



Original Study

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New Perspectives on the Sanctuary of Aesculapius in Nora (Sardinia): From Photogrammetry to Visualizing and Querying Tools

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Abstract: The ritual space of the Sanctuary of Aesculapius in Nora (Sardinia) is the main focus of a recent archaeological campaign led by the Cultural Heritage Department of the University of Padova. A partnership with 3DOM research group (Fondazione Bruno Kessler, Trento) has offered new opportunities for a digital investigation of the site. The aim of the project is to map and visualize the sanctuary with methodologies enabling different users to engage with the site in new ways. They offer different web tools for exploring, understanding and interacting with the site, by focusing on 3D modelling, semantic enrichment and the contextualization of digital records. The entire site of Nora has been surveyed by a drone, which produced a digital model of the peninsula. A number of outputs have been used for different scales of visualization and a range of purposes: an open source multi-resolution web renderer is used to navigate the point cloud, labelled using a system of bounding boxes. At the same time it provides access to a 2.5D model of each building. Plugins in QGIS are used to produce extrusions of any mapped feature, gaining height values from the point cloud, and attributes from the shapefile. Photogrammetric models of single ritual artifacts can be located in their own context and be displayed using 3D web renderers.

Keywords: Nora, Sanctuary of Aesculapius, Photogrammetry, Potree, Webgis

1 Introduction

The world of archaeology has always been receptive to investigating and applying new technologies. It is now dealing with products that are very effective in visualizing and querying data, such as 3D models from photogrammetry and increasingly efficient Geographic Information Systems (GIS), whose connection to the Web makes them constantly online and accessible. They can be considered a resource not only for research, but the even harder mission of cultural dissemination, the transformation of a scientific input into historical knowledge, context and value. On the other hand, a wide interdisciplinary approach in archaeology does encourage co-working practices and employing common standards, as asserted by the Principles of Seville and the London Charter (Denard, 2009; López-Menchero & Grande, 2011), which

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are a clear sign of a community acknowledging Digital Humanities as a part of itself. This contribution is intended to reach specific solutions for the analysis of the ritual complex of the Sanctuary of Aesculapius in Nora (Sardinia, Italy), as well as to explore opportunities for managing new virtual models in order to make them meaningful and informative about the complexity of the reality. The project is described step by step, from planning and carrying out the photogrammetric survey to the semantic enrichment and establishing feasible ways of publishing and disseminating. Even different targets have been considered, in order to convey both general and specific insights.

The sanctuary of Aesculapius, where new investigations have recently taken place, requiring a new topographic survey, is an appropriate site for such a wide experiment: it is strictly connected with the surrounding context, from the cliffs facing the sea to the processional road cutting the city and leading to the sanctuary itself. The results provide a range of models for different points of view that are suitable for future developments, especially for analysis and dissemination purposes.

2 The Site of Nora and the Sanctuary of Aesculapius

Since the early 1990s the University of Padova has been taking part in an inter-university excavation project in Nora, an archaeological site in the South of Sardinia, Italy (Fig. 1). The ancient city of Nora was situated on the southern coast of the island, a strategic point for the trading routes along the Mediterranean Sea. The city rises up on a promontory overlooking the sea and grew out of a seasonal Phoenician *emporium*. Little traces of the first settlement have been uncovered on the southern area of the site, where postholes cut on the bedrock suggest the presence of wooden huts settled facing the coast (Bonetto, Ghiotto, & Novello, 2005; Bonetto, 2014). The settlement developed during the Punic occupancy, fostering urban growth and exploitation of the hinterland. Proofs of a new permanent community have been shown by craft and sacred districts spotted in several areas of the site, and by a wide necropolis dated to between the late 5th to the 3rd century BC. (Oggiano, 2005; Bonetto, 2009; Bonetto, Bridi, Carraro, Dilaria, & Mazzariol, in press). After the Romans conquered the island (second half of the 3rd century BC) Nora grew up as a Roman city with temples, baths, a *forum* and a theatre. A peculiar urbanistic program took place in the Severian Age (early 3rd century AD), enhancing the monumental aspect of the city (Ghiotto, 2004; Bonetto & Falezza, 2009; Bejor, 2013). Since Medieval times the site has been abandoned and never settled again.



