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INTEGRATED PROTOTYPING AND RENDERING SYSTEM FOR THE DISPLAY OF CERAMIC FINDS

Fabrizio Avella, Elena Pezzini**, Viva Sacco***, Rosalia Magro******

*University of Palermo, Departement of Architecture – Palermo, Italy.
**Archeologist of Archeological Museum Antonio Salinas of Palermo, Italy.
***PhD in Histoire de l'art et archéologie islamiques - University Paris-Sorbonne, France and University of Messina, Italy.
*****Graduated in Architecture at the University of Palermo, Italy.

Abstract

The project, carried out in collaboration between the Department of Architecture of Palermo and the Archaeological Museum Antonino Salinas of Palermo, proposes a system of integration and reconstruction of ceramic artefacts, using modeling, 3D printing and rendering processes for an integrated museum exhibition system. In this way the viewers can observe the fragment nearing the re-reconstructed fragment in its original morphology and an interactive digital model in which can also observe the metric aspect and, where present, the decorative apparatus.

Keywords

SFM, Image-based Modeling, NURBS modeling, Polygonal modeling, 3D printing, Archaeological heritage

1. *Introduction*

The present work, is the result of the collaboration between the Department of Architecture of Palermo and the Archaeological Museum Antonino Salinas of Palermo, and proposes a system of detection and integration of ceramic artefacts for exhibition purposes: a type of pan "Pantellerian ware" IV-V century AD, found in Castello della Pietra, a bowl dating from the end of the X century, and the beginning of the XI century, found in Palermo in Piazza Bellini, and a bell-shaped cup of the second half of the XII, found at Palazzo della Zisa in Palermo.

The study develops and integrates a pilot project conducted in 2015, the outcome of which was to develop a polygonal model of the find and a NURBS model of the missing portion, used for both the 3D printing process and a visualization virtual system (Avella, Sacco, Spatafora, Pezzini, Siragusa, 2015).

Compared to the first project, the issues that were left unresolved have been addressed: the integration of finds with more complex form and with presence of irregular gaps and the rendering of the textured model, in its reconfiguration hypothesis: so it's possible to reproduce not only the morphological integration, but also the visual appearance of the material and the decorative apparatus, where present.

This last phase of the process allows to hypothesize the realization of an interactive 3D virtual catalog that shows the findings in their current configuration and their re-established integrity[1].

1.1 The finds

The potteries sherds, used as samples within this second stage (Avella, Sacco, Siragusa, Spatafora & Pezzini 2015) of the project for structuring a low-cost system for survaying, modelling, prototyping and interactive visualization, have been selected again among those destined for the new layout of the medieval section of the Antonino Salinas Museum in Palermo.

They are distributed along a wide time span (from 5th to 12th century) and have been found in three different archaeological sites: Castello della Pietra (in Trapani district) (N.I. 48251), piazza Bellini (N.I. 66803) and the Zisa Palace (N.I. 27357) in Palermo.

[1] The introduction is written by Fabrizio Avella, Project Coordinator.

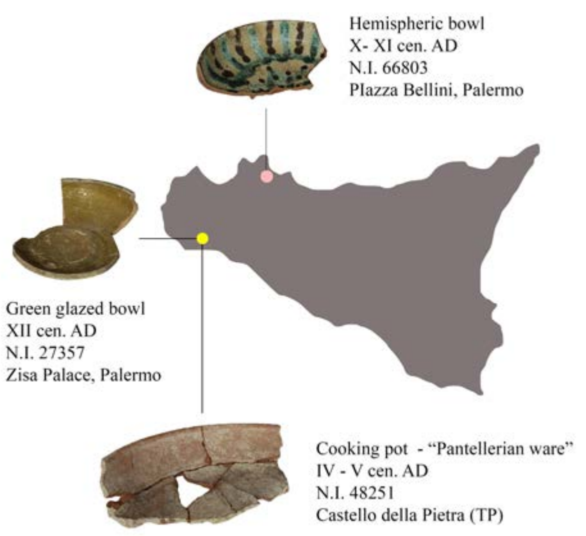

Fig. 1: Places of discovery of the finds.

