3D DIGITALIZATION AND VISUALIZATION OF ARCHAEOLOGICAL ARTIFACTS WITH THE USE OF PHOTOGRAMMETRY AND VIRTUAL REALITY SYSTEM

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ABSTRACT:

Digital technologies are increasingly being used in the field of archaeology to provide three-dimensional metric information to scholars and help them in the process of understanding and interpreting the site under investigation. Among different surveying methods certainly photogrammetry has many advantages being a low cost, reliable and fast technique, but most importantly it allows the creation of realistic and interactive 3D models that can be viewed and interpreted by a wider audience. This certainly makes the enjoyment of sites easier and makes data accessible from anywhere. This study shows three particularly significant case studies in the archaeological field where photogrammetry has served as support. These case studies are representative of specific situations in which archaeology requires digitization of artefacts. The first one concerns the Temple of Apollo in Gortyn (Crete, Greece), the second one is the ancient city of Nora (Sardinia, Italy) and the third one is the Museo Civico of Eremitani in Padua (Italy). The paper explains how 3D metric surveying has served for the representation and analysis of stratigraphic sections of buildings in the case of the Gortyn site, for the creation of virtual tours of archaeological sites in the case of Nora, and for the documentation and visualization of small artifacts in the case of the Museo Civico of Eremitani by highlighting potentials and criticalities of the method.

1. INTRODUCTION: ARCHAEOLOGY AND 3D DIGITALIZATION

In recent years the growing interest in digital technologies to facilitate metric surveying and to create very high resolution 3D models also concerns archaeology, especially for aspects related to the documentation and enhancement of cultural heritage sites. The digitalization process allows the generation of three-dimensional virtual models which contain all the metric information about the archaeological asset or artifact. The advantage of the creation of this digital models is the documentation and preservation of the data. The virtual storage in digital archive or database allows the study of the shape, the history, the colours and the dimensions of the object, also remotely (Morena et al., 2019).
Thanks to improvements related to digitization, this has become a practice in archaeology for several reasons.
First of all, digitalization process helps to recover information about the archaeological context during the excavation and the work in the field.
Manual drawing and surveying during excavations is a time-consuming step, yet it is still widely used to document the layers that are gradually uncovered during exploration. Laser scanning and photogrammetry are widely used techniques during excavation for improving and make faster the acquisition phase (Alby, 2015).
Archaeology in the field is in fact an inherently de-constructive activity (Howland et al., 2014) and combining digital solutions with the manual traditional way of data acquisition improves the way discoveries from the excavation are recorded, aiding the preservation and management of this information in a structured manner.
In this way, digitalization becomes the first step of knowledge process.
Secondly, digitalization concerns the interpretation and the visualization of the acquired data. In particular the creation of realistic and interactive 3D models of archaeological site make them accessible for anyone from every part of the world and their fruition more interesting for the tourists. Moreover, the implementation of a database containing information as a reference for documentation with the possibility of the introduction of these data and models for display on the web is a good way to make these data available to researchers and those interested in this area. (Khalaf et al., 2018).
This study shows experiences in which metric surveying has served as a support for archaeology, especially with reference to three different fields of application for the achievement of three different goals previously highlighted (Figure 1).
In particular different techniques of low-cost 3D digital acquisition are presented in order to promote the interpretation and visualization of the information concerned the archaeological assets.

Figure 1. The knowledge process for archaeological study.

This research is interested in investigating how photogrammetry can be a useful and low-cost tool for obtaining metric three-

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dimensional models for archaeological studies. Photogrammetry, in fact, allows the creation of digital 3D models faster and more reliable from a metric point of view than other techniques. In particular, the proposed method aims to obtain models that can be used for visualization purposes on web platforms and the creation of virtual tours.
Three different case studies will be shown relating to different situations in which archaeology requires digitization of artefacts. The first one concerns the Temple of Apollo in Gortyn (Crete, Greece), the second one is the ancient city of Nora (Sardinia, Italy) and the third one is the Museo Civico of Eremitani in Padua (Italy).
The remaining part of the paper proceeds as follows: the first section gives a brief overview of the recent state of the art about 3D digitalization in the archaeological context, the second section will examine the case studies selected for the implementation of digitalization techniques. Finally the third section deals with the discussion of the obtained results and conclusions.

