1st International Conference on
Metrology for Archaeology
Benevento, Italy, October 22-23, 2015

Archaeometric characterization and 3D survey: new perspectives for monitoring and valorisation of Morgantina silver Treasure (Sicily)

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***Abstract* – The Morgantina silver Treasure belonging to the collections of the Archaeological Museum of Aidone (Sicily) were involved in a 3D survey and diagnostics campaign for monitoring over time of the finds, in anticipation of their temporary transfer to the Metropolitan Museum of Art in New York, for a period of four years. According to a multidisciplinary approach, it has been developed a scientific and methodological protocol based on non-invasive techniques to achieve a complete and integrated knowledge of the precious items, of their conservation state and increasing their valorisation. All acquired data, i.e. 3D models, UV fluorescence and X-Ray images and chemical information, will be made available, in a integrated way, within a web oriented platform, that will represent a in progress tool to deepen the existing archaeological knowledge and technologies of production and to obtain referenced information of the state of preservation, before and after moving of the finds from their exposure site.**

I. INTRODUCTION

The Morgantina Treasure, (Fig. 1) one of the most precious collections of the Archaeological Museum in Aidone, consists of 16 pieces that were returned to Italy in 2010, following the 2006 agreement between the Italian and Sicilian governments and the Metropolitan Museum of Art in New York. A police investigation determined, in fact, that the provenance of the objects was the house of Eupolemos in Morgantina, where the precious items probably were hidden during the chaos of the Second Punic War. According to the 2006 Agreement, every four years the silver set must be shared by one museum and then the other, and since the beginning of 2015 the precious finds are now on display at the Metropolitan Museum. The group consists of several table vessels plus an arula, a phiale and two pyxides probably used for the ritual libations of a symposium. Most of the silver objects bear punch-dotted and incised inscriptions that give names, monograms or weight indications. The chiseled and embossed techniques on the bowls, the medallion, the pyxides and the arula are among the best examples of Hellenistic metalworking.

Fig. 1. The silver hoard from the Eupolemos's House - Archaeological Museum of Aidone (Sicily)

The silver set has been considered to be a composition made in early Hellenistic times from different groups –

the “result of acquisitions or juxtapositions” from different contexts, as P. G. Guzzo [1] puts it in his remarkable edition of this hoard. The slight differences observed in the silver objects through diagnostic non-invasive investigation, as shown in the following, corresponds fairly well to the groupings made by Guzzo [1] on the basis of the inscription techniques that appear on the objects. Despite the internal articulation in the material composition and the epigraphy, these three groups all seem to belong to the same period.

Unfortunately not much analysis has been performed on Hellenistic silver comparable to that from Morgantina, and we know relatively little about Hellenistic metal-working techniques. Pure native silver is very rare. Commonly silver is derived from minerals with significant lead content, such as galena, and the process of purification is very complex. The refining process, which seems to have been developed in Asia Minor in the third millennium B.C., remained unchanged for centuries and spread throughout the Mediterranean.

II. SCIENTIFIC RESULT AND DISCUSSION

Before the trip to New York have been decided to examine the silver pieces through a campaign of non-invasive diagnostic analysis and 3D survey in order to collect useful data both to monitor the conservation state over time (to check after four years) and to guarantee the virtual visit of the item during their absence. Finally, all provided data and information will be organized in a web-oriented interface framework for different level user and application aims.

A. DIGITALISATION MODELS VIA 3D SCANNING

Among the new technologies currently proposed for the application to Cultural Heritage, the potentialities of the 3D scanning technique represents a significant example of how originally far apart fields, such as the one of conservation, that of research and that of advanced industry, can find a common interest ground. Noninvasive experimental use of methodologies and innovative tools have been developed for analysis procedures of geometric dimensional data, restoration and monitoring.

In our case study, the innovative applied technologies had the purpose of creating a 3D collection data to assist the restoration and conservation of the Morgantina Treasure.

Now, after the transfer of the collection, the 3D digitalization is bringing to restorers and archeologists in documenting the process of investigations and presenting it to the public.