They are a cooking pot and two lead-glazed open shapes and present different problems both from the point of view of restoration and exhibition.

The cooking pot (N.I. 48251) is a "Pantellerian ware" baking pan found during the digging campaigns carried out in 1973-1974 at Castello della Pietra[2]. The "Pantellerian ware" was identified by Fulford and Peacock at Carthage, in stratigraphic levels of 4th and 5th century (Fulford & Peacock 1984). The excavation at Scauri, a location on the island of Pantelleria, have confirmed the identification. A pottery workshop with kiln, dated between the 4th and 5th century, has been excavated in the village of Scauri Scalo while, in the Scauri harbor, one shipwreck with "Pantellerian ware" load has been found (Santoro Bianchi, Guiducci & Tusa 2003, Baldassari 2015). The "Pantellerian ware" is a cooking ware particularly resistant to thermal shock due to the presence in the fabric of some volcanic minerals typical of this island. This production was developed from the 2nd century BC until the beginning of the 7th century but reached a diffusion peak in the 4th and 5th centuries when it was widely marketed along the routes of the central and western Mediterranean (Santoro Bianchi 2003). The exemplar found at Castello della Pietra belongs to a morphologic type widely exported from Scauri and diffused in the western Mediterranean between 5th and 6th century (Baldassarri 2015). It is a baking pan with everted and thickened rim (D or "half-almond" profile), made without the use of a fast wheel but finished on wheel. It was selected for the exhibition because it testifies, along with other pottery, a late roman phase at Castello della Pietra.

The hemispheric bowl (N.I. 66803), with simple rim and ring base, come from a decontextualized assemblage excavated in 1948 in the Piazza Bellini (Palermo). This piece is characterized by a green and brown decoration, achived by a series of dots and splashes of colours. In particular, the central motif is a star surrounded by a circle from which a series of bands alternatively green and brown branch off. The fabric of this bowl suggests that it is an Egyptian production[3].

The type of decoration that characterizes this bowl, allow us to insert this piece in a group of pottery known as "splashed ware". In the Islamic world splashed ware is one of the earliest types of glazed production, even if this group identifies potteries produced in different centres, which employ different techniques. In short, there is no clear definition of splashed ware but the common denominator is the presence of splashed decoration.

The introduction of the splashed ware, or better of the pottery with a splashed decoration[4], in Palermo has recently been established between the end of the 10th – first half of 11th century (Ardizzone, Pezzini, Sacco 2016; Sacco, in press). It has been supposed that the presence of these

[2] For the bibliography on the site see D'Angelo, F. (1997). La ceramica islamica (seconda metà X – prima metà XI secolo) dello scavo del Castello della Pietra (Comune di Castelvetrano), in *Atti delle Seconde Giornate Internazionali di Studi sull'area Elima (Gibellina, 22-26 ottobre)*. Pisa-Gibellina: Edizioni della Normale.

[3] We visually compared this fabric with some analysed petrographically, see Sacco, V. (in press). *Ceramica con decorazione a splash da Palermo (fine X – prima metà XI secolo)*, in 11th Congress AIECM3 on Medieval and Modern Period Mediterranean Ceramics, e Sacco, V. (2016). *Une fenêtre sur Palerme entre le IXe et la première moitié du XIIe siècle*. PhD thesis, Université Paris-Sorbonne e Università di Messina.

[4] For the difference between these two definitions see Ardizzone, F., Pezzini, E. & Sacco, V. (2016). The role of Palermo in the central Mediterranean: evolution of the harbour and circulation of ceramics (10th-11th centuries), in *Journal of Islamic Archaeology*, 2.2 (pp. 229-257) ; Sacco, V. (2016). Une fenêtre sur Palerme entre le IXe et la première moitié du XIIe siècle. PhD thesis, Université Paris-Sorbonne e Università di Messina ; Sacco, V. (in press). *Ceramica con decorazione a splash da Palermo (fine X – prima metà XI secolo)*, in 11th Congress AIECM3 on Medieval and Modern Period Mediterranean Ceramics.

type of pottery (both importation from Egypt and local imitations) is the consequence of closer contacts between Sicily and Egypt, possibly after the transfer of the Fatimid capital to Egypt in 973 (Ardizzone, Pezzini, Sacco 2016; Sacco, in press).

