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3D MODELLING FROM ARCHIVE AND LEGACY DATA: PRELIMINARY DATA PROCESSING ON THE ROMAN SHIPWRECK GRADO I

1. Introduction and state of the art

Digital technologies are widely employed to support documentation and studies of researchers, in order to make cultural heritage and maritime archaeology available. The potential of these tools allows us to obtain 3D models from data archives and legacy data that can be studied and visualized with innovative solutions and technologies (Mollema, McKinnon 2016; Atkinson *et al.* 2019; Green 2019). The creation of a virtual 3D model from disused and unattractive archive documents allows the general public to access innovative archaeological research concerning archaeological sites that are not visible or not exhibited in museums (Mertes 2014).

Usually, a large amount of data is produced during the excavation of a shipwreck; some of these, called legacy data, become essentially useless, or usable only through difficult and time-consuming processes. The recovery of legacy data represents an essential requirement to avoid the loss of relevant data (Secci *et al.* 2019; Woods *et al.* 2020). Through the processing and elaboration of different kinds of documentation and legacy data, it is possible to obtain a complete virtual 3D model in order to allow the general public to access innovative archaeological research concerning underwater cultural heritage.

The team of Maritime Archaeology of the Ca' Foscari University is working on different archaeological topics to enhance knowledge about shipwrecks through these technologies. The first project to use legacy data concerns the Napoleonic brig *Mercurio*; on this shipwreck, excavated from 2001 to 2011 (Beltrame 2019), the researchers used legacy data and scanned the negatives of the analogical images from the reports of past excavations, proposing a particular and original way to generate a virtual model of ancient shipwrecks from archival and heterogeneous data of a non-conventional photogrammetric survey (Secci *et al.* 2019). Furthermore, the brig was modelled on the construction drawings of the twin sister brig Cygne to obtain a complete virtual model and create a digital museum installation at the Museo Nazionale di Archeologia del Mare in Caorle, Italy (Beltrame, Barbiani in press).

Another project was undertaken on the Byzantine shipwreck of Cape Stoba. A cargo of wine amphoras was virtually reconstructed and arranged in the original position by processing and analysing different types of documentation realized during the excavations, from 2009 to 2015, to obtain a complete model of the cargo that can be navigated following the stratigraphic excavation and where the disposal of the nine types of amphoras can be analysed using a digital 3D database (Costa 2019).

In pursuit of these goals, the team decided to work on a more complex archaeological site, analysing and processing the documentation realized from 1990 to 2000 with different techniques, some of which, such as underwater analogic photogrammetry, are obsolete. For the Roman shipwreck of Grado, we used the perspective drawings of the shipwreck and the amphoras, various measurements taken during the excavations, the analogical images (which we have digitalized), and the cardboard study model made in 2000 in order to obtain a complete virtual 3D model in its different phases, from the hull and the cargo *in situ* to the reconstruction of the original ship before the sinking. This activity is part of the Interreg Italy-Croatia UnderwaterMuse - Immersive Underwater Museum Experience for a Wider Inclusion Project, which promotes a new kind of accessibility to a wider public through a digital approach to the underwater archaeological sites of the Adriatic Sea, both on new sites and on old excavations. The main aim of our action is the development of a methodological and technological protocol for the documentation and the communication of an archaeological site as a complex and multi-stratified context. The objective is therefore to transform the site into an underwater archaeological park (or eco-museum) through digital, innovative, and experimental methodologies and techniques in order to disseminate the importance of underwater cultural heritages.

2. The Roman shipwreck Grado I

The wreck, which lays at a depth of 15 m, 6 miles off the coast of Grado (Gorizia), was discovered in 1986 and underwent numerous excavation campaigns, from 1987 to 1999, coordinated by Paola Lopreato of the local Archaeological Superintendence, which have seen the complete recovery of the cargo and, by dismantling of each single piece, of the hull. This kind of recovery of the wooden elements was a consequence of a failed project of one-solution recovery, which compromised the entire bow of the ship that had been destroyed, underwater, by a storm. The hull, preserved for a length of 13.1 m and a width of 6.1 m before the destruction of the bow, on the starboard side reaches the level of the deck of which very little evidence is conserved (Fig. 1a) (Auriemma 1999; Beltrame, Auriemma 2013). A reconstructive study, by mean of a 1:10 scale cardboard model, built at the Centre for Maritime Archaeology of Roskilde, allowed the estimation of the original size of the ship as 16.5 m length, 5.9 m width, in the main section, and 2 m height. The model, thanks to the use of the frames and the conservation of the first planks attached to the keel (garboards), allowed the reconstruction of