The geometric survey helps us to evaluate the state of material preservation of the external and internal portions of the object and permits, each time the collection is moved to a new location, the registration of anomalies and stresses to which the object has been subjected through a systematic program of monitoring.

The process started on physical models is defined *Reverse Engineering* and the digital resolution up to 0.1 millimeters for each object was realized using a 3D portable scanning system with a structured light flash bulb (*Artec 3D Scanner_Spider*), permitting highly detailed digital models to be produced (Fig. 2).

Fig. 2. Acquisition phase via 3D scanning of a piece of the collection.

The choice of this technology was greatly determined by the physical characteristics of the 16 objects of collection to be scanned, including the size of pieces, the complexity of its outer surface, the light-reflecting properties of the surface of the metal object and the constraints on access/manipulation.

The size of the pieces varied greatly, ranging from large piece of *kyathos* (diameter 26 cm; height 20 cm), to pieces of average size, such as the concave cups (diameter 22 cm), down to smaller pieces, such as the *Émblema* with *Scylla* shown (diameter 8,3 cm; height 5,5 cm).

The selection of the specific instrument is influenced also by the characteristics of the 3D model required, in terms of accuracy and resolution, which depend on the intended use for the digital model [2]. In the case of the Morgantina Treasure, the process with a high surface detail can be managed also to ensure enjoyment to various categories of users: cataloging, restoration work, promotion, consumption and diffusion.

The campaign of indirect detection was carried out by the team in 20 working days, under the supervision of museum staff.

The acquisition structured light system is based on the capture of the points that make up the surface of a physical object returning a digital 3D model with a high degree of geometric correspondence to the real object.

The extremely versatile system (it do not require any special markers to be placed on the object being scanned), functional, rapid and capable of acquiring almost 1.000.000 points/sec., turned out to be particularly suitable for the geometric-dimensional characteristic of the object. The used tool captures images also (texture resolution1.3 mp; image color 24 bpp).

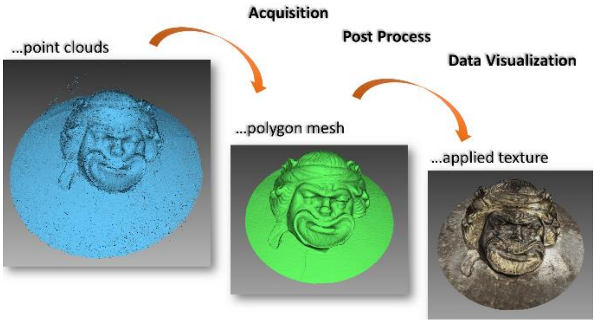


Fig. 3. Synthesis scheme describing the 3D scanning and data registration processing steps.

The structured light system works with a light source projecting a series of light patterns on the object to be scanned(blue led). The reflected image is captured by cameras and from the analysis of the distortion of the pattern the position is evaluated of each point of the surface to be scanned.

To obtain a complete 3D model, it is sufficient to move uninterruptedly around the object and filming it from various angles. Although the technical characteristics tell about an alleged irrelevance of the camera angle, it is easy to observe how rays, which are perpendicularly incident and/or not tangent, assure a greater final accuracy.

The related proprietary software (*Artec Studio*) automatically joins all the acquired frames in a single mesh. The algorithm, in fact, recognises the geometry of the object (points clouds processing)and it allows the correct alignment of the various captured 3D frames to visualise them in a single model (therefore conserving the reference system), eliminating as much as possible the presence of holes and shadows due to back drafts.

We acquired from a minimum of 5 to a maximum of 20 scans for each pieces of collection. A total of 180 scans were shot and 12GB of raw data were collected.

After the scanning and data registration process (the workflow includes the following stages: *revising and editing the data*; *alignment of scans*; *global data registration*; *fusion of data into a single 3D model*;*final editing of the 3D model; texture mapping*), the procedural phases of post processing and of polygon mesh tessellation have been performed through the software *Leios* (Fig. 3).