The green glazed bowl (N.I. 27357) was found during excavations conducted in 1973 at the Zisa Palace in Palermo. The Zisa Palace is one of the royal suburban residences built during the Norman period (12th century) inside the park of the Genoardo. Datable between 1164 and 1175, its construction has been attributed to the kings William I and II (Di Liberto 2013).

Fig. 2: Cooking pot of "Pantellerian ware" (Castello della Pietra, N. I. 48251).

The excavations, conducted in 1973 during the restoration of the building, are still unpublished[5]. Pottery finds are preserved at the Archaeological Museum and constitute an extraordinary set for their quality; they are in fact a rare testimony of the table ware used at the court of the Norman kings of Sicily. There are both luxurious ceramics imported from Egypt and the eastern Mediterranean and ceramics produced in Palermo. The bowl is a palermitan product of the second half of the 12th century. It is deep, with everted rim and high base and it is covered with green glaze. This bowl is very similar both to the bowls produced in the pottery workshop found during the excavations at the theater of Santa Cecilia in Palermo (Spatafora, Di Leonardo & Canzonieri 2014) and to the bowls attested in the kiln waste found in via Lungarini in Palermo[6]-[7].

Fig. 3: Hemispheric bowl (Piazza Bellini, Palermo, N.I. 66803).

Fig. 4: Green glazed bowl (Zisa Palace, Palermo, N.I. 27357).

2. 2. Survay through SFM and generation of polygonal meshes h

The methodology used for data acquisition was based on the *Imaging-Based Modeling* technique, which includes the photogrammetric process and *Computer Vision* through the development of algorithms and calculation strategies called *Structure from Motion*[8].

[5] Except for a brief news given by Tusa, V. (1976). Sull'archeologia medievale (con accenni agli scavi eseguiti allo Steri e alla Zisa), in *Atti del colloquio internazionale di archeologia medievale*, (Palermo-Erice, 20-22 settembre 1974) (pp. 104-109). Palermo: Università degli studi di Palermo. Istituto di storia medievale.

[6] D'Angelo, F. (2014). Un "gectaturi" del XII secolo a Palermo: lo scarico di fornace di Palazzo Lungarini, in Milanese, M., Caminneci, V., Parello, C. & Rizzo, M.S., (a cura di), Dal butto alla Storia. Indagini archeologiche tra Medioevo e Postmedioevo, in *Archeologia Postmedievale 12* (pp. 35-43). Firenze: All'Insegna del Giglio), with bibliography.

[7] This paragraph is entirely written by Elena Pezzini and Viva Sacco.

[8] (Remondino, F. e El-Hakim, S. (2006). *Image-based 3d modelling: a review. The Photogrammetric Record 21*, (pp. 269-291) e (Barazzetti L., Remondino F., Scaioni M., (2011).

Unlike traditional photogrammetric techniques that require the use of a calibrated camera or a photogrammetric camera, any camera can be used for the SFM, for which only a few parameters are required, providing to take only a measure, detected directly on the object or in the environment, that can serve to dimension the points cloud.

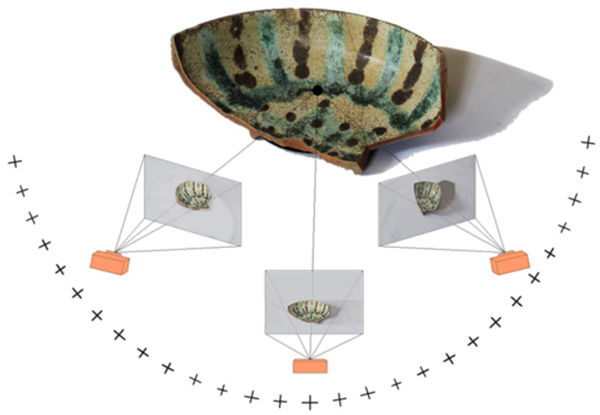

Fig. 5: Scheme for generating photo clusters.