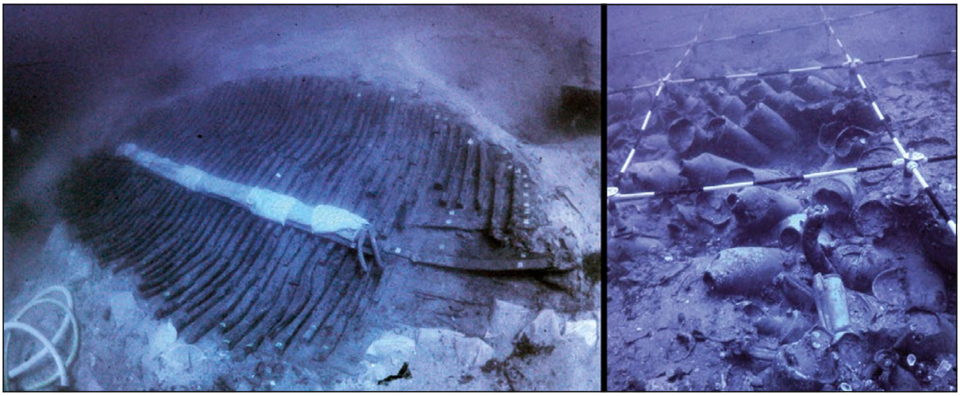

Fig. 1 – a) the hull during the excavation, after the recovery of the amphoras; b) a detail of the amphoras and the suction pump (photo Polo Museale Friuli Venezia Giulia).

the bow, despite the destruction of the planking and the loss of the junction of the keel with the stem (Beltrame, Gaddi 2000). The cargo was composed by a fragmented barrel filled with fragments of glass bottles and by different types of about 600 amphoras storing fish sauces that had been processed in various ways (Fig. 1b).

The main types of amphorae were the Tripolitana, the Knossos A/53 and a type of small northern Italian amphora, thus allowing the preliminary estimation of a total weight of the cargo of 23-25 tons and a dating of the sinking to the middle of the 2nd century AD (Auriemma 2000). The presence of a hole on the planking, close to the keel and where a lead tube was inserted, led to the hypothesis that this tube was part of a suction pump that kept fish alive during the journey (Fig. 1b). This means that the ship, perhaps before a restoration, possibly carried, on the deck, wooden water tanks for this special transportation (Beltrame *et al.* 2011).

The hull was assembled, probably in a shipyard of the Upper Adriatic littoral, using the mortise-and-tenon joints technique to connect the external planking, the deck, and the repairs of the planking. The cardboard model was made following the shell-first method, used by the Roman shipwright of this period, which implies the hull was built before inserting the frames, which only had the role of reinforcing the planking and to simply correct the shape determined by the junction of the planks.

Regarding the shipwreck, meticulous studies of the hull (Beltrame, Auriemma 2013) and the cargo (Auriemma 2000) have been realized. The surveys and studies have produced various kinds of results and data which provide an opportunity to experiment the use of this documentation to three-dimensionally reconstruct the entire shipwreck for an additional and more in-depth study of the shape of the hull; furthermore, these provide the possibility to share and disseminate to the whole public a complete and innovative visualization of an already investigated site that is no longer accessible. The original data available for the shipwreck consist of 1:1 scale perspective drawings (plans and sections) of the hull, of each single wooden element, and of the cargo of amphoras, a series of colour and black and white analogic slides and negatives to create photomosaics, a cardboard 1:10 scale model with its 2D reconstruction of the hull lines and its 3D digital model. A critical aspect of the project was represented by legacy and heterogeneous data collected during the excavation campaigns in the 1990s when the survey was obviously still not suitable to create a complex digital result. The work consists in different phases of data processing and the procedure can be schematically described as follows:

– 3D modelling of the *in situ* hull (§ 3.1);
– 3D modelling of the *in situ* cargo of amphoras (§ 3.2);
– combination of the two processing phases for the complete *in situ* shipwreck (§ 3.2);
– 3D reconstruction of the original lines of the hull (§ 4);
– 3D reconstruction of the stowing position of the amphoras (future step of the project);
– combination of the two processing phases for the complete original cargo boat (future step of the project).

