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THE ART OF POTTERY FROM THE PICENUM AREA: DIGITAL RECONSTRUCTION AND COLOR REPLICATION OF VASES FOUND IN THE DAVANZALI NECROPOLIS IN NUMANA

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Abstract

Digital replicas of pottery, due to their many benefits in terms of sharing opportunities and visualization, recently became popular in museum exhibits, often introducing virtual expositions for pieces belonging to collections all over the world. However, the accuracy of digital duplicates plays a paramount role in the perception of shapes and colors, since the most minute feature could easily lead to identify unexpected clues of an object. This is particularly true of pottery, whose materials, manufacturing techniques and decorations have been subject to dedicated research throughout history. This paper introduces some of the specific outcomes of a research program, oriented to the quick digital acquisition, 3D replication and accurate visualization at the different scales of the Davanzali necropolis in Numana, a settlement of ancient Picenum (Marche Region, Italy).

Keywords

Picenum pottery, 3D digital modeling, color acquisition for archaeology, digital photogrammetry

1. *The Davanzali necropolis in Numana*

During the first millennium B.C., the settlement of Numana raised in the Southern part of the Conero promontory and soon it became one of the most important trade harbours along the Western Adriatic coast. Our knowledge on the pre-Roman Numana mainly refers to data coming from excavations conducted in different necropolises, spread all over its territory.

The largest one is known as Quagliotti-Davanzali, excavated in the 20th century and connected to other funerary areas recently discovered nearby. A research project has been developed on this pivotal context since 2016 by a group of scholars of the University of Bologna, in cooperation with the Soprintendenza ABAP and the Direzione Regionale Musei of the Regione Marche. The project, which is still running, aims to study a considerable group of burials (241 tombs) located at the center of the Quagliotti-Davanzali area, extensively excavated in the 1970s. The research introduced in this contribution is part of a wider project, named "*From the finding to the landscape, archaeological analysis and virtual modelling of Picenian necropolises in Numana*", which was focused on digital replication of the necropolis, at the different scales of the finding (with particular attention to pottery) and the landscape (considering all the burials).

A few tombs have been already published so far, thus the new research project on the area offers the chance to examine for the first time a more consistent and homogeneous group of tombs of the ancient Picenian center.

Outcomes of this study, which is now in its final stage, offer significant keys to analyze historical, economic, social and cultural aspects of the pre-Roman Numana, considering that the Davanzali area was used from the 9th to the 2nd century B.C. (on the research project and its perspectives, see Baldoni and Finocchi, 2019).

During the maximum development of this emporium (6th to 4th century B.C.), Numana built up trade and cultural networks with many areas from the Mediterranean to Europe, especially with the Greek world (Greece and Greek colonies in Southern Italy): this wide range of contacts is well documented in the Davanzali necropolis by many objects deposited in the grave goods, whose pottery is the most abundant (Figure 1).