Figure 1. The site of Nora. Location of the archaeological site and overview on the site. Image: M. Vincent.

Excavations started in the middle of the last century, but half of the city still waits to be uncovered (Patróni, 1904; Pesce, 1972; Tronchetti, 2001). The sanctuary of Aesculapius has witnessed the same history. It stands on the southernmost point of the peninsula, surrounded by the open sea (Fig. 2). Recent excavations have actually revealed some postholes and archaic pottery (Bonetto & Marinello, 2018) attesting to occupancy since the 8th–7th century BC. This evidence, similar to the situation identified under the Roman *forum* in the south-east area of the peninsula (Bonetto, 2009) allows it to be reasonably supposed that archaic occupancy took place in this area too. The religious purpose of the area has been attested only since Punic times, when the sanctuary was part of a sacred belt enclosing the Punic centre along with two additional sanctuaries placed on the highest reliefs at the site. This first sanctuary was established as a *sacellum*, a small shrine built with big blocks, and a base for a typical eastern votive shrine, the *maabed* (Pesce, 1952–54), where the god's icon was sheltered. Only its architrave has been recovered: it was decorated with a relief of fifteen erect and facing snakes and, in the middle, the winged sun. To this same period dates a typical female protome with an archaic aspect recalling the typical *ex-voto* of the late-archaic age (2nd-half of the 6th century BC–1st-half of the 5th century BC. Bonetto & Marinello, 2018). It was found within a secondary deposit, but it is probably linked to the sanctuary. Analogous terracotta offerings are usually adorned with little holes to hang them on the walls of the temple (Croissant, 1983, pp. 6–7).

