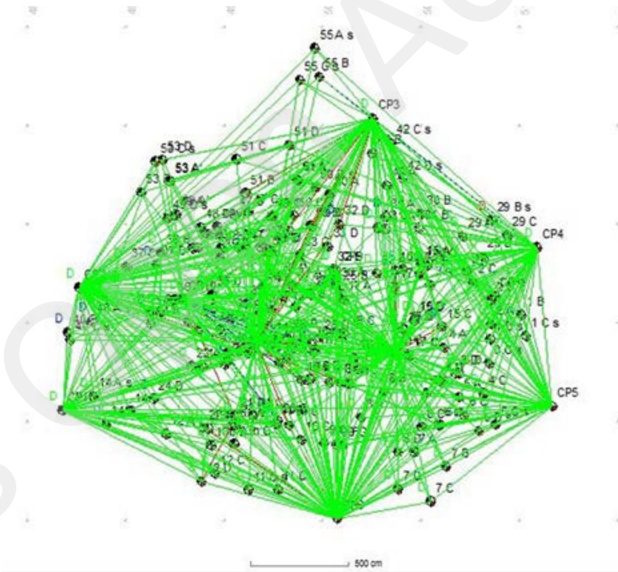


Figure 14: Triangulation of the points with DSM (processing: E. Costa).

Figure 15: 3D reconstruction of the marble cargo, Rhinoceros (reconstruction: E. Costa).

documentation and the measurements taken underwater by the naval archaeologist. The combination of these various types of information helped us to illustrate all the construction elements of the wooden ship, modeled on the actual dimensions of the shipwreck (Figs. 9, 10). For the rendering we used different textures for each species of wood, with specific wood grain and color, which is important to recreate realistic features of wood, essential for the study of the naval construction (Figs. 11, 12) (Costa, 2014).

This kind of documentation allows us also to analyze, study and appreciate technical details of the construction of the hull from different perspectives and allows us to measure construction elements every moments after excavation, without the necessity of re-exposing the underwater site.

Furthermore, this model will be used as the basis for a 3D reconstruction of the entire hull before the sinking.

The last case study is completely different; both in its environment, and the archaeological subject. It is a cargo of marble blocks and slabs sunk in the 3rd century AD in the shallow waters of Punta Scifo near Crotone, in Italy (Medaglia, Beltrame & Lazzarini, 2013) (Fig. 13). The depth of 6 m did not impose any limitation to bottom-time for the documentation, but the 20 x 15 m area of the shipwreck and, in particular, the dimensions and different depths of the marble blocks suggested the creation of a 3D model to show the third dimension, and to allow the next process of reconstruction, both of the formation processes, and of the original arrangement of the cargo aboard.

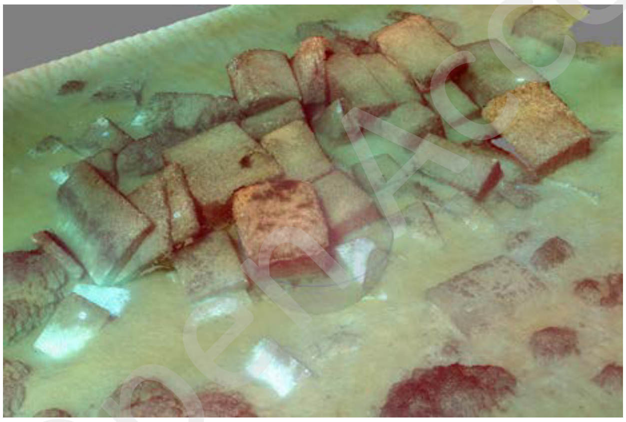
The possibility of working underwater for two hours, for each pair of divers, and the square shape of the blocks suggested the use of the DSM technique which requires the construction of a net of control points all around the site to take both linear measurements and depths (with a simple dive computer). The data were processed with Site Surveyor software to create a series of points with x, y, z coordinate (Fig. 14). It was then possible to import this net of points into 3D software to model and render the cargo (Fig. 15).

The photomosaic, made during the 2013 season, has recently been used to experiment a technique of documentation which is quite new in underwater archaeology.