2. STATE OF THE ART

Different techniques are used for the 3D digitalization of cultural heritage and archaeological site. However, in order to solve problems related to data acquisition and processing of complex asset in which an easy survey is not feasible for the dimension and position, photogrammetry is the most adequate technique to guarantee high level of metric quality and of details and at the same time to obtain lightweight and easily managed data on web platforms (Dell'Asta et al., 2016).
Previous studies have addressed problems related to both the acquisition and processing part of data from museums and archaeological sites using photogrammetry. Although all studies agree that photogrammetry is a low-cost technique for this type of study, some issues were highlighted in different previous research.
With regard to the acquisition phase, light conditions, the reflective material as metal, and the size of the object can greatly influence the final result (Farella et al., 2022).
In this direction, a novel approach was proposed to support non-experts working in museums with robust, easy-to-use workflows based on low-cost widespread devices, aimed at the study, classification, preservation, communication and restoration of cultural heritage artefacts combining the data acquisition using mobile equipment and visualization with a Real-Time Rendering (Apollonio et al., 2021).
Regarding the creation of 3D models, there are other issues such as the accuracy of artefact representation, texture quality and mesh simplification in order to optimize web visualization (Farella et al. 2022).
In order to obtain 3D models of high metric precision mesh and maximum colour fidelity textures macrophotography technique was proposed saving costs and processing time (Antinozzi et al, 2020; Marziali et al. 2017; Clini et al., 2016).
To solve the problem of reflective or translucent materials another study analysed spectral photogrammetry as a possible solution (Mathys et al., 2019).
Considering all these issues, in the following sections the instruments, the techniques and the methodology both for the acquisition and the processing of the data are presented according to the selected case studies.

3. DIGITALIZATION OF ARCHAEOLOGICAL SITES

3.1 Temple of Apollo in Gortyn

The first selected case study concerns the temple of Apollo of Gortyn in Crete which constitutes one of the most significant religious and civic poles since the birth of the Cretan polis.

The Temple of Apollo Pythios in Gortyn represents one of the most significant monuments of the city, which covers about 300 hectares and served as the capital of the Roman province of Crete and Cyrenaica. The building's extraordinary importance derives from the presence of a large number of Greek inscriptions dating back to the 7th century B.C. that were engraved on its stepped plinth and on stone slabs placed in the sanctuary area. Such inscriptions constitute the oldest code of laws in the ancient world. After the discovery of the monument in 1887, the elaborate complex of ruins was surveyed in a cursory manner using rudimentary instruments of the time (Halbherr, 1890). For almost a hundred years the remains of the sacred building did not attract scholarly attention and only in 1984 were they the subject of a two-dimensional manual survey (Ricciardi, 1987). Currently, the resumption of investigations (Bonetto et al., 2021, Bonetto et al., 2020) made it necessary to perform new surveys for the archaeological and architectural study of the building. Thus, a survey by total station of the planimetric layout of the various parts of the sacred enclosure was carried out, but a three-dimensional analysis of the complex preserved structural framework appeared immediately necessary. The full 3D survey appeared necessary both for the representation of the structural and stratigraphic sections of the building and for the analysis of the elements no longer in situ. In fact, in situ masonry is flanked by numerous architectural elements (columns, capitals, entablatures) in a collapsed position (Salvalaggio et al., 2021). Their study, aimed at reconstructing the building, necessarily required physical knowledge of their reality and thus a three-dimensional photogrammetric survey from which to derive point clouds, meshes and models.

The work therefore was organized as follows. The survey was carried out by dividing the area into distinct areas in such a way as to lighten the virtual navigation of the model. For each area, the survey was designed to have both an overview of the area and individual details. Each element can be detached from the rest and visualized separately to make an in-depth study of it.
A full frame camera Nikon D750 with a 35 mm lens was used for image acquisition in order to have textures in the models of the highest quality. In fact, for this type of analysis it is necessary to be able to zoom in on every detail and thus have great resolution.

The metric survey with close-range and the creation of a 3D model made it possible to read the evolution of the building and its functions over time and to show more layers and details than the manual archaeological survey.

In the following figures it is possible to see the high-resolution 3D models (Figure 2), the excavation area and the individual elements in detail (Figure 3 and Figure 4).