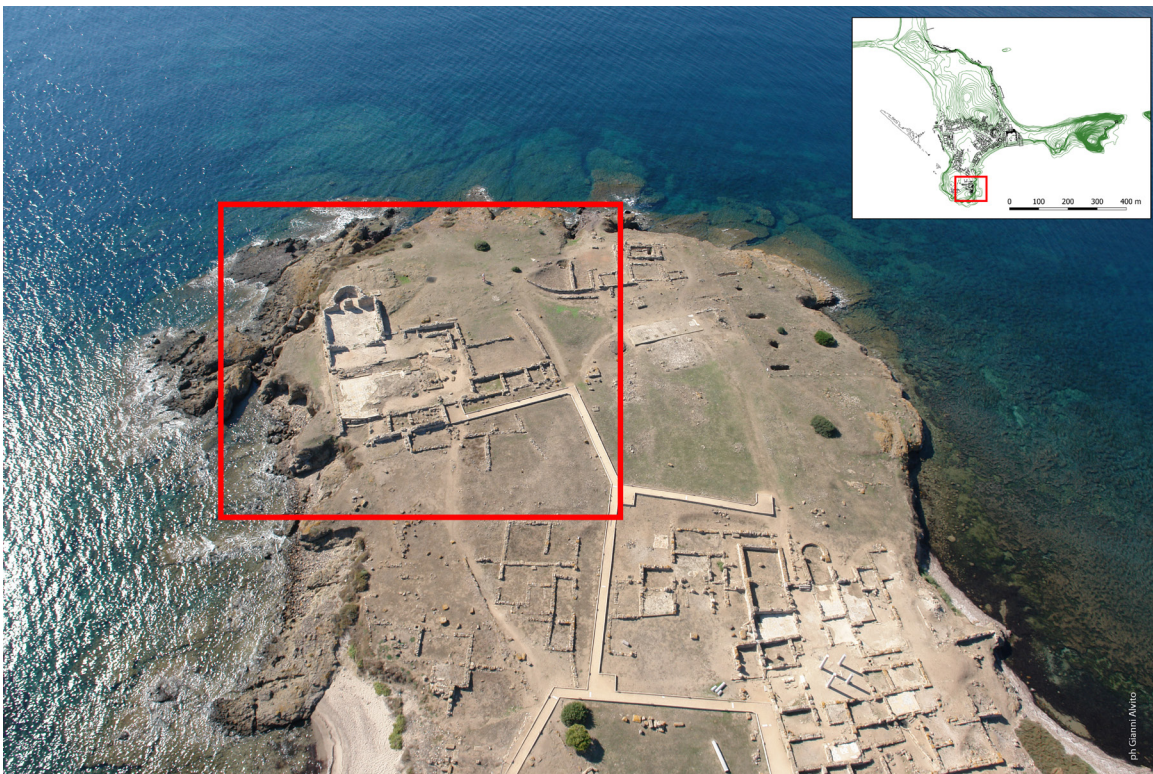


Figure 2. An aerial picture of the sanctuary of Aesculapius (in the red square). Image: G. Alvito.

The monumental enhancement of the sanctuary occurred during the 3rd century AD, together with a global renewal of the entire city. The sanctuary developed on three terraces, accessible by a staircase from the contemporary processional road. An open-air courtyard, decorated with a geometric mosaic, led to the temple itself. The temple was composed of two columns leading into the *pronaos* (Bonetto & Marinello, 2017). Beyond, the *cella*, probably uncovered and decorated with *opus sectile*, was the access to the inner and most sacred part, the *adyton*, which was an apsidal space divided in two rooms by a wall. This could have contained the statue of the god and the precious donations, or have contained a double cult. A western room opened from the temple, where first excavations revealed a votive deposit with six terracotta figurines

that had been ritually broken and dated to the 2nd century BC (two are 76 cm tall, whereas the other four figurines are 25 cm tall. They are currently housed at Museo Archeologico Nazionale di Cagliari). They represent offering or sleeping figures, and one of them is coiled by a snake (Pesce, 1956). This iconography led G. Pesce (1956, pp. 302–304) to relate the sanctuary to Aesculapius, the god of medicine, whose apparition during dreams could guarantee the healing of devotees (Fig. 3).

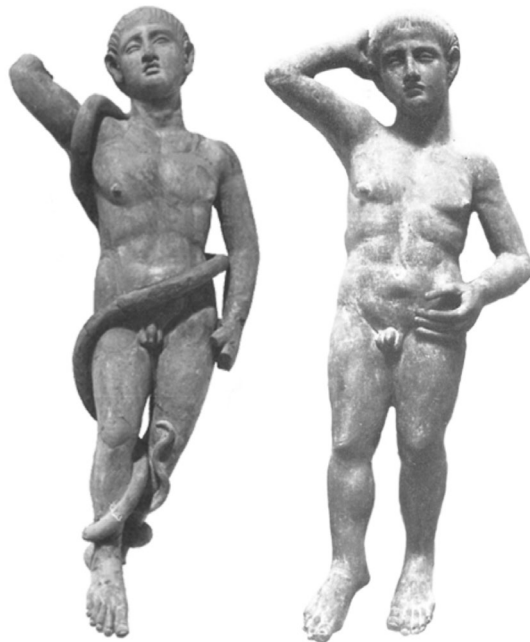


Figure 3. Reproduction of the Punic votive shrine (*maabed*) and two examples of terracotta sleeping figurines. Images: Bonetto et al., 2018; Angiolillo, 1985.

3 The Photogrammetric Survey

New archaeological surveys, aided by total stations and GPS, also needed to fit in a new cartography of the existing structures, both inside the sacred area and on the surrounding urban context. Ensuring correct alignment between new and past surveys was an essential task, which had to be achieved through

cartography that had to be precise, accurate and even informative, both as regards metadata and archaeological information.

The dimensions of the peninsula (more than 16 hectares) warranted an UAV (Unmanned Aerial Vehicle) photogrammetric survey, aimed to map the entire site on a scale of 1:100. The flights and the processing were carried out in May 2017, in partnership with 3DOM (Fondazione Bruno Kessler, Trento), the Master on GIScience and the Department of Cultural Heritage (University of Padova). Choosing the right period for flying is not trivial: whilst May could be considered a favourable month, given average climate and visibility conditions, modifications to the flight paths had to be made to respond to the seagull colonies nesting on the site and raising their chicks. Nevertheless the result was a set of 2400 aerial pictures, both from nadir and oblique flights, with a medium resolution (or Ground Sampling Distance) of 1.7 cm. Flights were planned as a net with 75% forward and 50% side overlap. Blind spots, such as streets under the trees or mosaics under pavillions were integrated with a terrestrial photogrammetric survey, providing 1500 additional pictures to the dataset. The processing of the entire dataset, performed in Agisoft Photoscan (versions 1.2.6 e 1.3.4) and constrained with a GPS-based network of Ground Control Points and some random coordinates measured on natural features, resulted in a final planimetric Root Mean Square Error of 0.025 m and 0.087 in heights. It produced a dense point cloud of more than 450 million points that was further processed on a grid of tiles in order to manage the large size of the model.