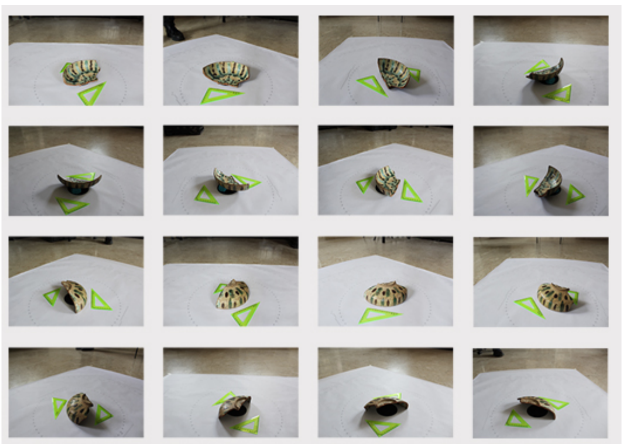

Fig. 6: Cluster of photos (N.I. 66803).

The general workflow involves capturing data from a photographic set called *cluster*. The findings were placed at the center of a self-constructed photogrammetric table in A0 format, suitable for scanning medium-sized finds to determine the number of poses (up to a maximum of 64 for each set).

Photos were taken using a Canon EOS 1300D Reflex Digital Camera with a 18/55 mm lens, equipped with a *Complementary Metal-Oxide Semiconductor* (CMOS) sensor. The maximum resolution of the camera used is 8.0 megapixels, equivalent to 3264x2448 pixels. In the photo set are placed the squares that will be used in the next stage for points cloud dimensioning and facilitate the matching phase.

Another key aspect was to perform a good set of shots (at least 24 shots), treating environmental lighting with a homogeneous distribution of light on all surfaces, taking care to set the ISO between 100/400 to avoid excessive noise; in addition, it has been attempted not to create shadows other than the one produced by the object itself using a tripod. This initial step is crucial to getting point clouds of good quality.

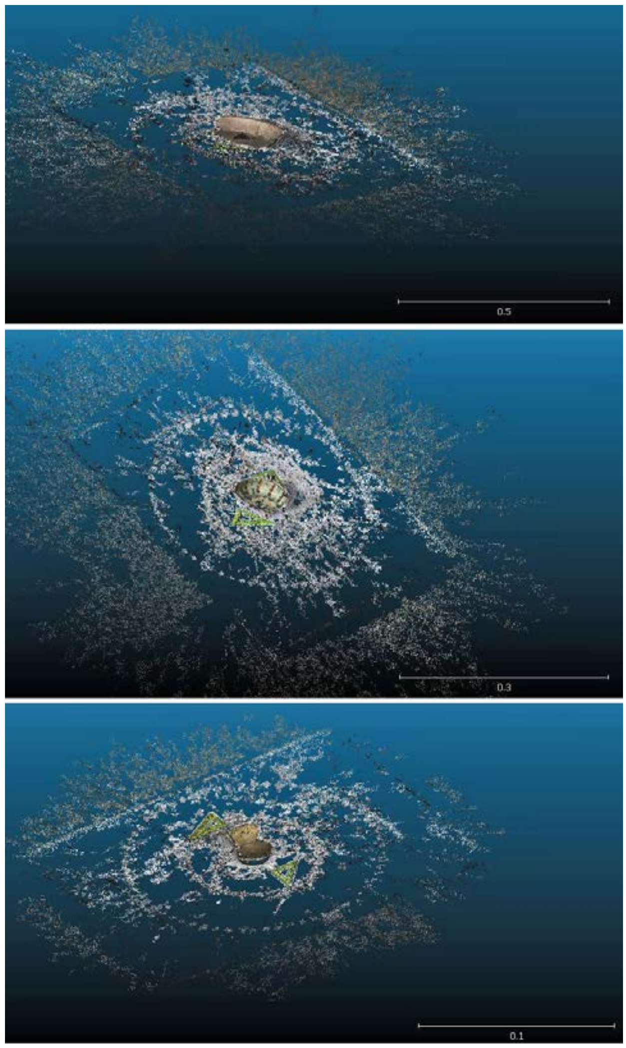

Fig. 7: Point clouds (N.I.. 48251, N.I.. 66803, N.I. 27357).