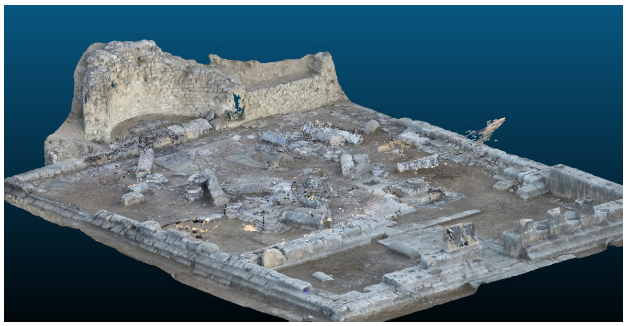

Figure 2. Photogrammetric reconstruction of the exavation area Apollo Temple in Gortyn (Crete).

Figure 3. Photogrammetric reconstruction of a detail of the apse of the temple.

Figure 4. Photogrammetric reconstruction of architectural elements inside the temple.

3.2 Nora

The second case study is Nora, one of Sardinia's major centres from the Phoenician, Punic and Roman periods.
The ancient city of Nora is known in ancient sources as the oldest city on the island (Bonetto et al., 2018). The settlement was founded by Phoenician merchants during the 8th century BC and soon became a commercial point of reference for exchanges between merchants and inland Nuragic populations (Bonetto, 2021). The centre developed on a narrow tongue of land and on a promontory that was gradually occupied in its entirety. In Roman times the city expanded to occupy an area of 15 hectares, which were affected by paved roads, private and public buildings, infrastructural works, and productive spaces. The city was abandoned in the early Middle Ages and almost forgotten. With excavations in the middle of the last century, important portions of the Roman phase city have been unearthed, but most of it lacks an integral survey of structures. In addition, the large mass of tourists who visit the site each year, about 70,000 people, do not have a digital tool for viewing and learning about the site that could attract new people or ensure remote knowledge. Therefore, this appeared entirely necessary both to operate the promotion of the Archaeological Park through online tools, to allow virtual visits and to better know a reality that constitutes the fundamental basis of the economic development of the area.

Among the various digital techniques, certainly those concerning the immersive and interactive visualizations of excavation data generate a lot of interest among both scholars and tourists. Among these, virtual reality applications such as virtual tours are particularly useful to make the visit of an archaeological site accessible to everyone, even remotely. Virtual tours are a good and low-cost method for increasing the level of interaction between visitors and archaeological site and museum objects (Khalaf et al., 2018).

Besides the precious information that virtual tour shows, this technique presents the advantage of the low price of the 360° camera used for the data acquisition and the related software for the processing (Mah et al., 2019).
However, problems relating to the incorrect alignment of images can cause errors and unrealistic views by the viewer.

For this reason, the instrument used for the acquisition of the images was the Kandao Obsidian R 8K 360° VR camera, which is capable of capturing very high resolution 360° 3D images and videos thanks to six fisheye lenses (Figure 5).

Figure 5. Kandao Obsidian R 8K camera positioned along the tourist route of the excavation.

The images were acquired in such a way as to make the virtual visit as close as possible to the real one, by choosing significant viewpoints and at such a distance as to make the journey fluid and dynamic.
Thanks to the use of spherical cameras, it was possible to create a virtual tour of the entire city to be enjoyed remotely or through virtual reality viewers. A realistic and navigable virtual tour was realized through the acquisition of 360° images (Figure 6, Figure 7 and Figure 8).

Figure 6. Panoramic view of the archaeological site of Nora.

Figure 7. Panoramic view of the archaeological site of Nora.

Figure 8. Panoramic view of the archaeological site of Nora.

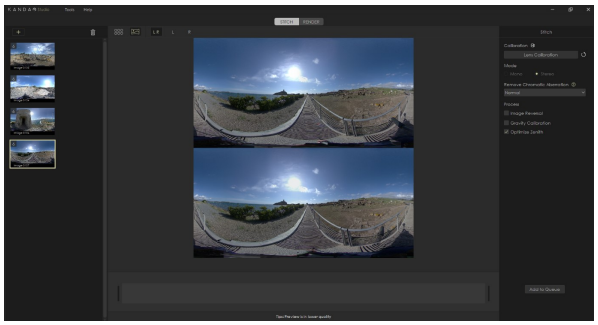

Figure 9. Processing of the panoramic view using the Kandao Studio software.