The orthophoto of the sacred area of the sanctuary of Aesculapius, with a resolution of 2 cm, allowed the digitization of a new map of the sanctuary. This new map, along with the new digital terrain model and the orthophoto enabled a GIS project to be set up, where every feature class could be enriched with an introductory database. Land surveys from excavations have been loaded as well, hence testing the topological accuracy between maps from different sources (Fig. 4).

4 The Visualizing Purpose

The second part of the paper is dedicated to a sequence of visualizing experiments, resulting from the substantial informative potential achieved with the photogrammetric survey. Indeed, the survey provided much more than a single basemap. Such a complex model of point clouds and meshes is a significant resource, both as a basemap and as a new way of visualizing, analysing and approaching the archaeological site. Every different step of visualization (point cloud, mesh and vector maps) targets a range of scales and increases the depth of understanding that can be achieved. Therefore they could be addressed in different ways and scales to different addressees (application of virtual archaeology for research and dissemination purposes is widely discussed: acute considerations and case studies can be found in Forte & Beltrami, 2000; Nicolucci, 2007; Forte, 2014; Dell'Unto, Landeschi, Apel, & Poggi, 2017; Galeazzi, 2018). The first target is the community of scholars, especially those dedicated to studying the site of Nora itself. This model of the reality can be a tool for exploring, measuring, querying, comparing, and eventually integrating previous excavations. In other words, the aim is providing researchers with a study tool, easily accessible and customizable, that could be queried offsite in order to gain quantitative data (such as length measures, volumes and heights). As an alternative, scholars could use the model as a basemap for their own projects, as they have already done with a brand new virtual reconstruction project, that is now in progress at the University of Padova. A second target could be administrators, who can use the high degree of certainty that the survey provides and the effective three-dimensional environment to inform their decision-making policies. Finally, we have the community of tourists and people interested in cultural heritage. They deserve tools to explore, understand and be enriched by what can be so opaque as an archaeological excavation. Their first need is to contextualize both monuments and artifacts by means of a more realistic three-dimensional visualization, a consistent three-dimensional positioning of archaeological records for contextualizing purposes and a semantic enrichment of what is shown. The visualizing tests reported below are still on a local repository, yet all the tools that have been used are web tools that are conceived to be published online as soon as they are completed and tested.



Figure 4. First outcomes of the project. The photogrammetric processing was focused on long area of the site, mapping the sanctuary and the so-called processional road leading to the temple. Orthophoto, DTM and vector maps are the main outcomes.

4.1 Visualizing the Site as an Enriched Point Cloud

The most complete and agile representation of the site is provided by the point cloud. Indeed, it represents the closest reproduction of the real world, as regards metric accuracy. Not only it is a flexible model, since it can be easily changed in density and point size, but it is a fitting tool to display the entire site within its surroundings. The visualization of the point cloud on the web has been assigned to Potree, an open source web point cloud renderer, created by the Wien University of Technology (Potree's source code can be downloaded from <http://www.potree.org>; Schuetz, 2016). It is based on Three.js, the WebGL 3D rendering library, which makes Potree well suited for visualization purposes, since it enables interactive 3D graphics to be rendered on a web browser. Potree relies on a modifiable nested octree model, which recursively subdivides a unit of space into 8 sub-units to store point cloud data and load only those nodes visible from the current point of view. This hierarchical structure allows a fast and multi-resolution handling even of large datasets. The processing is managed by Potree Converter, a tool which builds the octree data structure from the point cloud assembling an HTML template page for the renderer (Fig. 5). The page is provided with a panel of tools, for quantitative and qualitative purposes. They operate on rendering options, related to density, point size and interpolation options. They are also tools for spatial and topographic queries, namely for getting coordinates and heights, but also for measuring areas and volumes or producing cross-sections that can be exported as *json* or *dxf* formats. Beyond geometrical learning, a useful feature of Potree is the Annotation tool, which supports the semantic enrichment of the model and is remarkably useful for dissemination purposes by marking punctual spots. The use of an open source system allows independent management of the renderer, exploring new solutions especially for a semantic labelling of architectonic complexes. The sanctuary, as well as other archaeological structures at the site, has been defined by a new solid transparent geometry, to which size and centre coordinates are attributed, and which acts as a bounding box around the structure. A newly defined area of interest, which is responsive to the pointer, would be identified by its own label, containing a link to a new web page where more information is stored.