Thanks to semi-automatic algorithms, that is able to take account of the surface geometry (curvature, adjacency edges, density of the polygonal mesh), it removes artifacts scan.

The high-quality 3D digital models are responsive to the complexity of the geometric-formal of the analyzed objects and the digital collection reproduces really well the decorations in organic form (Fig. 4).

The collected data so far are a great start to deepen the existing knowledge from the archaeometric to conservative point of view [3-4].

Fig. 4. 3D digital model of the Émblema *with* Scylla *shown.*

B. DIAGNOSTIC NON INVASIVE INVESTIGATION

Digital X radiographs, UV fluorescence data and X-ray fluorescence analysis (XRF) of all the silver objects were carried out directly *in situ* using portable instrumentation [5-7]. The acquisitions carried out on the sixteen silver objects have produced:

- 110 XRF spectra for the analysis of silver and gilded surfaces, and of the area affected by corrosion phenomena, that is, the formation of silver and or copper degradation products;
- 40 hours of UV fluorescence (450 nm, 540 nm, 600 nm) acquisition for the identification of materials present on the surface, that is, integration, adhesives, protective materials;
- 27 X-ray exposures (2 projections for each objects) for structural analysis.

These non-invasive methods have provided complementary results, for a more comprehensive evaluation of the state of conservation and of executive technique. In particular, the non-invasive diagnostic study was directed to:

i) distinguishing the original material from degradation and/or restoration materials;

ii) obtaining a deeper knowledge of the production technique;

iii) assessing the current state of conservation and acquiring useful data for scheduled monitoring.

The X-Ray imaging has allowed to document details related to the technology of assembly and the execution of embossing (Fig. 5).

The radiographic data, which analyzes the internal structure of the object by comparing the varied absorption of X-rays, has provided information on the presence of fractures, which for the most part were subject to previous restoration (Fig. 6), also highlighted by observations under Wood's light.

Fig. 5. X-Ray acquisition on Mastòs (NI 9): upper-lower projection

Simultaneous observation of UV fluorescence image shows along the discontinuities the presence of organic material (adhesive) applied during prior restoration work carried out to solve fractures visible on X-ray. This deformation allows to suppose that the fractures are due at the time of the clandestine excavation.

For most of the analyzed finds, UV fluorescence in the visible range acquisition has allowed us to map materials present on the surface, which were used for protection or integration during the past restorations. This technique highlights the use of different types of adhesives present in fractures already evident in the X-ray images.

Such mapping has not always been done in documenting previous conservation efforts.

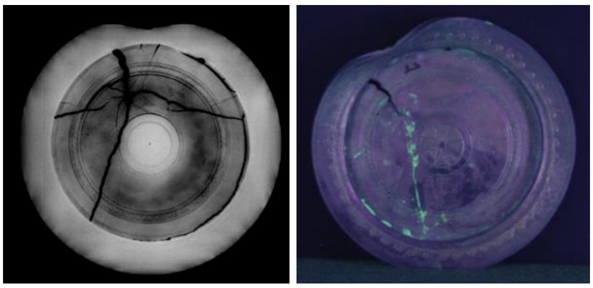
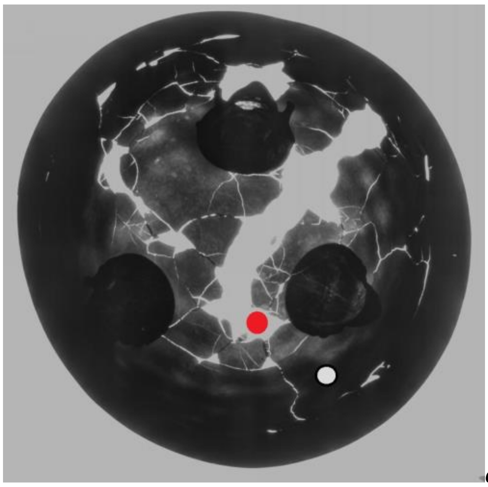


