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QUICK DIGITIZATION TECHNIQUES: THE CASE STUDY OF NUMANA NECROPOLIS

The systematic collection of data coming from different sources (Foni, Papagiannakis, Magnenat-Thalmann 2010), the easier dissemination (Scopigno, Dellepiane 2017), the understanding of complex shapes (Pintus *et al.* 2016) together with the simultaneous work on the same contexts by scholars physically based in different places (Soler, Melero, Luzón 2017; Inglese, Docci, Ippolito 2019) are just some of the possible advantages deriving from the use of digital models applied to the specific field of archaeology.

The research introduced in this work considered these premises in order to apply and test methodologies and tools meant to quickly replicate the archaeological context in Numana through consolidated and novel digital approaches. To date, survey technologies combined with three-dimensional visualization provide effective analytical and interpretative potential, even introducing the diachronic timeline in the recording of interventions that have taken place over time in a specific site.

The translation into digital replicas of artifacts or findings is usually a process that involves technical skills proper of computer graphics professionals who dedicate their effort in developing state-of-the-art methodologies and software tools knowledge for the purpose. This way, it seems to be difficult for actors belonging to different disciplines to apply these exclusive approaches to replicate archaeological objects or sites to be studied or investigated through digital media. This issue appears to be even stricter when the case studies belong to different scales, often pointing to elements whose diversified peculiarities and dimensions have to be analyzed individually. The digital acquisition and later replication of the necropolis in Numana were deeply focused on the double need to apply an easy process, also accessible to non-specialized operators, and a versatile working pipeline targeted to the object scale (which is the dimensional domain of artifacts and findings) and to the territorial one (which is the domain of archaeological sites).

1. Modeling at the object scale

This section introduces some purely technical aspects characterizing the production of digital models that were generated during the research, pursuing the aims of archaeological analysis in classical terms of morphology, color and dimension. The representation of the shape at the object scale, dealing with the thickness of the surfaces and the definition of materials and their finishes, required to fix precise critical issues, which will be explained further on.

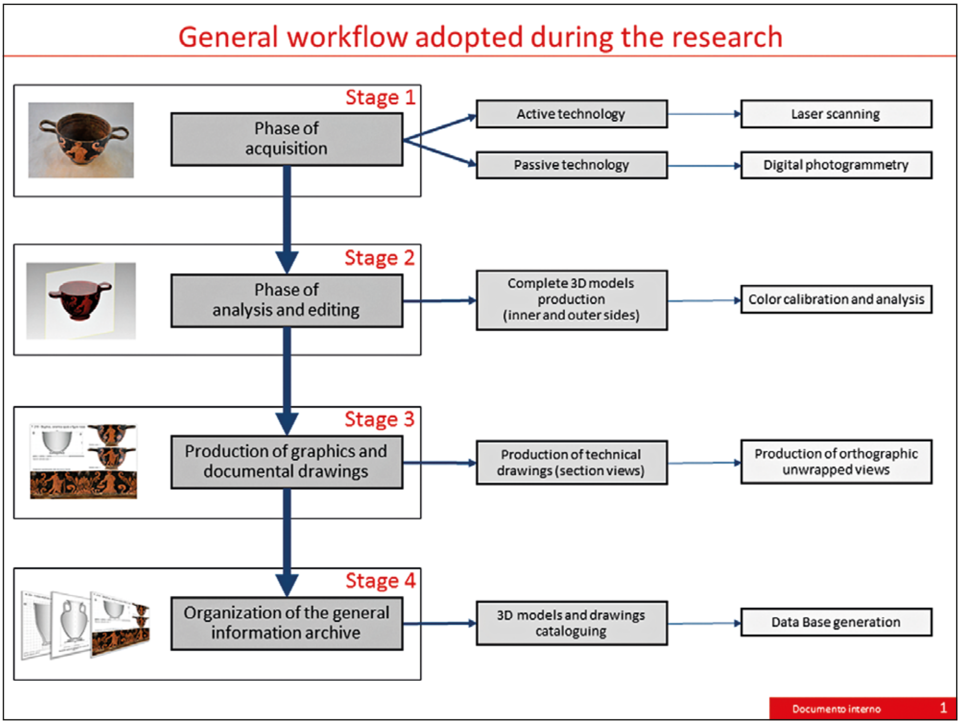

Fig. 1 – General scheme of the workflow applied to digitalize, analyze, document and organize all the artifacts investigated during the research work.