Automated and accurate orientation of complex image sequences. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XXXVIII-5/W16, online, pp. 277-284).

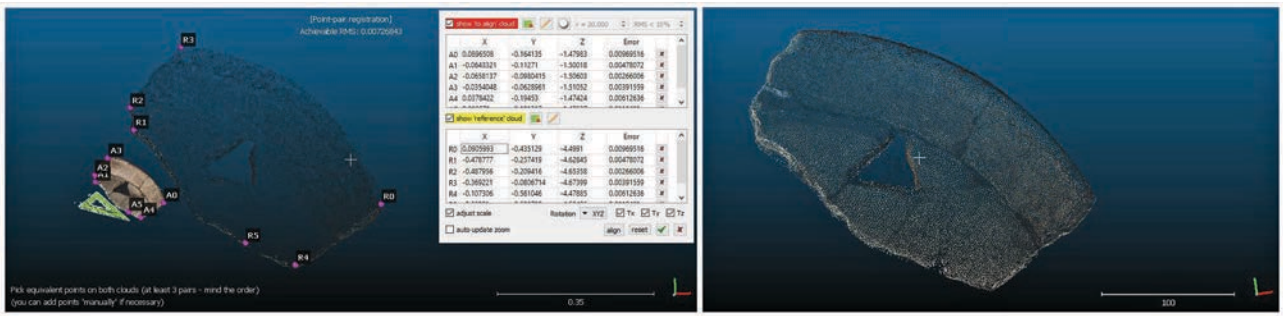

Fig. 8: Collimating and scaling of point clouds (N.I. 48251).

Once the image repository is defined, the next step concerns the processing of photographic data through the open source software *Python Photogrammetry Toolbox* (PPT) (Moulon & Bezzi, 2012) and the use of the *Bundler adjustment application*.

The first step with the Bundler application is to identify the common points between the different (*features detection*), whose quality is a key condition for the successful outcome of the process. Thanks to this automatic operation, PPT software can calculate the position of the camera in the space relative to the object and store its parameters by elaborating a point cloud, but initially only a low density point cloud (*sparse point cloud*). The next step is to merge the features: once you extract the homologous points in common between the various images, the process moves forward to the *matching* step. In this way, you have a first three-dimensional representation of the object, using an algorithm called SIFT (*Scale Invariant Feature Transform*).

The second step involves transferring these values from Bundler application to the PMVS / CMVS application, which automatically initiates the recognition of matching between the photos, and the end result will be a cloud of dense points (*dense point cloud*) a series of three-dimensional points that characterize and represent the scene. In the case of the objects studied the number of vertices obtained by doing this procedure is as follows:

- for N.I. 66803 the cloud consists of 177412 points;.
- for N.I. 48251 the cloud consists of 177326 points;
- for N.I. 27357 the cloud consists of 146183 points.

The next step concerns the collimation of the point cloud and its optimization, eliminating those vertices that do not belong to the surface of the object.

This can be done through two free open source software, namely *CloudCompare* e *MeshLab* (Cignoni, Callieri, Corsini, Dellepiane, Ganovelli, Ranzuglia, 2008). One fundamental aspect that needs to be considered is that the point cloud, because of the geometry of the object, may be incomplete. The solution here is to change the position of the object and get a second points cloud. The alignment or collimation of the two point clouds is done with the *CluodCompare* software. The procedure consists in identifying some pairs of homologous points (at least 4) and by means of a rototranslation and scaling operation, the two clouds are aligned.

The next phase concerns the generation and optimization of the polygonal mesh made through the MeshLab software and the use of *Poisson Mesh Reconstruction* algorithm (Kazhdan, Bolitho & Hoppe, 2006), allowing the shape of the original object to be realized.

To get a more detailed mesh, we need to use the *Subdivision Surfaces: loop* command, which allows you to increase mesh vertices by generating an optimized one. In the application of this process it is noted that the elaborated meshes of the objects studied presented a triangular surface consisting of a certain number of vertices and faces:

- the polygonal model N.I. 66803 consists of 91846 faces and 45925 vertices;
- the polygonal model N.I. 48251 consists of 4208782 faces and 2104391 vertices;
- The polygonal model N.I. 27357 consists of 78926 faces and 46956 vertices.