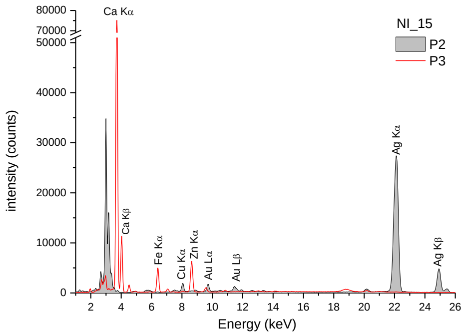
Fig. 6. X-Ray and UV fluorescence acquisition on find NI 16a

Finally, the analysis of the X ray fluorescence has enabled us to identify chemical elements, which provide information on both the silver alloy and the application of gold leaf decoration, as well restoration material localized by X- ray and UV fluorescence imaging (Fig. 7a-b).

Among the constituent materials of precious artifacts, in addition to gold and silver in the silver matrix it was also found copper, but in this variable ratio with to silver, splitting the 16 findings in three clusters (Fig. 8).



a)



b)

Fig. 7. a) X-Ray image on Mastòs (NI 15): inverted grey levels of the upper-lower projection; b) XRF spectra acquired on the original surface(P2, grey) and on the integration (P3, red) shown in RX.

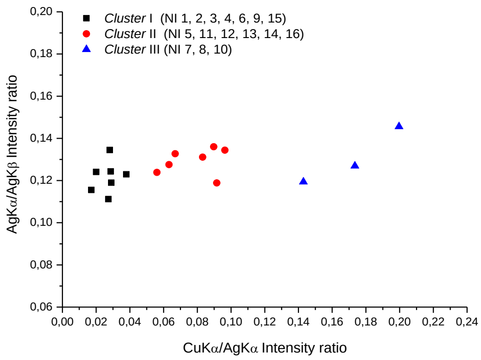


Fig. 8. Bi-plot of the whole set of Silver (NI 1-16) based on the XRF data relating to characteristic emission lines of copper (Kα) and Silver (Kα e Lα).

Different colour highlights the three groups obtained on the basis of the Cu/Ag ratio.

The copper content was probably added voluntarily into alloy to modify properties rheological and mechanical properties of the melt, since the copper (above 3%) allow to increase the resistance of the silver and lowers the melting point.
In correspondence with the gilded surfaces it has not been found the presence of mercury (attributable to the technique of gilding with amalgam) and consequently it is likely that the gold leaf has been applied to the silver surface by thermal treatment.
Moreover, useful chemical markers were also identified for the monitoring of the blackened areas due to the formation of silver or copper sulfides, as shown for find NI 7 in figure 9, bromide or chloride.

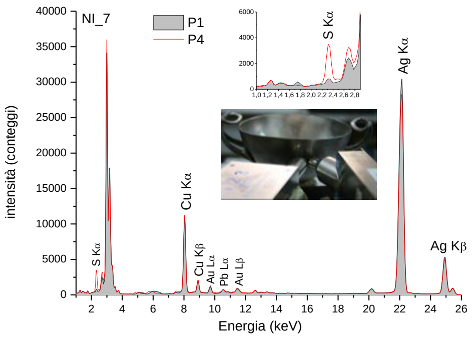


Fig. 9. Silver Skyphos (NI7): Spectra acquired at the surface in good preservation state (P1) and the one affected by blackening (P4). From the zoom reported is well evident the high signal counts of sulfur peak.

C. WEB-ORIENTED INTERFACE FRAMEWORK

Using the 3D scanning approach applied on Cultural Heritage [8-12], the Morgantina silver gilt Treasure collection, has been converted into 3D digital model[1]. In order to make this collection accessible in a user friendly way, we are developing a web-oriented interface framework.
Its main functionalities are the cataloging of already existing or totally new 3D scans and the management of additional metadata. Indeed, one of our main aims is to augment the digital version of the artifact with semantic annotations about it, such as the history, measurements data, expert comments and so on. Another point of value of the proposed system, raises from the possibility of subdivide the initial scanned mesh into several layers of interest: each layer can show different aspects of the artifact.
The proposed framework could be useful also in the implementation of a versioning catalogue for the monitoring and preservation of the cultural heritage state. Moreover, developing the framework in a web-oriented way will help the researchers from over the world since data will be eventually available online.
The prototype is developed by using the Unity engine, version 5.0. Unity is a platform with an integrated game engine and is developed by Unity Technologies. It is mainly employed to develop video games for different platform, such as PC, consoles, mobile devices and websites. It allows to handle 3D model and other kinds of assets, as material, light, image, and video. Unity 5.0 provides an IDE called Mono Develop to code in two different program languages: C# and JavaScript. For this work C# has been used. Although Unity is usually used for game development, it is also suitable for generic purpose application related to 3D modeling.