Figure 5. Potree's interface. The web renderer shows the point cloud of the site, providing a toolbox for geometrical analyses of the model. One of these tools produces the profile along a cross-section, as shown on the bottom window. Labels on the point cloud semantically inform the model.

4.2 A 2.5D WebGIS

The second level of examination seeks to gain a more detailed insight into the single architectural complex, sourcing directly from a GIS platform (QGIS 2.18).

The three-dimensional component of the model is firstly collapsed into a 2D shape, a footprint which can be easily annotated, then it is finally rebuilt in its third dimension in the GIS environment, preserving the connection between model and attributes. In this case the target of the model is restricted to a specialized community, where true-likeness is not the first demand and simplification is rather seen as a benefit. The model is the result of the running of Qgis2threejs Plugin (a plugin by Minoru Akagi, available on <https://github.com/minorua/Qgis2threejs>), which helps in combining DTMs, map canvas images and vector data for 3D representation in a web browser (Fig. 6). Actually, it would be correct to define the model as a 2.5D representation, since it is just based on a vertical extrusion of polygons. The application of the extruding plugin is actually the last step of a sequence of operations aimed to define the height value to be stored in the attribute table of the shapefile. Summarizing the sequence, it starts from the most authentic storage of height values, which is the point cloud, which is inspected by the software 3DFier. Then absolute heights are translated in relative values, eventually assigned to each polygon.



Figure 6. WebGIS page by Qgis2threejs. The plugin's output in an HTML page preserving height values and attributes for every feature.

Hence, before applying Qgis2threejs, the software 3DFier (by Delft University of Technology, available on <https://github.com/tudelft3d/3dfier>) has been employed to get the effective height of every standing element: this has been inferred from the related point cloud that has been segmented using the two-dimensional polygonal file itself and inferring the highest and the lowest z values for every segment. The output consists on a set of meshes, as many as the mapped features are, whose heights range between the highest and the lowest points, as absolute values. Actually, these models have a minimum LOD (level of detail) so they cannot preserve the complexity of the point cloud. Usually the smaller the feature is, the more accurate the mesh is.

A second python script has been written and executed to extract these values and to calculate a mean relative height for every feature. This is assigned to every polygon by a simple Join operation in the GIS environment.

Once the reference height is stored in the geometry, Qgis2threejs can be applied, producing the web-based model of the sanctuary. Its atomic components are represented in a 3D environment, providing a sample of the actual scene of the excavation, but preserving a symbolic appearance to keep the information clear. What is additionally remarkable is that the outcome is ontologically correspondent to the GIS itself: every feature can be arranged in a Table of Contents and queried through its attribute table, even in the web environment. Unfortunately, these last instruments are essentially built for visualizing cities more than archaeological structures, since urban buildings usually have more regular heights than archaeological remains. Though such a workflow is meant to provide a symbolic model of the archaeological structure, it can result in shortcomings affecting the height of the structures, especially when they are noticeably variable. These shortcomings can be attenuated to a degree by assessing the slope on which a structure rests, helping to prevent it from affecting the height of the structure itself. Still, it is likely that discrepancies would remain.