3. Data processing: *in situ* shipwreck

3.1 *The hull*

The 3D reconstruction of the *in situ* hull was obtained by processing the documentation of the excavation campaigns and the 1:1 scale documentation of every wooden element made by C. Beltrame and D. Gaddi in the laboratory after the dismantling and recovery of the hull. We used the software Rhinoceros for the elaboration of the 2D and 3D models. First, we modelled the frames and longitudinal elements, tracing the 2D lines on the 1:1 perspective drawings made in the laboratory that had been extruded, cut on different planes and joined to obtain a 3D model of every structural wooden element of the hull. Second, we moved them to the correct position, based on the *in situ* plan. Indeed, the original excavation drawings concern two maps, the first with the entire hull (external and internal planks, frames and longitudinal structural elements), the second with the highlighted structure and disposition of the frames. These elements were rotated consistently with the correct sections of the hull, obtained from the recovery project, which included a structure to lift the entire hull, designed at regular graphic sections every 50 cm

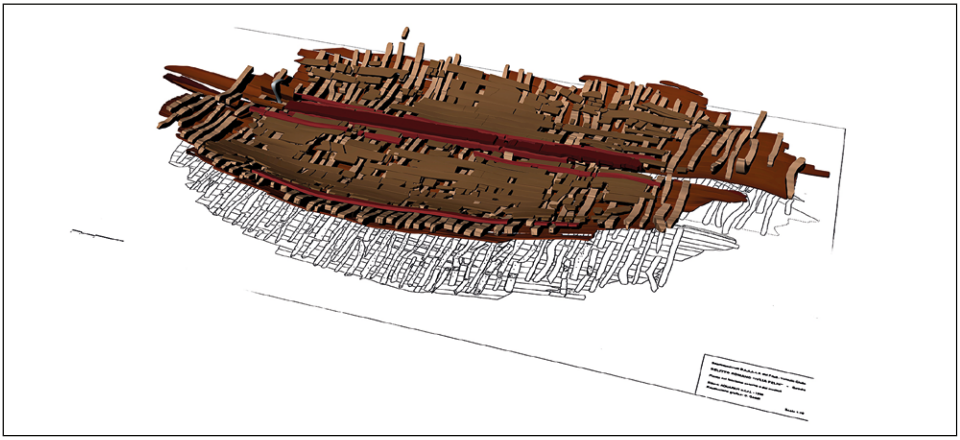

Fig. 2 – 3D model of the *in situ* hull (elaboration E. Costa).

on the hull; each of them was extrapolated and transversally placed in the correct section position extracted from the drawings of the structure. The external planking was created as a unique surface projected from the bottom onto the frames to maintain the perfect corresponding shape, it was extruded on the measurement of the thickness of the planks and was subdivided into twelve planks of the port side and nineteen planks of the starboard side, consistent with the correct shape from the drawings. The complete model of the *in situ* hull was subsequently compared and adjusted with the millimetric measurements of the archaeological sections, manually realized during the excavation. Every fragment of the inner planking was created on the *in situ* plan of the site and was leaned on the frames (Fig. 2).

3.2 *The cargo of amphoras*

The model of the cargo of the amphoras was created using two different procedures, which were subsequently compared and integrated. The excavation phases of the cargo of amphoras were documented daily in 1990 with a series of black and white analogic images designed to create a simple photomosaic. Consulting this kind of legacy data, stored in the archive of Polo Museale Friuli Venezia Giulia, was time-consuming due to the large amount of pre-processing operations. To obtain a digital workspace, the images had to be scanned and every group of images, due to their different light exposure, had to be separately enhanced and corrected in order to obtain better alignment of the images. Furthermore, the scanned images do not have Exif data and they do not maintain the parameters of digital images (position of principal point, focal length and distortion of the lens) that had to be employed by

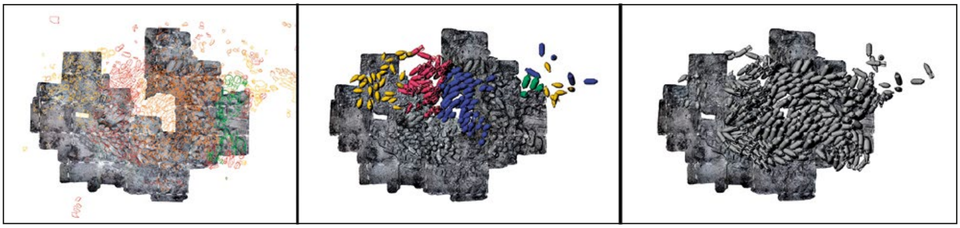

Fig. 3 – a) 1990 photogrammetric survey and vectorization of the 1995 plan; b) photogrammetric survey with the missing amphoras; c) photogrammetric survey with all the amphoras of one layer (elaboration E. Costa).