Today a number of software solutions, based on the Structure-From-Motion (SFM) and Dense Multi-View 3D Reconstruction (DMVR) algorithms, can produce three-dimensional data even with a low cost equipment (McCarthy & Benjamin, 2014). They allow the production of high quality 3D models by using unordered image collections that depict a site or an object from different viewpoints. The main advantage of having uncalibrated cameras, or other types of image acquisition devices, is the easiness of the acquisition process (Dellepiane, Dell' Unto, Callieri, Lindgren & Scopigno, 2014).

These algorithms simultaneously estimate the parameters of internal and external orientation and the coordinates of the object. Some interesting tools for close range applications have been developed in the areas of computer graphics, computer science and automation to support 3D acquisition in a short time and at low costs (Remondino & Rizzi, 2010; Koutsoudis,Vidmar, Ioannakis, Arnaoutoglou, Pavlidis & Chamzas, 2014).

A Nikon D700 camera with a 20 mm lens was used for the photogrammetric survey of a double set of images. Approximately 120 photographs were taken acquired and oriented to model the wreck. The images were processed with the Photoscan software of Agisoft, one of the major commercial SFM-DMVR software currently available. Photoscan is an advanced image-based 3D modeling solution aimed at creating professional quality 3D content from still images; based on the latest multi-view



Figures 16 and 17: 3D reconstruction of the wooden ship, textures (reconstruction: F. Guerra).

3D reconstruction technology. It operates with arbitrary images, and is efficient in both controlled and uncontrolled conditions. Photographs can be taken from any position, providing that the object to be reconstructed is visible in at least two images; both image alignment and 3D model reconstruction are fully automated. The SFM method uses a number of unordered images that depict an object from arbitrary viewpoints and attempts to recover camera parameters and a sparse points cloud that represents the three-dimensional geometry of a scene.

Camera position and scene geometry are reconstructed simultaneously through the automatic identification of matching features in multiple images. These features are tracked from image to image, enabling initial estimates of camera positions and object coordinates, which are then refined iteratively using non-linear least-squares minimization. The procedure of image processing and 3D model construction of the bas-relief can be described as follows:

- The first stage is the camera alignment: the software searches for common points in photographs and matches them, and also finds the position of the camera for each picture and refines camera calibration parameters. As a result a sparse points cloud and a set of camera positions are formed;
- The second stage is building a dense points cloud based on the previously estimated camera positions and the pictures themselves;
- The third stage is obtaining the 3D polygonal mesh, representing the object surface based on the dense points cloud;

- The fourth stage is applying the texture to the polygonal mesh.

The model of the marble blocks produced by this technology is very satisfying, both in accuracy and appearance; indeed the view of the context is very realistic and very attractive (Figs. 16, 17).

From this model it is possible to create ortho-photos and sections, closely resembling the two-dimensional documents commonly used by archaeologists for recording data and publications (Drap, 2012 a).

This technique allows the use underwater of a solution which makes a product very similar to that of a laser scanner, which is impossible to use in this environment and which would cost much more. We must also consider that the points cloud is already photochromatic, contrary to the laser scanner which uses a default color: this characteristic allows us to match the original color to each item.

The technique of photogrammetrical documentation with points clouds appears to be the most promising one, especially in the practicability and cost, because it needs only a simple underwater camera and open-source software (Skarlatos, Demestiha & Kiparissi, 2012). Its appeal is great, and this is a characteristic which we cannot underestimate in the perspective of better diffusion of the archaeological research products.

Conclusion

considering the practical problems of the examples proposed, such as the great depth of the sites, the need to cover the subjects after the documentation and considering that the archaeological excavation is usually a destructive operation (Drap, 2012 b), we can say that photogrammetry and 3D reconstruction together give the best solution. This combination allow us to optimize the work underwater, and to acquire a more complete database than with two-dimensional drawings, affording a good basis for reconstruction studies of the ship and cargo. It is also obvious that three-dimensional visualization presents a global vision of an archaeological site that cannot be obtained by any other survey method (Drap, 2012 b). The 3D model allows a better view of the shipwreck in its context, because it is possible to move , rotate and view the site from any perspective (Green, 2004). Furthermore, it produces an image with great appeal for the public, who are able to appreciate much better the archaeological site with no experience of reading traditional archaeological documentation.

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