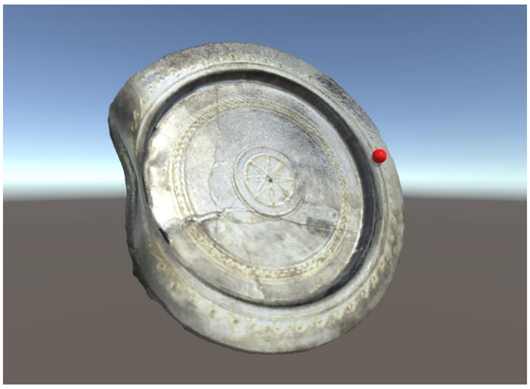


Fig. 10 An example of textured 3D model into the viewer of the proposed system. The red sphere on the bottom is used as marker for semantic annotation.

Through the developed software, Morgantina artifacts can be selected from a list of the digitally acquired objects. Each of them, has its own 3D environment, with the mesh located in the center. Typical navigation actions, as rotating and zooming are provided, so that the surface and details of the object can be analyzed from all the points of view. The user can navigate the environment with the mouse or using the proper buttons on the GUI. Moreover, two visualization modes are provided: shaded and textured. Shaded mode (Fig. 10) is better for geometric details analysis, since general shape is usually clearer without texture. Using this mode, the alteration in the original structure of the Cultural Heritage could be investigated (e.g., deformation, missing parts). On the other hand, Texture mode (Fig. 10) gives information about the colors and generally the state of conservation of the surface. Indeed, it could be helpful in finding chemical reaction (e.g., oxidation) or pigments scratches.

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[1] *Archeomatica project*: http://www.archeomatica.unict.it/

In each scene, the rendered object contains semantic annotation, as textual and visual data. Among the latter, we provide images and graphs, that are useful for comparisons with the same artifacts in different time. Interactive parts of the mesh, are enriched with these major details and are emphasized with markers. When users select a marker, a tooltip appears or a sided info-box shows the related information. The sided info-box window is particularly useful to show visual data.
The kinds of semantic information are: X-Ray for fractures analysis and manufacturing techniques identification; UV spectral image to detect previous restoration evidences; XRF spectral data for chemical composition analysis and corrosion material detection; optical microscopy for details about the manufacturing techniques. All the semantic annotations onto the meshes, are labeled with one or more tags. For instance, all additional notes concerning corroded regions are labeled with tag "alteration". This functionality will be useful in future version, because we are considering to develop a query system to filter annotations selecting just some of them identified by specified tags.
As other future works, we are planning to improve the framework with several functionalities. For instance, the possibility to subdivide the visualization of an object into subparts (e.g., the handles of an amphora). Another improvement is to add an editing system to allow the user to add their own 3D models, and add annotations wherever they wish. We are considering to release the software for several platforms (like smartphones or tablets), and exploit a 3D engine different from the Unity and to use novel libraries like WebGL, specifically developed for web.

III. CONCLUSION

The data so far collected represent a key starting point to deepen the existing knowledge from the archaeometric point of view, but also to provide an objective reference for monitoring the state of conservation of the precious items constituting the Morgantina Treasure belonging to the Archaeological Museum in Aidone (Sicily). The ongoing web-oriented platform consists an active tool to management of metadata, which will gradually be implemented through knowledge acquired by specialists and at the same time contribute to the valorisation of these archaeological findings to the wide public.

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