Therefore, we focused on the investigation of

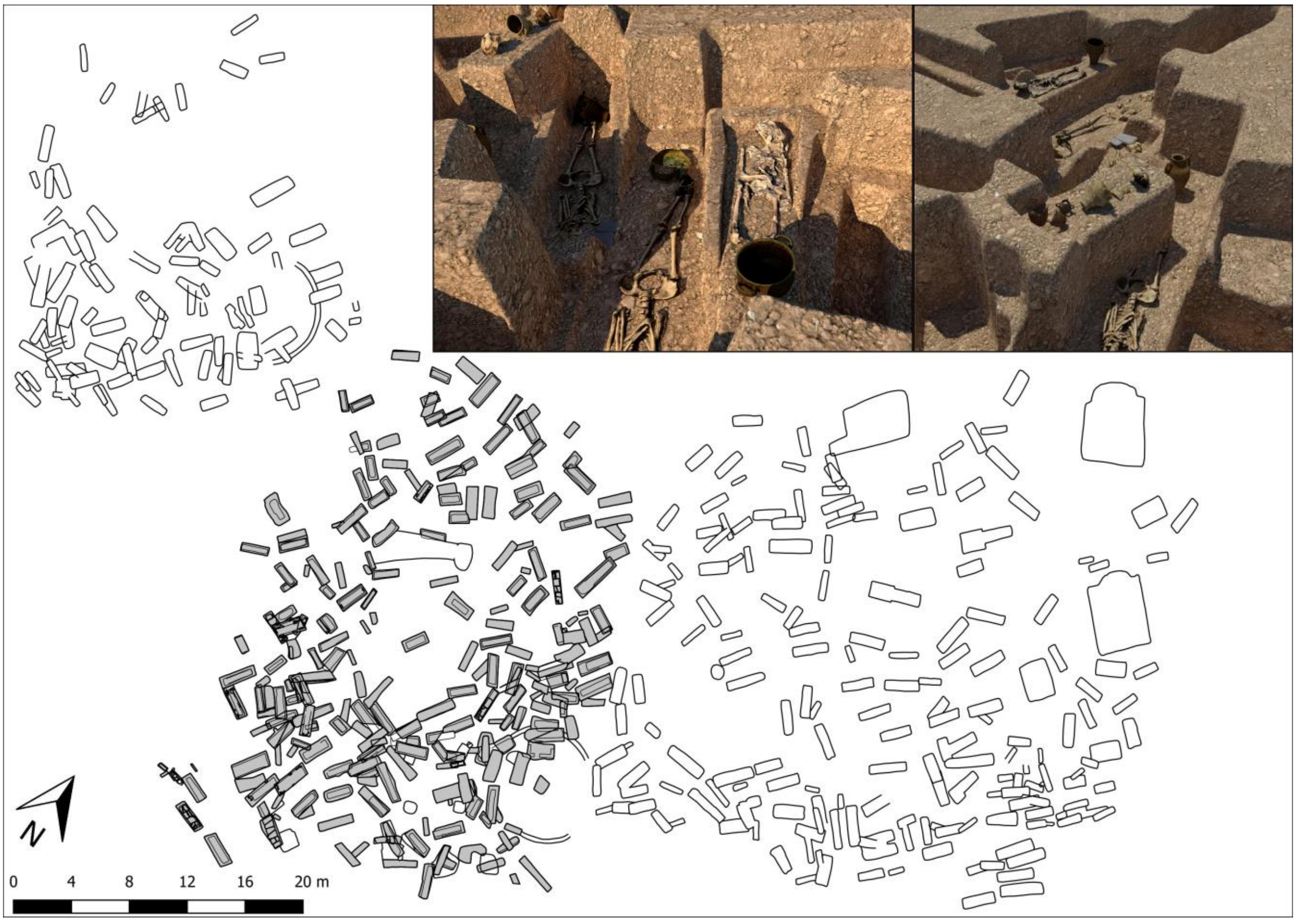

Fig. 1: Masterplan of the Quagliotti-Davanzali necropolis; it is highlighted in grey the Davanzali area currently under study. On the upper right, some samples of the 3d model created for a sector of the necropolis.

the several types of vases found in tombs, ranging from coarse ware to fine pottery. Amongst the latter, there is a considerable number of decorated vases, especially red-figured ones, produced in Numana (the so-called *Alto-Adriatic pottery*) and from Greece and Western Greek colonies (*Attic* and *Italiote pottery*).

2. *The pottery: types, production and the meaning of colors*

Through the interpolation of the available data from the documentation produced at the time of the excavations and the new surveys carried out in the field, traditional studies on the funerary assemblages led to the production of 3D models related to the main phases of exploitation of the necropolis, useful to read the ancient landscape and its modifications during the considerable period of its use (9^{th} to 2^{nd} century B.C.).

A detailed model was created for a specific portion of the necropolis (Baldoni, 2021; Baldoni, et al. in press), in an attempt to reconstruct the state of the burials at the time of the excavation (in the 1970s), to promote this model as a tool for the archaeological context analysis and its enhancement.

The chosen sector falls into a central area of the necropolis, close to one of the oldest tombs in the whole settlement (tomb 390), and it is distinguished by a notable superimposition of graves, which persisted in the same area for a long period, namely from 6^{th} to 3^{rd} century B.C.

This circumstance provided a convincing test field for digital reconstructions in a complex stratigraphic context, and it led to the documentation of whole funerary assemblages, characterized by rather heterogeneous objects.