The software has a very intuitive and user friendly interface. It is possible to check the result of the overlays and manually set certain options in order to avoid problems of incorrect image alignment (Figure 9).

Finally, the virtual tour was completed using the Kuula web app (https://kuula.co/), which allows the addition of transitions between images and the management of the relationships between them. Moreover, it is possible to enrich the tour with additional information about the site.

The tour starts from the plan of the archaeological site of Nora (Figure 10) in which the route followed by tourists is highlighted in gray, along which some points of interest have been chosen: clicking on the hotspot in red moves one from one image to another following the tour route (Figure 11 and Figure 12), clicking on the hotspot in blue allows one to admire the site from positions generally not accessible to tourists (Figure 13 and Figure 14). The plan can be accessed at any time during the tour by clicking on the appropriate icon.

Once the virtual tour has begun, it is possible to move between images simply by clicking on the arrows in white.
The virtual site visit, therefore, can be done either sequentially by following the connections between one image and another or randomly by locating the site of interest directly on the map depending on the user's interest.

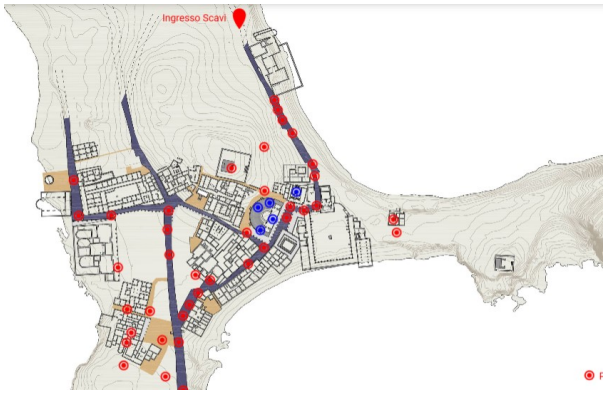

Figure 10. The start of the virtual tour from the plan of the archaeological site of Nora.

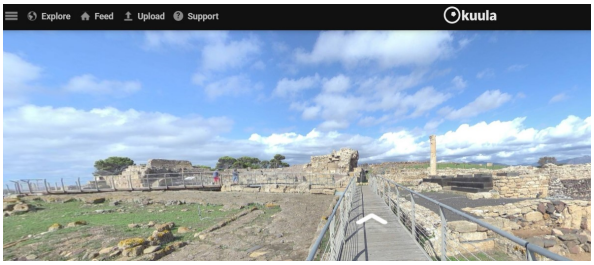

Figure 11. Point of view during the tour route where the white arrow that allows movements appears: clicking on it takes you to Figure 12.

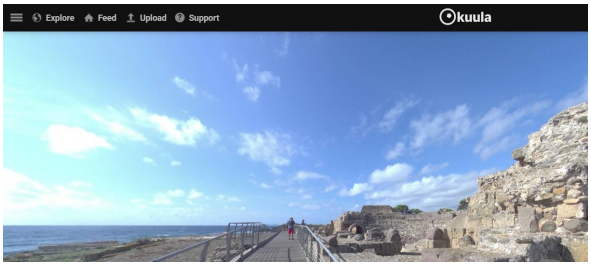

Figure 12. Point of view during the visit route following Figure 11 in which the white arrow appears to allow movements.

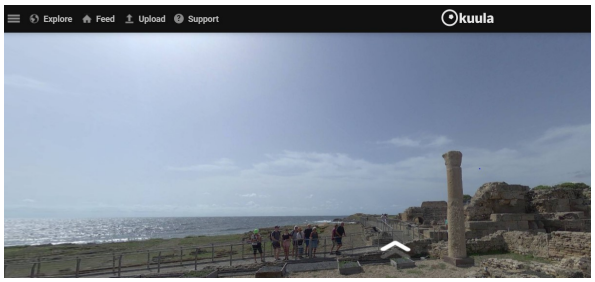

Figure 13. Viewing spot not accessible to tourists.

