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**UNDERWATER
PHOTOGRAMMETRY
OF THE BOU FERRER
ARCHAEOLOGICAL SITE**

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INTRODUCTION

Photography is a well-established tool in the documentation of Underwater Cultural Heritage (PCS), it is used with different techniques and is oriented towards three main objectives: scientific, documentary and informative. Each one of them fulfills different missions in the underwater archaeological excavation that can be summarized as follows:

- Scientific photography: completes the investigation, they are images, but it is considered a data set, it helps to answer the research questions and extends to laboratory work.
- Documentary photography: complete the diary with more information and document the memory of the intervention, record data on the color, shape and location of the materials, record the proportion and orientation -for which it includes a graphic scale, an arrow of North orientation and a normalized color chart- shows the detail and the general, the processes and stages of the intervention.
- Informative photography: narrates the process, illustrates it and makes it understandable; highlights the moment, evokes and provokes, invites to think and conveys beauty to a non-specific audience.

Digital photogrammetry participates in these three large areas if the methodology is agile and the equipment affordable. The evolution of digital cameras has led to a significant reduction in the cost of equipment and a significant reduction in its size, together with an increase in quality and the optimization of file formats. In this digital context, photogrammetry applied to PCS is a recent technique that seeks to streamline and improve the archaeologist's documentation work. Its application is currently being generalized in the deposits, it

is aspired to replace conventional planimetry by another model that provides the same or better information, but more quickly and accurately. The communication of research results is becoming a requirement of society and photogrammetry allows scientific documentation to be extended to other uses such as dissemination. For Tejerina (2016) "a paradigm shift is taking place in the field work methodology that now seeks comprehensive documentation with techniques that for the first time allow us to obtain all this volume of information, making it possible to obtain a complete picture of the whole scene that we have around or of complete objects in three dimensions". Photogrammetry has the ability to present data in a clear, unambiguous and aesthetically pleasing way.

For Burke, Smith and Domingo (BURKE, SMITH AND DOMINGO, 2007:128) "the most important thing to accurately document a site is to ensure that the location of each indication can be linked to the rest, in such a way that no measurements remain. in the air, minimizing any source of error. In this line, Caballero (CABALLERO, 2006:75) states that "what really matters as archaeologists is not the objects themselves, but the relationship that exists between them (...) excavating is above all documenting the relationships that exist between contexts". These methodological positions are formulated for archeology on land, but they can necessarily be extrapolated to the documentation of the PCS. Even when it comes to documenting the excavation of a wreck, considered as a single set, from an exact moment, there is an internal stratigraphy that, if well documented, can provide substantial value. There must be no difference, therefore, between the methodology used on land and that used underwater.

Photogrammetry aims to obtain a three-dimensional model created from multiple photographs taken from different points of

view. The images are processed with specific software capable of detecting common points that appear in several images, from these points, the program calculates their relative positions and positions them in a three-axis coordinate system (Figure 1).

The Bou Ferrer archaeological site is the wreck of a Roman merchant from the early imperial period, for which recent research suggests a length of more than thirty meters. It carried a main cargo of Dressel 7-11 type amphorae, with four morphological variants, and a secondary cargo of lead ingots, stowed on the center line, on both sides of the keel. It is located in front of the city of La Vila Joiosa, on a muddy seabed at a depth of 24.5 meters, without the presence of *Posidonia oceanica*, in an environment of cloudy waters.

Since its discovery, in 1999, different excavation campaigns have been carried out, all of them promoted by the Generalitat Valenciana. In the interventions of the years 2014 and 2015, a three-dimensional photogrammetric record was made to obtain 3D models and metric precision orthophotos as a complement to the planimetry and documentation work. Thanks to the experience acquired and the results obtained, the planimetry of the 2016 campaign was carried out entirely with photogrammetry techniques, documenting three phases of the excavation (Figure 2).

Before any underwater photogrammetric restitution project, an initial evaluation of the site and the real physical conditions is necessary. In the case of the Bou Ferrer wreck, the following circumstances exist: it is located on a bottom at a depth of 24.5 meters, but the lower part of the deposit is more than 27 meters deep; the waters are generally cloudy and the morphology of the site, in its current state, is very complex, with significant unevenness and large holes, which make it difficult to capture images that cover

all the spaces. Most authors agree that the capture phase in photogrammetry accounts for 70% of the entire workflow, compared to 30% for the rest of the process. On the Internet portal Historic England, specialized in cultural heritage, its authors state that “in photogrammetry, the quality of the results depends almost entirely on the quality of the capture. Bad photography will inevitably lead to inaccurate results.” These recommendations always refer to field work carried out on land; in the underwater environment, the difficulties force us to estimate this percentage above 90%, taking into account the need for planning, the high probability of having to carry out replicas and the strong determining factors of the marine environment. All these circumstances are accentuated in the case of the Bou Ferrer wreck due to the conditions of its natural environment.