Excluding metal objects and focusing mainly on pottery, it has been possible to digitally acquire both locally produced fine vases, typical of the different phases of the Picenum culture, and many vases with figures imported especially from Athens and Magna Graecia.

This is a fundamental matter to better understand the role of Numana in the complex Adriatic trade, especially during the 5^{th} and 4^{th} centuries B.C.

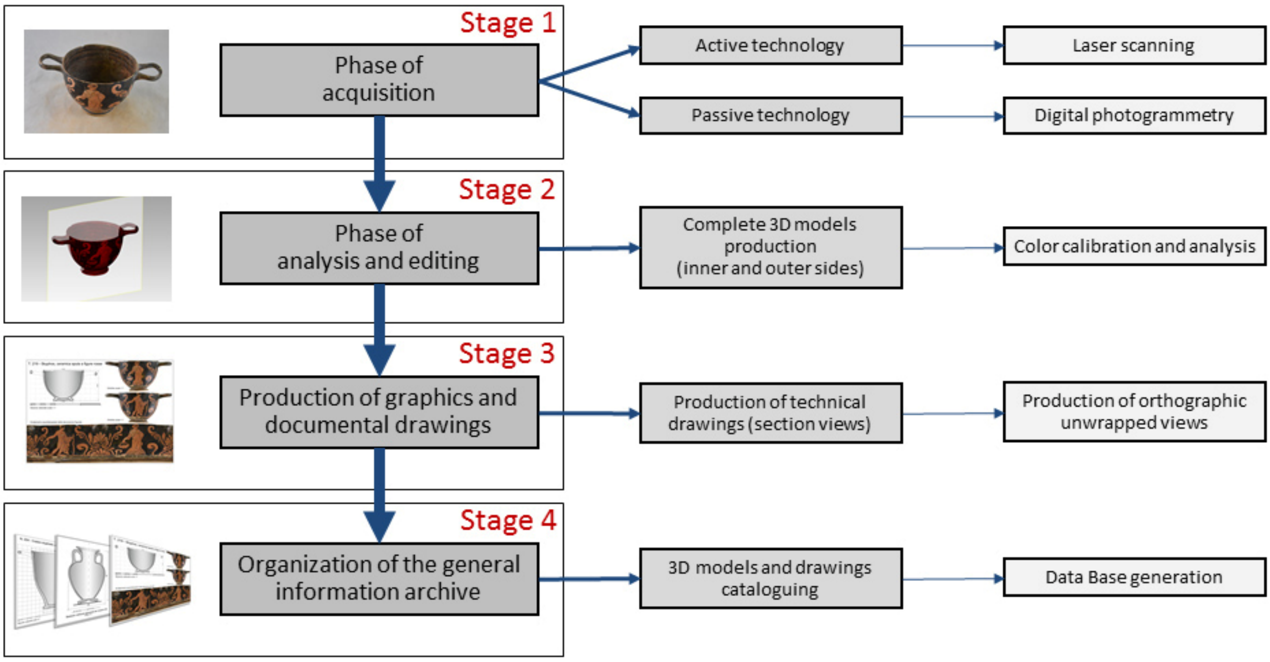

Fig. 2: The general workflow adopted to produce digital colored replicas of the imported pottery found in the Numana necropolis.

The analysis of this type of materials using photogrammetric and laser-scanning techniques is part of a rather recent but already consolidated tradition of studies (Trinkl, 2013): the digital documentation of these finds opens up new possibilities to investigate Attic and Italiote productions, letting researchers at first to perform an objective analysis of the morphological aspects of a single vase. There are also numerous perspectives to consider when referring to the decoration of vases, especially in the red-figure pottery (Bursich and Pace, 2017), certainly well represented in the contexts of Numana. Recent investigations demonstrated the usefulness of the digital documentation and archaeometry in the study of multiple characteristics of the figured decoration of vases, for their attribution to a single painter or to a workshop, as well as in properly studying their iconography, or in determining their state of conservation (Vak, 2013).

To accomplish these purposes, it is particularly important the possibility to examine in depth the figured decoration, which is often not perceptible in its details in reproductions made in the traditional way.