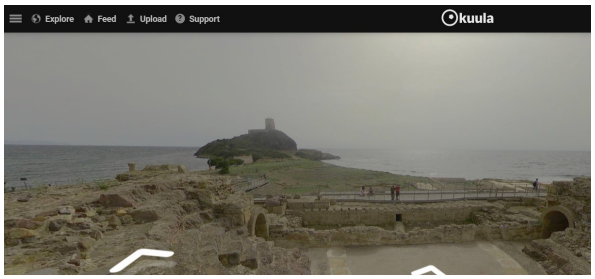

Figure 14. Viewing spot not accessible to tourists.

3.3 Museo Civico agli Eremitani in Padua

The third case study is the digitalization of archaeological artifacts of the Museo Civico in Padua.

The Museo Civico agli Eremitani in Padua represents the richest and most prestigious nucleus of archaeological and art-historical collections in the city of Veneto (Banzato, 1993 and Banzato, 1998). In particular, it preserves a very large series of artifacts from the Egyptian, Greek, Roman, Veneto and medieval periods that are the result of research activities in the Padua area, but also of donations from private collectors.
As part of the *Hybrid Sustainable World* project, funded by the Veneto Region in 2020, it appeared necessary to initiate digitization of a first series of small and medium-sized archaeological finds belonging to necropolis and places of worship from the Venetian and Roman periods (Figure 15). Digitization appeared to be the most effective means of making the rich archaeological heritage available to all scholars through its remote analysis.

The advantage of using the technique of photogrammetry for archaeological data acquisition is mainly its low cost and the speed of acquisition. It also allows the conservation of shapes, colours, materials even in case of small objects or with complex geometry (Quattrini et al., 2017). In addition, problems related to the accessibility of archaeological artefacts are overcome due to the ease with which this technique can be used.

On the other hand, other problems arise related to the visualization phase of the acquired and processed data. The obtained 3D model, in fact, present very high resolution. In particular, the biggest problem lies in the huge point clouds that do not allow the visualization of the generated models on online platforms. Digital 3D models obtained from photogrammetric processing must be optimized to solve problems due to different texture resolutions, gaps and inconsistencies due to geometric complexity.

For this reason, during data processing with the open source software Meshlab (https://www.meshlab.net/), the 3D models were thoroughly cleaned and improved with an high texture resolution, and correcting defective and missing parts. In addition, the models were made lighter in terms of visualization and computation performance.

Figure 15. Artifacts from Museo Civico (Padua).

All the models obtained from the processing were stored in the Sketchfab (https://sketchfab.com/) web portal to give visibility to the museum by communicating the research results to a wider audience, not just academics. the models were catalogued according to the acquisition technique, materials, and their location within the museum. To improve the search of archaeological objects within the database, tags were added to reference metadata characteristics.

In this way, not only was a scientific archive of the museum's collection created, but the visualization and history of objects

that are normally difficult to view during a classic museum visit because they are placed in display cases is made accessible.
Moreover, the Department of Cultural Heritage of University of Padua is developing a special platform (ArchaeoHybrid) for the digitization and visualization of ancient artifacts which allows a dimensional and material study of the original of much facilitated and made faster, avoiding scholars' movements, long authorization processes, stays at museum sites and other logistical difficulties.

4. CONCLUSIONS

This paper showed some successful digitization experiences that occurred in three different situations of archaeological sites to be enhanced. In fact, digitization has been a tool for knowledge and interpretation of archaeological sites in an innovative way. Digitization was implemented through the use of metric surveys with low-cost technology mainly based on photogrammetry, which allowed obtaining 3D models used for the purpose of documentation and visualization of archaeological data through virtual tours and web platforms.
For the case of Apollo temple in Gortyn the physical knowledge of the building through 3D survey was necessary both for the representation of the structural and stratigraphic sections of the building and for the analysis of the elements no longer in situ. While for the case of Nora and the Museo Eremitani digitalization made available archaeological heritage to all scholars through its remote analysis.
The findings of this study have a number of practical implications. These technological solutions, in fact, ensure greater dissemination and knowledge of the archaeological site with the aim of accentuating the interest of scholars and the public. Indeed, heritage data become accessible from anywhere in the world, which offers enormous potential for conveying information, immersive experiences, and increasing interest in these places.
Further research could also be conducted to determine the effectiveness of the photogrammetry applied in more challenging context related to museums and archaeological sites such as micro object or with complex geometry.

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