CAPTURE STRATEGY

Planning is essential if results-oriented objectives are sought and it is necessary to optimize the time under water to obtain reliable and quality data. As we have mentioned, it is necessary to record the shape, texture, dimensions and color, so that the documentation work is preserved and offers guarantees in its subsequent study.

Carrying out an improvised coverage records insufficient information that results in a processing with errors in the model. Authors such as Neumann (NEUMANN, 2009), P. Stoermer and Q. Abdullah (P. STOERMER AND Q. ABDULLAH, 2014) have developed methods for calculating the necessary number of photographs in aerial photogrammetric coverage, with flight height data and lens focal length¹. The underwater scope has certain similarities with the aerial one since the coverages are, in reality, flights over the bottom, and require

¹ <https://support.pix4d.com/hc/en-us/articles/202560249-TOOLS-GSD-Calculator#gsc.tab=0>

a type of calculation similar to that of aerial photogrammetry, although simplified. At the Bou Ferrer site we have used a modified and adapted Moya model (MOYA, 2017:99) based on the recommendations of these authors. It has been planned to record the surface of the excavation trench started in 2015, and create the 3D model and orthophotographs of that sector. It is a rectangle perpendicular to the center of the ship that cuts it at the height of the cockpit. The measurements of the rectangle are 6 meters wide by 17 meters long. To this rectangle we added 1 meter on each side to ensure the registration of the margins, with which the surface to be documented occupied a total area of 152m².

It is necessary to know the depth of the bottom on which the wreck rests and the maximum depth inside the excavation sector to determine the geometry of the site. In our case, as has already been mentioned, the depth of the bottom is 24.5 meters and that of the interior of the excavated sector slightly exceeds 27 meters. That is, there is an interior difference in level (Z axis) of 2.5 meters (figure 3).

The next step was to decide the photographic equipment that would be used to carry out the work, what is the size of the sensor that it incorporates and what lens will be used, with the focal length data expressed in millimeters. To this calculation has been added the correction factor that produces the refractive index of seawater, which is 1.33. For the work presented here, the photographic equipment incorporated a 15mm DF full format equivalent lens.

The next step was to estimate the portion of the deposit surface that the equipment with which we planned to carry out the work in each photographic shot must cover. Knowing the viewing angle of the target, we use this data to solve the surface segment that it will cover for a given height. The height is decided

based on the visibility of the water, hence the importance of this process. The horizontal angle of view of our underwater lens is 84° and a vertical angle of view of 62°.

An average visibility of 2 meters was established at the site, this distance will be the height (h) of the triangle formed by the viewing angle. With these two data it is already possible, by trigonometry, to solve the value of the sides of the theoretical triangle that is formed between the background and the camera sensor. This calculation is carried out in a simple way with the help of one of the online calculators such as TrianCal, which gives us a measurement of 3.6 meters for the longest side. Once the calculation is done, we export it to an application such as Geogebra, from the same calculator, so that it draws the already solved triangle for us (Figure 4).

The result is a horizontal vector of 3.6 meters, this is the length that will cover each photograph that we take at a distance of two meters from the background (Figure 5).

The process is repeated to calculate the vertical angle and obtain the measure of the shortest side of the rectangle (2.4 meters) that is exported to Geogebra so that it draws the solved triangle, as in the previous example.

The base/height ratio concept indicates that, to take photographic coverage, we must take into account an established relationship between the distance from the camera to the object and the distance that the camera must travel to take each photograph. It is about following a guideline to generate the necessary angles and distances between photographic shots that allow valid information to be obtained from which the photogrammetry software will be able to perform the calculations. The displacement between different photographic shots is related to the distance between the camera and the object to be documented and it is established that this displacement must be between 10% and 20%

of the distance between the camera and the object.

There are different opinions about what the overlap area must be. In aerial photogrammetry a value of 60% is used, on land we try to work with the greatest overlap possible without reaching such high values, there are several authors who recommend an overlap of 30%. In any case, it must be borne in mind that with greater overlaps, better results are always obtained because more coincident points are available, which translates into a higher resolution point cloud and a higher quality final model. The overlap concept is illustrated in Figure 6.