Further attention to the Picenum area is paid to the local production of red-figured pottery, starting from the second half of the 4th century B.C., the so-called Alto-Adriatic pottery, which is still interested by a limited number of analytical studies on the decoration and the colors used.

Due to these premises, the Davanzali necropolis in Numana is an interesting context for a large-scale experimentation of digital techniques to reproduce the finds, as well as, hopefully, a

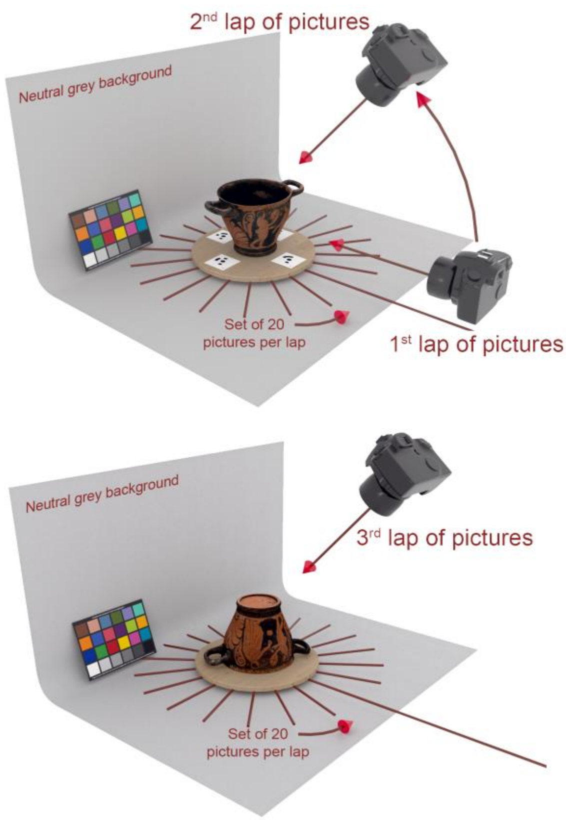

Fig. 3: The general acquisition sequence, with 3 laps of pictures shot around every ceramic.

paradigmatic case study for other similar contexts in pre-Roman Italy and beyond.

3. *The virtual reconstruction of pottery*

Ceramic vases, and particularly figured ones, are some of the most diffused archaeological artifacts to consider when dealing with a specific period or geographical region, and their accurate representation in form of 3D models is an efficient way to easily share accesible information among scholars, archaeologists or museum visitors, who are generally common targeted users interested in the detailed analysis of pottery.

Very often, in fact, findings are found incomplete or in form of fragments, so that a general classification or a deep study on them is slightly difficult. However, a versatile digital representation of shapes at the object scale, reporting the thickness of the surfaces, the definition of materials and their colored details, requires to address precise critical issues, mostly related to the geometric 3D morphologies, whether they are preserved in their entirety or found in portions to be later reassembled.

Following a discrete taxonomy made of noticeable peculiarities, useful to scholars and restorers to pinpoint features to better identify the original painters and their techniques, a specific four-staged acquisition methodology was applied in this research to digitally reconstruct a number of ceramic findings belonging to the Davanzali necropolis.

But before documenting in detail the pottery, we decided to generate a virtual model of a wide portion of the necropolis, in order to clarify an overall view of the tombs and their grave goods.

This preliminary step proved to be useful for the consideration of the context in which vases were found; a quick method to generate the morphology of the ancient landscape was then proposed, through the synthesis of excavation drawings and their diachronic interpretation.

Starting from plan views belonging to different eras and already organized in GIS technical maps, two-dimensional plan drawings were extracted. False-color graphic representations were then developed, depending on the depth detected and transcribed for the individual burials.

These images, obtained at a suitable resolution, served as a raster map to project the contents on a three-dimensional mesh, with a subdivision congruent to the map definition (about 1 px = 1 cm), modifying its explicit shape according to well-known displacement mapping algorithms.

Depending on the color intensity expressed by the map, the algorithm deforms the mesh by shifting the vertices to the height associated with the reference color. Although it cannot be considered as a faithful survey technique, this method can replicate a credible condition of excavation in three dimensions, also starting from documents already present in the archives.