Issues related to the geometric 3D documentation of complex ceramic finds, whether they are preserved in their entirety or found in portions that are then reassembled, are traditionally intertwined to the shape of the object and the operational context of its digital acquisition. The investigation of heterogeneous types of ceramics was mainly carried on in this research at the object scale, considering materials differentiated in terms of microscale details, glossiness and textures.

To allow the acquisition of a huge number of ceramic findings in a reasonable time, the proposed methodology originates from photogrammetric surveys. Acquisition methods by laser scanning were initially tested, to privilege digital photogrammetry in the end due to the ease of use, the relative greater cost-effectiveness of tools and accessories and the wider versatility in contexts where an active acquisition would make survey operations much more complex. In the end, the general 'workflow' for the digital replication of the artifacts at the object scale was organized as follows (Fig. 1):

– 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 main and accessory decoration;
– 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 to be potentially organized in digital archives aimed at disseminating knowledge deriving from the analysis of the finds.

2. The acquisition stage

A standard and consolidated photogrammetric pipeline (Schonberger, Frahm 2016) was then adopted to quickly get digital models of ceramics, also taking advantage of the camera equipment easily used by common, non-expert users. Ceramics 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 artifact to be digitized. Every artifact was captured rotating the table at equal angles (about 18 degrees), shooting from a tripod with locked camera settings. At least 60 pictures of every ceramic were taken, changing the height of the shooting position and carefully turning objects upside down. These parameters also guaranteed enough overlapping for every shot, taken at a reasonable distance with objects illuminated by some diffuse lights placed outside of a photographic illumination box. Ceramics were initially documented using a Nikon D7000 DSLR camera with a fixed 50 mm. lens kit placed on a tripod at an adequate distance.

To faithfully replicate the color appearance of the digitized ceramics, single shots used for the photogrammetric reconstruction were color-calibrated, using a standard color target in images. A common solution for target-based color characterization (McCamy, Marcus, Davidson 1976) relies on the ColorChecker Classic produced by X-Rite, which shows standardized patches with known reflectance. The chart is made of a 279.4 mm × 215.9 mm plastic sheet consisting of 24 color patches surrounded each by a black frame, to favor contrast and easy color identification. Eighteen common colors in the chart include the representation of true natural colors (such as skin, foliage, and sky), additive and subtractive primary colors together with six grayscale levels with different optical densities. A sufficient depth-of-field value was chosen to prevent pictures taken from being influenced by diffraction blurring.

The photogrammetric 3D reconstruction, in terms of bundle adjustment, camera orientation, sparse cloud and dense one generation, was carried on following the usual pipeline adopted by the commercial software Agisoft Metashape, running some custom scripts to better identify the base plane orientation and the distances among RAD targets.

3. Analysis and editing

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 (Fig. 2), produced through simple calculations of arithmetic