For the Bou Ferrer field, a 50% overlap was established in order to ensure coverage in all visibility conditions. The next step was to plan a layout that would allow obtaining enough images to build the model, the following table summarizes all the data with which the coverage planning was carried out.

For the documentation of objects with a round bulk, photographic coverage is usually carried out describing circles around the piece, but in the documentation of an extensive site, it is more appropriate to take the photographs in rectilinear paths through streets, in a similar way as is done in aerial photogrammetry, because it allows better control of both planning and camera positions.

In our case, if we respect a base/height ratio of 20%, and the photograph is taken 2 meters away from the background, it will be necessary to move, in each photographic shot, about 40 centimeters in both directions, along and across the zone.

The calculation of the number of photographs necessary to document the excavation sector is obtained by dividing the two distances that correspond to the length by the width of the rectangle (19x8m.) by 40cm. which results in a grid that is 47.5 streets long by 20 streets wide. The number of shots

necessary to cover the excavated area is 940 photographs (Figure 7).

Although Agisoft Photoscan is a very powerful software in the identification of common points between images, the aquatic environment, as we have already seen, homogenizes the environment: the light is very diffuse and the color tends to blue monochrome from a certain depth. This results in an increased difficulty for the app to sync images by identifying identical colors, textures, and shapes. For this reason, the use of unique targets, which generate control points recognizable by the software, is highly recommended to gain reliability in the PCS documentation.

The targets are generated by the same program and are coded with a unique number and shape that must not be repeated in the documentation of the same site, or at least of the same sector clearly differentiated from the rest. They can be printed in various sizes, in our case two sizes have been used, 5x5 cm. and 8x8cm. The former are useful for documenting small spaces or materials, and the latter work very well for general site marking.

The targets printed on white paper were cut out and laminated, leaving a wide margin of plastic on the paper so that it seals well and prevents water from entering due to the effect of pressure. In the margins of the plastic several holes were made to pass the plastic flanges with which the targets are fixed on the background elements. A series of fixed targets were placed in the deposit, maintaining a certain uniformity and anchoring them on materials that would not be extracted.

In certain sectors of interest, the documentation must provide as much data as possible. These are usually areas of special relevance, which in our case correspond to the stowage of a series of lead ingots on both sides of the keel, the first level of amphorae over the hold, or a well-preserved mattress of vine

shoots.

In these cases, the capture was intensified by taking the photographs crosswise, with four shots for each position, orienting the camera on both sides, towards the front and back, following the advice of Wackrow and Chandler (WACKROW AND CHANDLER, 2011), to who “oblique (horizontal and vertical) and converging images will minimize systematic errors caused by lens distortion”.

Carrying out an elevation by photogrammetry has been a very simple complement to execute (Figure 8). It is a profile made in the 2016 campaign for which only a few minutes of immersion were needed, it was made by a single person, with a GoPro H4 camera. The photogrammetric model was generated with 26 photographs to confirm the existence of at least four floors of amphorae preserved in the ship's hold.

The adoption of photogrammetry as the basis for documentation was extended to all the amphorae extracted from the site in order to obtain a three-dimensional model of each of them and their corresponding metrically correct archaeological drawing. With the use of this system, the overall photogrammetry improves because the number of reference targets increases. During processing, the application detects the targets at their exact location within the model. As each target is associated with a number, and this number with an object, we will be able to know at any time the exact place it originally occupied within the site.

When the pieces were extracted from the site, they were individually photographed to create their digital model, always keeping their target/label in the same position. The digitized objects make up the 3D collection of the site.

When the photographs of each object were taken, the available control conditions were used (Figure 9) to obtain complete

2 http://www.agisoft.com/pdf/tips_and_tricks/PhotoScan_Memory_Requirements.pdf

documentation. In addition to the model, a photograph with a scale, with a color chart and in RAW format was also taken and archived, although all the coverage was made in JPG format.

This way it is possible to individually analyze the formal features of each piece and compare them with the others. Each three-dimensional model can be relocated to its original position within the reservoir and related to the whole (Figure 10).

PROCESSING OF PHOTOGRAPHS FOR THE PREPARATION OF THE PHOTGRAMMETRIC MODEL

Before processing the images to obtain the photogrammetric model, we must assess the size of the photographic batches to be processed, evaluating both the resources of our team and the possibilities of alignment in a batch with a large number of photographs. Since the software used, as indicated, is Agisoft PhotoScan, we will take as a reference the performance and resource consumption table provided by the brand².