Fig. 4 – 3D model of the *in situ* hull and cargo (elaboration E. Costa).

photogrammetric software to create the inner orientation. A sufficient overlap and the automatic camera calibration of the software Agisoft Photoscan allowed the alignment of the images, the creation of a dense point cloud and the elaboration of a 3D model.

We had to retrieve the metric data from the plastic grid on the site that was regularly built every 1.50 m; the insertion of the obtained coordinates optimized the system convergence during the alignment phase of the images and improved the metric accuracy of the photogrammetric model. This alignment of the images is therefore metrically correct and the check with the coordinates on the sites could be defined as the correctness of the entire photogrammetric model, even without the digital parameters. We obtained four different projects of the excavation phase, which will be useful for future works regarding the dissemination of the procedures concerning excavation of an underwater archaeological site with amphoras and a hull. For this study

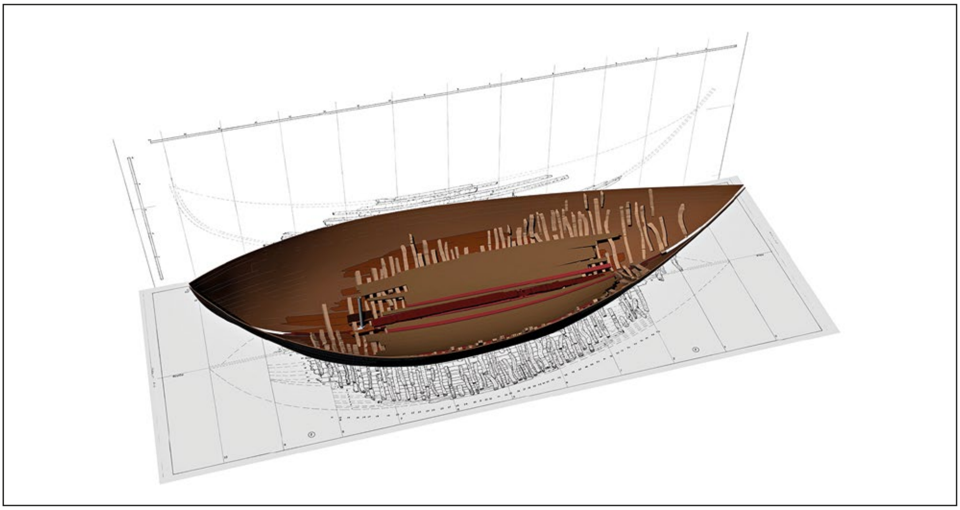

Fig. 5 – 3D model of the original lines of the hull (elaboration E. Costa).

we decided to document the last phase of the excavation process with this technique, which represents more than half of the cargo of amphoras.

In 1994 the cargo was completely excavated and, before the recovery of all the amphoras, an archaeological plan of the cargo was realized (Auriemma 1999). The plan was employed to integrate the 1990 photogrammetric survey with its missing parts. The software Rhinoceros was used to virtually model the amphoras and to overlay and integrate the two surveys (Fig. 3a). The two surveys perfectly correspond, and first we integrated the missing amphoras from the 1990 photogrammetric model and those in the 1994 plan (Fig. 3b), then we modelled all the amphoras of one layer (Fig. 3c).

To reconstruct the entire cargo, despite the photogrammetric model, we reproduced the same analytical process of the Byzantine shipwreck undertaken in 2016-2019 (Costa 2019), processing the 3D prototypes model of the seven typologies with a 360° revolution of the archaeological drawings together with the integrations of the handles. We matched each model with the photogrammetric model and with the existing plan, positioning xy coordinates on the drawings and z coordinates according to the overlapping of the amphoras and the measured vector from the feet and necks. The typologies of amphoras were differently coloured and modelled in seven different layers, allowing the analysis of their disposition on the site and facilitating the reconstruction of the original stowing position. The two processing phases were combined and the 3D model of the hull was integrated with the cargo of amphoras to obtain the complete *in situ* shipwreck (Fig. 4).