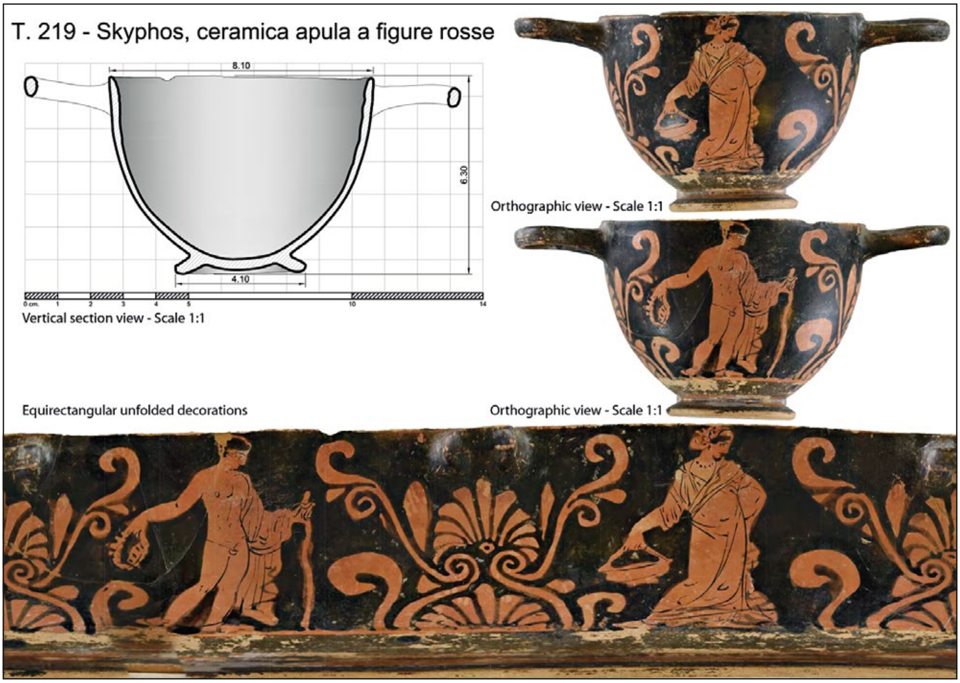

Fig. 2 – An example of section view and 2D representations of a ceramic artifact inferred from the 3D digital model. 3D representations were used to replicate the thickness of the ceramics studied and unfold the decorations on the object's lateral surface (Museo Archeologico Nazionale delle Marche, inv. 27416, Courtesy of Ministero della Cultura - Direzione Regionale Musei Marche).

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 document, 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, Golub, Strebel 1994).

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 in Mara (Mara *et al.* 2007). This process led 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 ceramics, 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.

Then, 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 Patias, Petsa 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, Gotsman, Elber 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 Mara, Krömker 2013).

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 divided into folders organized in a hierarchical way, from Work in Progress files, to Final models, to 2D Drawings and so forth.

Recap forms were also produced to accommodate metadata proper of the digitized object, its geographical location by discovery site and place of conservation, the detection technique, other files possibly linked and often related to different levels of detail for the same artifact. These data may, in the future, be collected and cataloged in dedicated databases, in which 3D models could act as graphical indexes to provide users with easy access to much more detailed alphanumeric information.

6. Modeling at the spatial scale

To generate a virtual model of the necropolis, in order to present an overall view of the tombs and their found goods, a quick method of generating the morphology of the ancient landscape is proposed through the synthesis of excavation drawings and their diachronic interpretation.

Starting from floor plan views belonging to different eras and already arranged in GIS technical maps, two-dimensional views of the investigated area were extracted. False-color graphic representations were then processed, 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 mesh congruent to the definition of the map (about 1 px = 1 cm), modifying its explicit form according to well-known displacement mapping algorithms (Cook 1984). 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 (Wang *et al.* 2003). Although leading to a surely unfaithful survey, this method allows to replicate a credible condition of excavation in three dimensions, also starting from 2D documents already present in the excavation archives.

'Displacement mapping' is basically different from 'height mapping': in computer graphics, a heightmap is a raster image in which each pixel stores values, such as surface elevation data, for display in 3D computer graphics. Heightmaps are commonly used in geographic information systems, where they are called Digital Elevation Models (DEM). They are an ideal media to store digital terrain elevations; compared to a regular polygonal mesh, they require substantially less memory for a given level of detail. Displacement mapping is also different from 'bump mapping', which substantially never modifies the surfaces on which it is applied on (Blinn 1978).

We adopted a variant of the general displacement mapping algorithm: displacement mapping includes the term mapping which refers to a texture map being used to modulate the displacement strength. This approach was already adopted in archaeology, as reported in (Debevec *et al.* 1998) and (Tzouvaras *et al.* 2019).

Isolating hypothetical ground levels at different ages of the site development in Numana, 2D maps processed by GIS overlays belonging to different excavation campaigns were draped on generic flat surfaces, in order to produce quick 3D visualizations of tombs. The displacement mapping principle is the one mentioned by Gumhold and Huttner, in which:

$$p'(u, v) = p(u, v) + d(u, v) \cdot n(u, v)$$

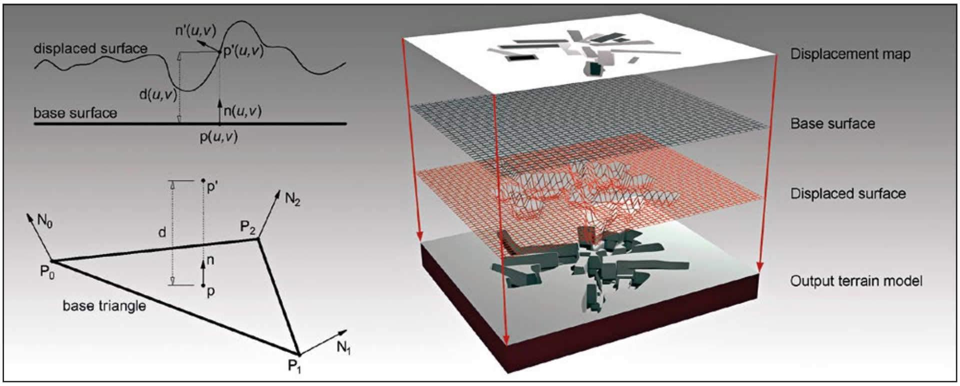

Fig. 3 – Geometric representation of the mathematical approach behind the displacement mapping technique adopted: a general base surface is proportionally deformed according to different weights expressed by a 2D map.