Although initially the photographic batches to be processed did not usually exceed 100 photographs, as the site has been expanded in successive campaigns, the number of images needed to obtain orthoimages has also grown. This way, the batches of images in the last campaign could easily exceed 500 images, thus raising the demands on our team in each of the steps that we will describe below.

In the first place, low or medium quality processing is carried out, something that will allow, with the equipment we have in the campaign, to be able to verify that the images taken during the coverage are sufficient to obtain an optimal model. This step is crucial to notify the team responsible for the capture in case it is necessary to repeat the coverage,

totally or partially, depending on the preliminary result obtained.

Once this first phase has been completed, we will begin the final processing, which will allow us to generate the orthoimage that will serve as the basis for the archaeologists' registration and documentation work. Taking into account the network of targets dispersed in the deposit, whose importance and use we have already commented on previously, the first step consists in the detection of these points by the software. Being targets encoded by PhotoScan, it has an automatic detection function, where the software itself positions a marker with the specific number of each of the targets. This information will be essential to support the alignment of the images and the creation of the dense point cloud, the basis for creating the three-dimensional model in successive steps. This way, the software, in the case of not finding enough stereopair information between the provided images, will resort to the targets themselves as valid points in the image alignment.

Once the target network has been detected, the alignment process begins (figure 11), which will give rise to a first point cloud, which will serve as the basis for the subsequent creation of a dense point cloud and depth maps. During this first phase, in addition, we will obtain a location of the capture point for each of the photographs, something that is very helpful when visualizing the capture strategy itself. In the case of locating areas where the number of points obtained is not quite sufficient, the position of the cameras helps us to check in subsequent captures where to increase the number of photographs, or how to orient the capture itself. It is also at this point that we introduce the metric values that provide a scale to the photogrammetric model. For this we use the network of targets already detected during the first phase of work, since we know the distance between points we provide the

software with partial measurements between each of the targets, something that ends up providing a global scale to the workspace (figure 12).

The second step consists of obtaining a dense point cloud (figure 11), which will serve as the basis for creating a mesh. Although there are other applications capable of managing the point clouds and continuing with the process, perhaps more efficiently, in our case the entire flow has been worked with the same program. This decision was essentially based on offering the rest of the participating team a flow based on simplicity as well as efficiency. We thus gave the possibility that any member of the team could complete the entire process until obtaining the orthoimage from the same software following a few simple steps.

Once the mesh creation process is complete, the texture is applied to the surface to obtain a model with a photorealistic appearance, which will allow the creation of an orthoimage. This image, which offers us a zenithal view of the site, is free of all optical aberrations and has the same validity as a cartographic map. After generating the orthoimage, it is printed and laminated to provide it to the underwater team, who use it as a stratum plan or as the basis for the necessary annotations to continue with the excavation work.

After generating the image, it is exported to vector design software, in our case AutoCAD from Autodesk (figure 13). In this type of software we can make the drawing by vectorizing everything that is considered especially noteworthy to carry out the documentation of the documented level: count of amphorae individuals, naval carpentry, etc.

In the last campaigns we have also incorporated the photogrammetry flow described previously to the parts documentation. This way, we have started the creation of the photogrammetric model of each of the amphorae extracted from the

archaeological site with the double objective of having a three-dimensional model of each one and its traditional archaeological drawing to complete its typological study.

Due to the large number of pieces already extracted, we devised a system that would speed up the capture of each one of the amphorae as much as possible. To do this, we used a support that allowed us to place the amphora vertically, with its pivot at the bottom and the edge at the top. After capturing the object in this position, making up to three rings to ensure complete coverage of the piece, a second shot was made, this time reversing the position of the amphora. This second capture greatly helps to document elements such as border, handles and pivot, which in the previous position are partially hidden. To complete the capture phase, partial measurements of the object were taken, indicating easily identifiable natural elements

as a reference (figure 14).

After the creation of the corresponding model, the reference points that have served us to take the partial measurements are identified, and each one was given a point or vector within the point cloud. The software used allows at this point to establish partial measurements between points, thus providing an automatic scaling to the model, a scale that is maintained after its export to the 3D PDF format, from which we can make all the necessary queries and even capture a perfect section of the image. part. This process has allowed us to obtain both the 3D model of the pieces, as well as their traditional drawing for a detailed classification. All this information is processed and stored in the corresponding database for future consultation and detailed study of the objects found during the excavation of the Bou-Ferrer wreck.

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