4. Data processing: reconstructed hull

After the excavations and the recovery of the shipwreck after dismantling (given that the single recovery solution failed), the hull lines were studied through the building of a 1:10 scale model in cardboard and plexiglass realized at the Centre of Maritime Archaeology in Roskilde by C. Beltrame and D. Gaddi (Beltrame, Auriemma 2013). This was subsequently surveyed, by the same researchers, using a measuring Cam2 Faro Arm to obtain a schematic geometric model of the constructive lines in correspondence with the frames and the planks. The cardboard model was also manually surveyed by G. Penzo (2000) to create the plan and the prospect of the starboard side. These data were integrated and compared to obtain the digital model of the preserved part and of the hypothetical lines of the hull.

First, we reconstructed two different surfaces, one on the transversal sections of the hull lines, manually surveyed, and one on the vector lines of the Faro Arm survey, but, since none of them naturally shaped, we decided to use the potential of digital tools to adjust some sections reaching a correct surface at a medium solution between the measures of both surveys. To check the correctness of the created surface of the hull, the scale cardboard model was surveyed with photogrammetry obtaining a point cloud used as a comparison. After that, we projected the original shapes of the existing planks on the surface, based on the 1:10 drawings of archaeological remains of the hull and we cut it into the twelve and nineteen existing portions of the hull. Then, the frames were duplicated from the *in situ* model and were rotated to perfectly match the surface, confirming the accuracy of the reconstructed shape of the hull lines. The inner planking was created on an inner surface in contact with the frames, reconstructing the original lines from the fragments (Fig. 5).

5. Conclusion

The next step of the activity on the Grado I Roman shipwreck will be the reconstruction of all the missing elements of the ship, showing, with different colours, the archaeological remains, the elements reconstructed on the basis of existing sources, and the elements completely reconstructed on hypotheses or comparisons with other shipwrecks. The work regarding the cargo, in contrast, will continue with the reconstruction of all the amphoras in the stowing position, before the sinking, starting from the disposition of them on the *in situ* model of the cargo. Then, the amphoras will be rotated from the tilted position of the sinking to the vertical position of the original cargo and will be moved in the stowing place, in correspondence of the frame and inner planking of the reconstructed hull.

Concluding, the recovery of archive and legacy data represents an essential requirement to avoid the loss of relevant information, but, at the same time, this kind of survey and documentation presents some critical aspects that could be resolved with a solid know-how in digital techniques. This work, as an action of the Interreg Italy-Croatia UnderwaterMuse - Immersive Underwater Museum Experience for a Wider Inclusion Project, wants to promote a digital accessibility for a wider public, following the main aim of the projects to disseminate the importance of the underwater cultural heritage. Digital technologies and innovative solutions allow the new visualization of sites that had not been available to the public before, such as the Grado I shipwreck.

At the same time, our work aims to focus on the relevance of the reuse of legacy data as an important tool in studying and analysing old documentation on shipwrecks; recreating an archaeological site through virtual technologies opens up the possibility of continuing the study of a site even after the archaeological investigation has ended, improving the scientific process of archaeological research.

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Elisa Costa, Carlo Beltrame

Dipartimento di Studi Umanistici

Università Ca' Foscari Venezia

elisa.costa@unive.it, beltrame@unive.it

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ABSTRACT

Ca' Foscari University is addressing different archaeological issues to enhance knowledge about shipwrecks through digital technologies. In the last few years, the team has applied virtual modelling and digital techniques on archive and legacy data, starting with an innovative museum installation regarding the wreck of the Napoleonic brig Mercurio and cargos of amphoras of the Byzantine shipwreck of Cape Stoba. The potential of digital technologies has allowed us to analyse and elaborate different kinds of documentation, including archives, to obtain 3D models that could be studied and visualized with innovative technological solutions. The paper presents an original proposal to create a 3D virtual model of an ancient shipwreck based on archival and heterogeneous data. Regarding the Grado I Roman shipwreck, we processed perspective drawings of the hull and the amphoras, measurements during the excavations, digitalization of analogical images and of a survey of the cardboard scale model to obtain a complete virtual 3D model of the shipwreck. Legacy data represent a precious source for bringing to life obsolete representations of cultural heritage.