From the general terrain model obtained, new section views can be extracted, an operation that makes it possible to easily relate the burials excavated with the pottery found within; in fact, once the digital reproductions of the ceramic elements were inserted in their finding location, it becomes possible to effectively recreate the context at the time of the excavation and analyze, with the help of the third dimension, the methods

Fig. 4: A digital model of an Attic red-figured skyphos from the Davanzali necropolis (T.216, inv. 27356). On the left (a) the Agisoft Metashape 3D model from color calibrated raw images, on the right (b) the same photoset processed with COLMAP + openMVS.

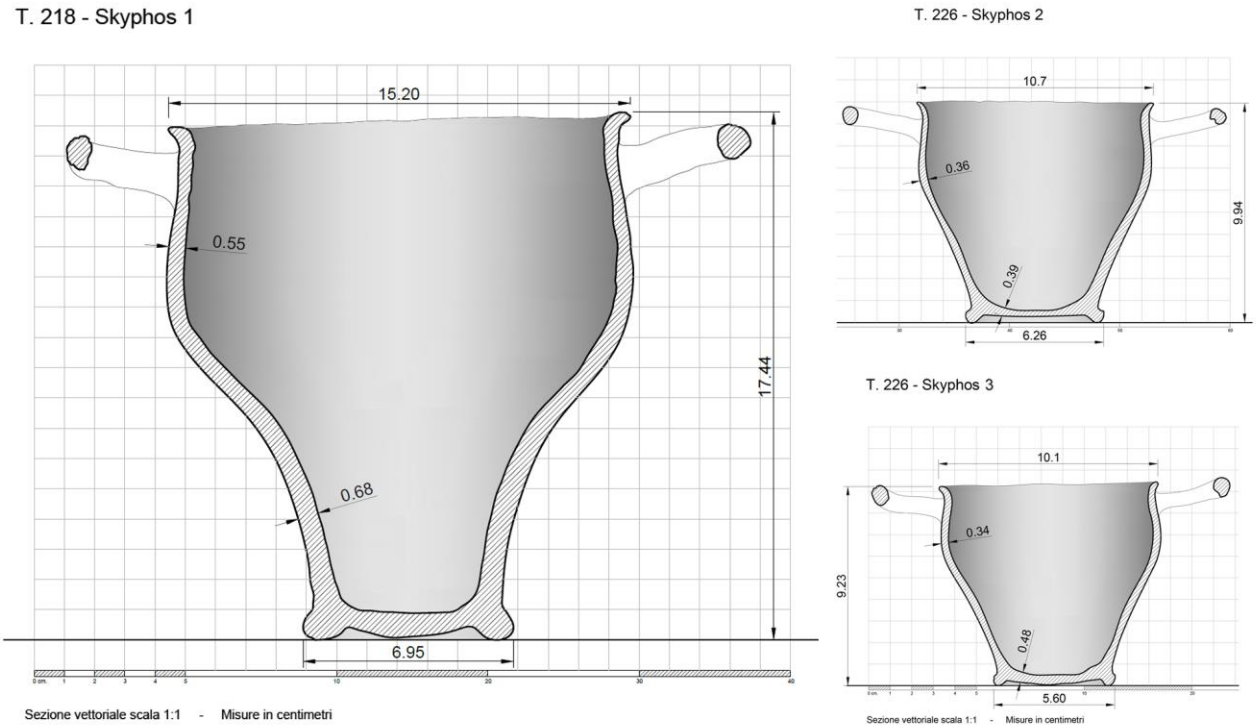

Fig. 5: Section views of some vessels processed through the digital reproduction pipeline. 3D models were cut by vertical planes, then the silhouette was exported in a CAD file format to add dimensions and annotations to documents produced.

of deposition for the individual objects and, consequently, the funeral ritual and posible damage conditions for vases, following a careful analysis of post-depositional dynamics.