The polygonal model is, now, usable for later stages [9].

[9] The paragraph is entirely written by Rosalia Magro.

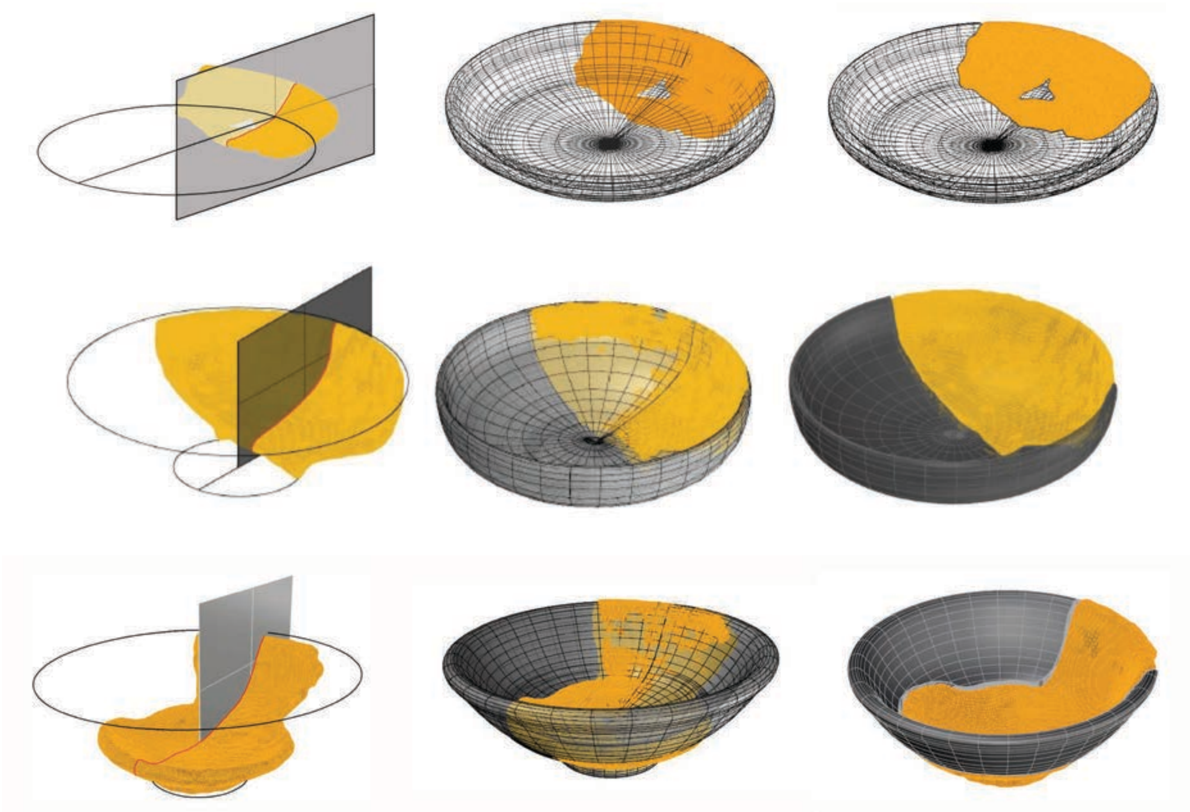

Fig. 9: Extraction of the section, overlapping the NURBS model with the polygon mesh of the specimen and juxtaposition with the portion of the surface reconstruction (N.I. 48251, N.I. 66803, N.I. 27357).

3. Modeling, 3D printing and texturing

Modeling of the missing part of the finds was done using the Rhinoceros software, by NURBS modeling.

The finds have a geometric matrix that can clearly be traced by surfaces of revolution, but exhibit the inevitable irregularities due to manual realization.