5 Contextualizing Artifacts

The progressive increase in the scale of visualization, from the whole archaeological site to single monuments, has been brought further by trying to re-contextualize in the archaeological site those artifacts that have been discovered and are now in storage or displayed in a museum. As point features usually record the location of these discoveries, the point data have been enriched with a link to a renderer where the photogrammetric reconstruction of the artifact can be explored. The sanctuary of Aesculapius offers many significant records, unearthed during the history of its excavations. Bringing them back, at least virtually, can be considered a significant step in helping to improve the dialogue between sites and the collections within museums. The virtual environment is gradually becoming a secondary showcase, a repository for models and also a virtual restoration lab: broken pieces can be virtually put back together and given new life. Moreover, restoration hypotheses can be tested and different sources can be referenced. In the case of the recently unearthed archaic female protome at the sanctuary, fragments have been virtually pieced together along common edges and made available via a web renderer produced in a Blender add-on, blend4web (Fig. 7).

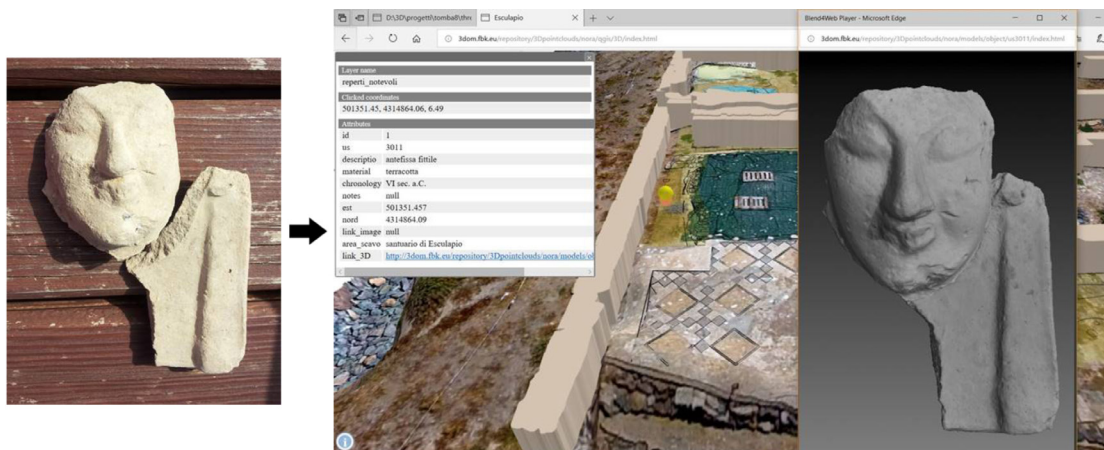


Figure 7. Re-contextualizing artifacts. Virtual restoration of the archaic protome, accessible by a Blender add-on.

6 Conclusions

To conclude, the sanctuary has been at the center of an experiment of visualization and data enrichment of a topographical and archaeological survey. We tested different forms of virtual representation and

archaeological communication, to identify suitable tools for managing the outputs of current survey technologies. In addition, several scales of visualization and detail were considered to satisfy different targets and purposes. The project is meant to provide archaeologists with both traditional and advanced tools to support new surveys and interpretations. The simulation of the excavated reality facilitates the extraction of geometrical data (especially heights) directly from a desktop and the reconsideration of previously-removed contexts. Ongoing restorations of the sanctuary of Aesculapius have been partially changing its aspect and surrounding morphologies: the virtual model can be considered as a repository of its previous conditions. Arranged with pictures and excavation data, the 3D model is also the environment where ancient sacred landscapes can be tested and inspected. The photogrammetric model of the sanctuary is the reference for reconstruction projects, since it is a source of information about geometries and materials. Combining terrain models and virtual hypotheses of the ancient urban context would open a range of interesting applications to inspect the sacred landscape from various perspectives, such as viewshed or agent-based analyses. Two tendencies can be pointed out as very attractive and deserving for the future management of complexity. One would be semantic enrichment, in order to turn 3D models into educational instruments. The second would be the connection of models: as an overlapping of progressive layers, covering but informing each other and providing context for removed artifacts, which could be virtually placed back in their original location. The science is evolving: this contribution can be considered a step towards achieving a deeper historical investigation of the site by combining GIS potentialities and the outstanding role of the third dimension.

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