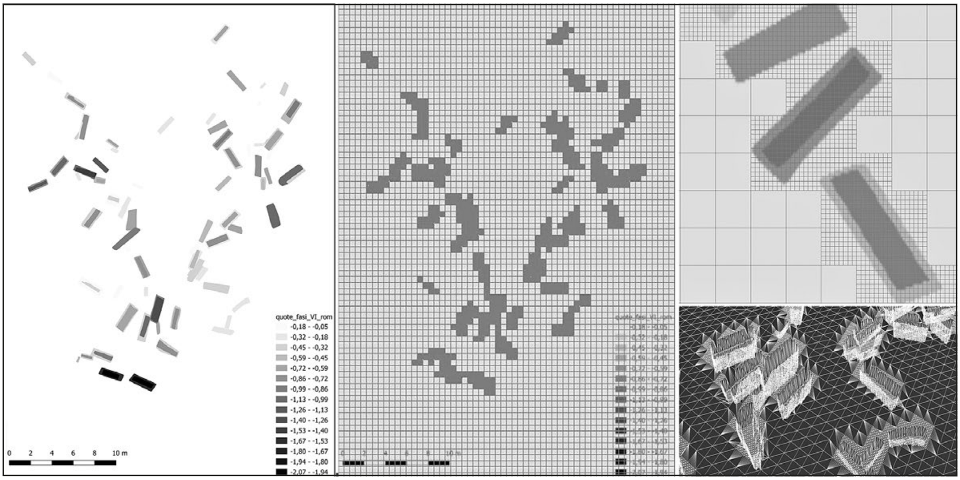

Fig. 4 – The displaced surface was triangulated to reach a better layout, in order to cover the edges of the 2D reference bitmap generated by GIS maps produced in different times. Even if this is not an accurate metric representation, it proved to be useful in 3D documentation of excavation levels, determining superimpositions over time.model scale and placed at the territorial scale in the reconstructed scenario.

This equation considers an initial base surface p(*u,v*), a normal field n(*u,v*) and a scale field d(*u,v*), all parametrized and defined over a two dimensional domain (Gumhold, Huttner 1999). The normal field is often calculated from the normalized cross product between the partial derivative of p in *u* and *v* directions, p'(*u,v*) in the upper formula (Fig. 3). The base

Fig. 5 – Final output of a reconstructed tomb scenario, with the different objects digitalized at the model scale and placed at the territorial scale in the reconstructed scenario.

surface was discretized and approximated by triangles, called base triangles, whose dimensions were smaller close to tombs' edges, to better fit the terrain deformities of excavations (Fig. 4).

Taking advantage of the general terrain model obtained with the application of geometric displacement, new section views can be extracted. This simple operation makes it possible to easily relate the burials excavated in different times. Moreover, once the digital reproductions of the accessories have been placed in tombs as they were found, it becomes possible to recreate a plausible context reproducing how the tomb was settled at the time of the excavation.

The third dimension brings this way some interesting research opportunities, considering the orientation of the individual objects and, consequently, the funerary ritual: our quick reproduced digital models foster a careful analysis of post-depositional dynamics (Fig. 5).

The proposed approach, in more general terms, proved to be effective in Numana, where different displacement maps collected through the documentation produced over the years led to a complete diachronic analysis of different terrain levels, dated back to different years related to depositions.

A future perspective for this research work brings into the archaeological discussion how this methodology can be successfully replicated in different contexts, where a high number of findings and a landscape that could have been documented with different techniques and different times could converge into a digital replication process. Output results were encouraging, and the final goal of a systematic reconstruction proved to be reachable also by operators not necessarily involved in visual computer science or scientific visualization.

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ABSTRACT

The general digital reconstruction of the necropolis in Numana was carried on following a methodology targeted to a quick survey at different scales: from the single ceramic or artifact to the whole archaeological landscape. Fostering the application of common computer graphics techniques, an easily replicable process was set up, in order to produce 3D models mainly adopted for archaeological analysis and collection of data that could have been acquired in different times, with different approaches.