In order to obtain the analytically correct surface, steps had to be taken in the following phases: on the mesh of the model, three points were identified that would allow to identify some circles lying on parallel planes; the model has been subsequently rotated so as to identify an *xy* support plane; the interpolation of the centers of the circumferences allowed to define the vertical axis found by choosing the hypothetical one that had the slightest possible deviation from the centers of the circumferences; the insertion of vertical section planes allowed, therefore, to extract one or more sections usable for the construction of surfaces of revolution or two-tracks sweeps.

The sections extracted were compared to the existing ones, using traditional methods of archaeological survay, finding, in some cases, discrepancies considered decisive for the definition of the final morphology.

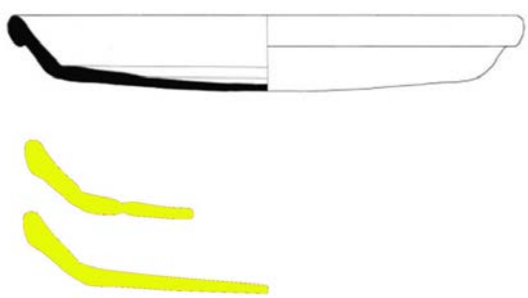

Fig. 10: Comparison between the section o the traditional survay and sections obtained from polygonal mesh (N.I.. 48251).

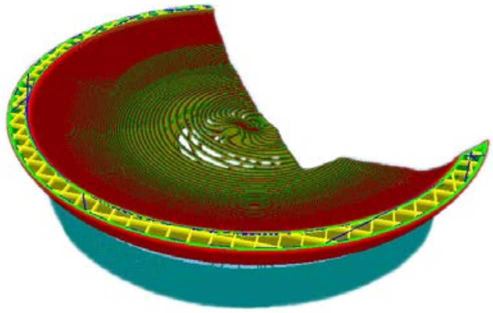

Fig. 11: Preparatory slicing to 3D printing

The reliability of the reconstruction was subsequently verified by superimposing the analytical surface with the extrapolated mesh from the relief phases, measuring very low readings, considered acceptable, considering that the ideal surface, calculated with the absolute precision of analytical modeling, could never be perfectly superimposable to the surface of the finds, in some cases very irregular.

To extract the missing part from the cutting surface, it was preferred not to operate by Boolean subtraction operation but by extracting the fracture surface of the find, used as cutting elements of the reconstruction surfaces.

It has been found that this methodology, however complex, has yielded better results than the Boolean subtraction used in the previous pilot project for the approach of the repertoire and reconstruction models.

Once the modeling phase is completed, the criteria for the different output phases are set: 3D printing and texturization of the virtual model.

The 3D printing process was carried out through the optimization of polygonal meshes of the finds and the mesh transformation of NURBS surfaces, exported in STL format (*STereoLitography interface format*) and imported into the CURA software for setting slicing and generating the GCode (Maietta 2014).

The printer used is of the Delta type, and the models were made in PLA (*Polylactic Acid*).

Prints of both the reproduction of the specimen and the model of the reconstructed parts have been made, so as to make a first verification of their correct alignment.

After the plastering and coloring phase, it could be verified the matching of the reconstructed parts and the finds.

The advantages of this method have already been exposed (Avella, Sacco, Spatafora, Pezzini, Siragusa, 2015), but they are reported here: chemical inertia of the material used, characteristic that does not interfere in any way with the ceramic material; total reversibility of reconfiguration intervention; access to the original fragment at any time for any study; giving the observer the opportunity to see the fragment and its dimensional and morphological reconfiguration.

The elaborated models have also been used for the application of textures that allow a digital display where the material simulation of the find is also proposed.

The directions for material reconstruction have been carried out with different methods: in case of the finding N.I. 66803 the texture was extrapolated directly from the mesh, where the RGB dot point information was present, and the space coordinates for positioning on the three-