3.*1* *The digital workflow adopted*

To ensure the acquisition of a huge number of items in a reasonable time, the proposed methodology originates from now consolidated photogrammetric surveys and *terrestrial laser scanning* (TLS) campaigns. Although some laser scanning devices were initially tested, digital photogrammetry was privileged due to the ease of use, the relative cost-effectiveness and the versatility in contexts where an active acquisition pipeline would make survey operations more complex. In the end, the general "workflow" for the digital replication of the artifacts was organized as follows (Figure 2):

• acquisition stage for artifacts, where samples under examination are digitized from time to time using color-calibrated photography;

• phase of analysis and editing of the digital model inferred, with definition and optimization of the surfaces of the models, their informative enrichment relevant to the decorations and figured parts;

• production of the graphic and documental drawings stage, in which the three-dimensional models are treated for the realization of explanatory drawings according to traditional rules of representation;

• organization of the general information archive, where models and analytical documents are collected in digital archives aimed at disseminating knowledge deriving from the analysis of the finds.

3.2 The acquisition stage

A standard and consolidate photogrammetric pipeline (Schonberger, Frahm, 2016) was adopted. The camera equipment can be easily used by common, non-expert users too, increasing the number of artifacts acquired in this stage. Vases were placed on a rotating table, which was previously prepared with the application of a set of *Ringed Automatically Detected* targets (RAD) printed upon stickers, then applied to the circular flat surface bearing the artefact to be digitized. Every artifact was captured rotating the table at

equal angles (about 18 degree each), shooting with locked camera settings.
At least 60 pictures of every vase were taken, changing the height of the shooting position and carefully turning objects upside down (Figure 3).

These parameters grant overlapping for every shot, taken at a reasonable distance from objects illuminated by diffuse lights, placed outside of a photographic illumination box. Vases were initially documented using a Nikon D7000 DSLR camera with a fixed 50 mm. lens kit placed on a tripod.

3.3 Analysis, editing and color calibration

To faithfully replicate the color appearance of the digitized vases, single shots used for the photogrammetric reconstruction were color-calibrated, framing a standard color target in images. A common solution for target-based color characterization (McCamy et al., 1976) relies on the *ColorChecker Classic* produced by X-Rite, which shows standardized patches with known reflectance.

A proper depth-of-field value was chosen to prevent diffraction blurring, while fine tuning for colors considered the issues expressed by Simone et al. (Simone et al., 2021).

The photogrammetric 3D reconstruction, in terms of bundle adjustment, camera orientation, sparse cloud and dense one generation, was carried out following two different pipelines, in order to evaluate the final outcomes of a commercial workflow (using the Agisoft Metashape software) and that of an open source ones (COLMAP for the *Structure-from-Motion* and *Multi-View Stereo* point cloud reconstruction pipeline and OpenMVS for the final 3D mesh generation).

Some custom scripts were also developed to better identify the base plane orientation through RAD targets (Figure 4). Once successfully produced, textured 3D models were studied and analyzed following traditional representation methods to isolate decorations and figures.

They can be decomposed, in fact, into their basic cognitive elements, displayed under different synthetic sources of lighting, unwrapped in cylindrical projection views to facilitate an in-depth iconographic, stylistic and shape analysis (Mara, Sablatnig, 2006).
To ease these operations, 3D models were catalogued to identify geometric invariants, such as local symmetry or internal rotation axes. 2D drawings were later inferred from 3D models slicing them with suitable section views produced through simple calculations of arithmetic means between the coordinates of the bounding box planes surrounding single models, and symmetrically calculated on the reference system adopted in the reconstruction.

For circular or elliptical rotational geometries, where the inner side was often difficult to capture, we went back to the ideal geometry, minimizing the sum of the square distances of the axis searched for from contour points identified on the models' surfaces (Gander et al., 1994).

3.4 Production of graphics and documental drawings

Once the virtual geometry and its references were defined, digital models were sliced to get views passing through the planes identified as by Mara (Mara et al., 2007). This process leads to produce a faithful representation of the ceramic thickness, with a maximum error deviation never exceeding 2.1 mm when compared to reference ground models acquired with active technologies.

Where it was simply not possible to identify the internal surface of the vases, additional sectional elements were drawn offsetting external surfaces inward according to values as far as known. The section profile was then exported from the three-dimensional model to CAD software, where two-dimensional drawings were perfected (Figure 5).

Thence, attention was paid to the graphic representation of figured parts. For some time now there have been contributions in the literature that suggest analytical expressions to obtain cylindrical projections of the mappings pertaining to the figures in historical pottery (Karras et al., 1996).