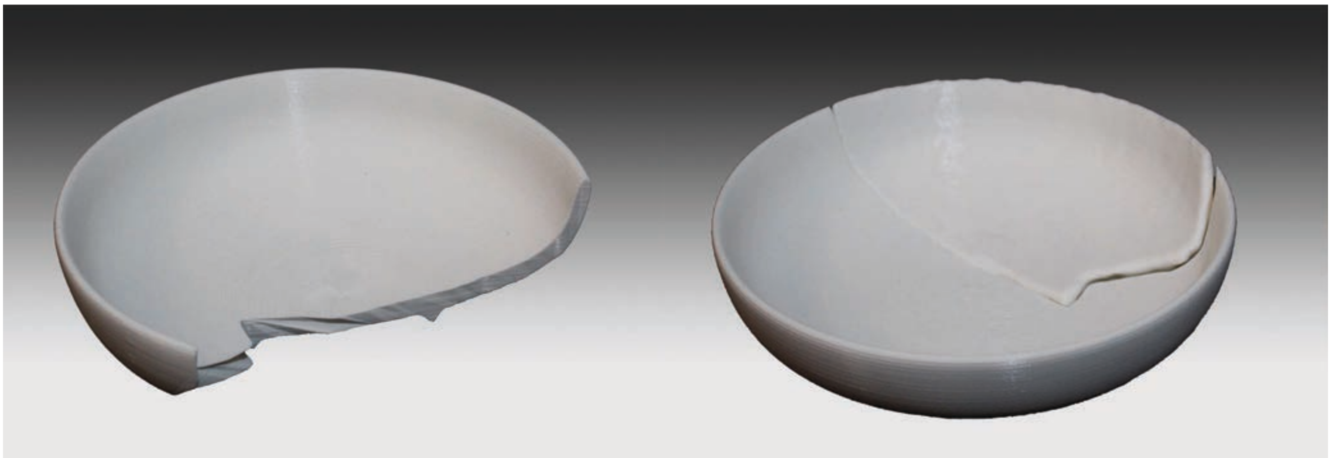

Fig. 12: 3D printing of the integration surface and matching with the reproduction of the find (N.I. 66803).

Fig. 13: Integration between the original findis and reconstruction by 3D Printing (N.I. 48251, N.I. 66803, N.I. 27357).

dimensional model. For the other two finds (N.I. 48251 and N.I. 27357) the texture was obtained directly from the RGB information of the photo shoots.

Regarding finding No. 66803 we were in the presence of a decorative radial matrix apparatus of which only a portion of the fragment was available, but it showed the presence of a radial matrix decorative apparatus. Therefore, the overall geometry has been rebuilt isolating a quarter of the original texture and repeating it according to a polar array to complete the missing part. The central portion has not been defined, because of the absence of information that cannot be deduced from the decoration of the find.

The textured model can therefore be displayed in its morphological and material integrity and imported into any interactive display system[10].

4. *Conclusions*

The process presented is suitable to develop an integrated system for the conservation, enhancement and display of archaeological heritage, offering the user various modes of observation.

[10] The paragraph is entirely written by Fabrizio Avella.

In the real display, the visitor can have the perception of the evidence put beside the integration in 3D printing, thus appreciating the overall morphology and the original size, often not perceivable by observing only the fragment.

The digital display, "in situ", which can happen simultaneously to the real one, allows to appreciate the complete reconfiguration with the possibility of observing the object even from different points of view than the one offered in the exhibition, which often occult portions which remain invisible. Digital models, besides, offer the advantage of perceive material reconfiguration and decorative aspects, which can be updated after further studies.

Furthermore, they may become part of an interactive database where you can enter information about the finds, references to contemporary or typologically comparable ones, and whatever else considered necessary for its comprehension.

The fruition of the digital model can also be done online, in order to generate an information network addressed both to virtual visitors and to scholars in the field.

The database, which can be constantly updated, becomes thus a powerful tool for enhancing archaeological goods by potentiating the logic of the museum exhibition: you can go beyond the real visit to the museum and the information about its precious material can be transmitted anywhere in the world.

On the basis of the foregoing, it is believed that 3D printing and digital visualization can be considered an integrated system that presents very interesting aspects for the fruition and valorisation of archaeological goods[11].

Fig. 14: Rendered model (N.I.. 48251).

Fig. 15: Rendered model: upper, lower, front and assonometric views (N.I. 66803).

Fig. 16: Rendered model: upper, lower, front and assonometric views (N.I. 27357).

[11] Conclusions are written by Fabrizio Avella.

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