More recent works hypothesize the use of triangular strips adapted to the surface of arbitrary objects to unfold them more easily through unfolding algorithms (Massarwi et al., 2007).

Although the cylinder is the simplest geometric primitive to carry out a representation arranged on a curved surface, we decided to use spherical primitives to obtain an equirectangular projection of the textures of the photogrammetric model, to facilitate the interpretation of figures and decorations with a final rendition much more similar to traditional manual drawings (Rieck et al., 2013).

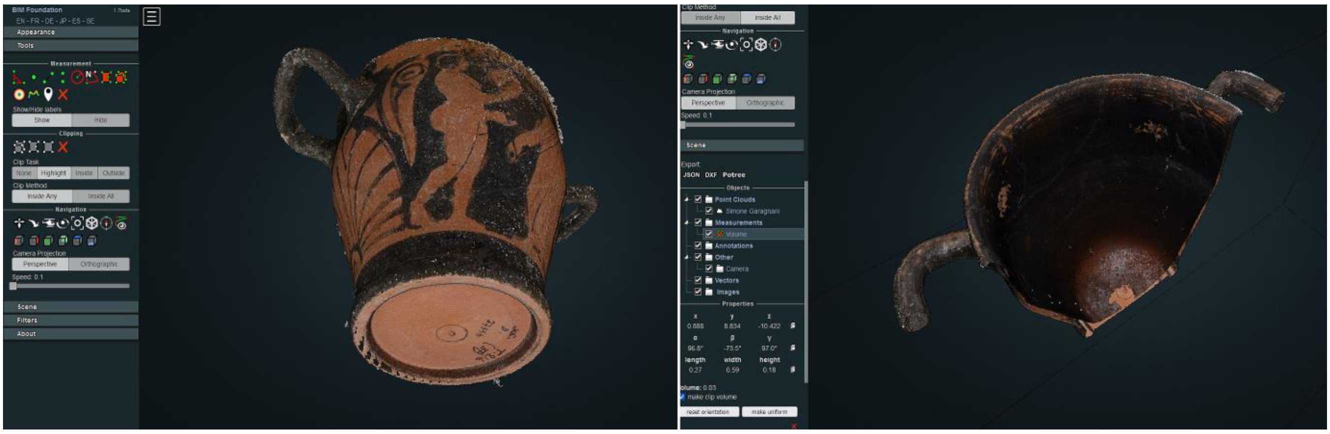

Fig. 6: Some views of the 3D web archive. In this figure, 3D representations generated from point clouds, which can be explored interactively (repository authored with the Potree open source software).

3.5 Organization of the general information archive

During the research work, many samples were collected and digitized following the approach introduced: files and data were gathered into repositories organized in a hierarchical way. 3D final models, 2D drawings and color metadata proper of the digitized objects such as their geographical location and place of conservation were collected. These data may, in the future, be linked to museums or public institutions databases, in which 3D models will act as graphical indexes to provide users with easy access to much more detailed information. The overall methodology proved to be a significant resource for enhancing the vast cultural heritage of the pre-Roman Numana (Figure 6).

4. Conclusions

The whole research program proved that a considerable number of samples belonging to different eras in the Davanzali necropolis can be digitized in order to collect reliable information on pottery shapes and colors. So far, some more examples of digital models that were produced are collected in the website dedicated to the research project (https://site.unibo.it/dal-reperto-al-paesaggio-numana/it). All the results of this research carried out on color greatly enriched our knowledge in the various ceramic productions present in the Numana area, both for those already known (such as those imported from the Greek world) and for those specifically made in the Piceno area. These outcomes proved to be relevant in reaching the aims of the project, which also include the enhancement of the heritage of Numana, in order to make it known also to a wider public of non-specialists, also planning *ad hoc* future exhibitions and events in which the public can explore the authored digital models for example through the use of 3D viewers, touch screens or VR goggles, to easily understand and browse the information embedded into the virtual replicas.

Acknowledgement

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This scientific paper was written by the authors following this general attributions: the section 1 was prepared and checked by V. Baldoni and E. Zampieri, the section 2 was prepared and checked by A. Gaucci and M. Silani, the section 3 was written by S. Garagnani and the section 4 (Conclusions) is the result of a summary expressed by all the authors.

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