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Geometric survey and characterization of artifacts through portable devices: an experience of mobile laboratory inside the Aeolian Museum of Lipari

Dario Giuffrida[1], Viviana Mollica Nardo[1], Oreste Adinolfi[2], Maria Amalia Mastelloni[3], Rosina Celeste Ponterio[1]

[1] CNR-IPCF di Messina, Viale F. Stagno d'Alcontres 37, Messina, Italy, dario.giuffrida@ipcf.cnr.it, mollica@ipcf.cnr.it, ponterio@ipcf.cnr.it
[2] FARO Europe GmbH & Co. KG, Am Wiesenbusch 1, 45966 Glabeck, Germany
[3] Former Director of Polo, Parco Archeologico e Museo "L. Bernabò Brea", Via Castello 2, 98050 Lipari, Italy

***Abstract* – In the last decade portable devices for analyzes on Cultural Heritage (e.g. laser-scanners, spectroscopes, XRF) has reached levels of reliability such as to be able to replace benchtop instrumentation for survey *in situ*. One of the most effective application of these devices concerns the digitization and the diagnosis of artworks preserved inside museums. Indeed, moving art objects or finds from its place of preservation to specific laboratories can often result difficult due to several reasons as fragility, big sizes, risk of damage, lack of authorizations etc.**

The paper shows the results of a collaboration between the IPCF-CNR of Messina and the Archaeological Museum of Lipari aimed at the creation of a mobile laboratory for chemical analysis and 3D digitizing of finds presenting different issues. The activities have been carried out using two performing and contactless tools: a laser-scanner arm by Faro (sometimes in combination with an external camera) and a handheld Raman spectrometer by Brucker.

I. INTRODUCTION

The technological innovation of the last decade has significantly reduced the quality gap between the performance of traditional bench-top instrumentation and transportable and portable devices [1]. This has made it possible many useful and effective applications in the field of Cultural Heritage: firstly, for urgent and rapid measurements to be performed during archaeological excavations; secondly, not least, for diagnostic or digitizing campaign planned within archaeological areas or museums, where, moving art objects or simple finds to specific laboratories can often result difficult due to several reasons (fragility, big sizes, risks of damage, lack of authorizations etc.). Today, this obstacle can be overcome by the possibility of using portable devices, which are having great success on several fronts:

1. for museums, digitization and diagnostic campaigns in situ can be an opportunity to increase the information potential of their collections (including not-exhibited artifacts) and to create digital archives (containing all metric data, such as 3D models, or archaeometric analysis results) to be used as a basis for the study, for restoration or dissemination.
2. scholars and specialist can, instead, perform and manage the analysis of a multitude of samples in the same place of their preservation, whereas it is often much easier and safer to transport one or more survey tools rather than objects of historical-archaeological interest.

In museum contexts, the most requested and useful instruments are those which allows to obtain three-dimensional reproductions of objects [3] (metrically correct fac-similes) and those for chemical-physical investigations, useful for obtaining information about the composition of materials at various levels of depth and for several purposes. The former mainly consist of range-based tools as triangulation laser-scanners (fixed or mounted on mobile mechanical arms) and digital photogrammetry (an image-based technique based on metric, single-lens reflex and compact cameras), used in association with each other or independently.

The latter, instead, consist of non-destructive tools for chemical-physical analyses (Raman and FT-IR spectroscopy, XRF, etc.), able to add detailed information about the composition of materials and to provide specific answers to diagnostic issues, attribution, dating or geographic area of provenience [4, 5]. In fact, the identification of pigments, binding media or materials components, can be connected to a specific production technology, workshop or artist and contribute to determine the dating or the provenience of a given artifact.

The execution metric and compositional analyses has now become for museums a necessary and preliminary step to any kind of intervention (restoring, maintenance interventions for conservation); moreover, the resulting digital models can also be valid supports able to ensure the accessibility to some artifacts and to improve the experience of visiting.

This paper shows the main results of a measurement campaign carried out by the IPCF-CNR of Messina at the Aeolian Regional Museum of Lipari with the aim to study some artworks through portable and handheld devices. According to the different issues characterizing each artifact or the specific request made by the Museum, single or combined techniques were used.

II. MATERIALS AND ISSUES

The Aeolian Museum, created in 1954 by Luigi Bernabò Brea and Madeleine Cavalier inside the Castle of Lipari, preserves and exhibits important finds with great informative potential, all coming from the excavations carried out in the Aeolian Archipelago from the 40s to today. The list of objects interested by the analyses includes the following archaeological finds belonging to the section of Classical Archeology:

- 12 theatrical clay masks dating between the first decades and the end of 4th cent. BC, with dimension ranging from 6 to 25 cm in height (fig. 1), coming from the urban necropolis of *Lipára*: they are part of a corpus of theatrical *coroplastic* finds (the richest of the whole ancient Greek Heritage), consisting of over a thousand specimens of miniaturistic statuettes and masks [6].
- 2 figured calyx craters dating at the middle of 4th sec. BC (fig. 2): the first (i.n. 340bis), attributed to the Painter of Maron, active around 340 BC, represents an episode of the myth of Hippolytus; the second (i.n. 10,648) attributed to the painter of Adrastus (perhaps active in *Lipára*).
- a Greek stone *arula* characterized by an inscription dedicated to Artemis difficult to read (4th sec. BC) coming from a sanctuary located next to the city wall and the necropolis;
- 2 decorated lids of *lekanai*.

For each class of artifact, different requests were made by the museum, as summarized below.

For theatrical masks [7] the aim was to analyze the composition of pigments still preserved on the surfaces of clay, whose identification and characterization could provide information about attribution, dating or provenience and could help in the choice of materials to be used for future conservative interventions. In addition, a 3D high resolution geometric survey has been requested for different purposes: the creation of a digital archive useful for needs of study, conservative intervention, digital integration of lacking parts and for a future project of virtual fruition [8] in augmented realty.

Fig. 1. The 12 clay masks analyzed: (a)11114-E (h. 7.8 cm);(b)10,827 (h. 6.9 cm); (c)11114-b (h. 7.2 cm); (d)9729 (h. 7.9 cm);(e)9219 (h. 11.5 cm); (f)13,558 (h. 11 cm); (g)14,585 (h. 16 cm); (h)14,584 (h. 13 cm); (i)6766 b (h. 13 cm); (l)11,248 (h. 9.5 cm); (m)3375 (h. 6.3 cm); (n)9768 (h. 16.5 cm).

A particular study-focus has interested the mask n. 11114-E (fig. 1a), considered a *unicum* in Lipari as well as in the whole Mediterranean area due to the presence of two flanked half-faces (an old and a young) in a single piece: in this case, the survey was also aimed at generating a virtual reconstruction of both character (fig. 1, a).

An accurate 3D geometric survey has been also requested for two important calyx craters exhibited in the classical section of the Museum: the crater attributed to Adrastus Painter and the Maron's Crater (340 a. C.) (fig. 2).

(a) (b)

Fig. 2. (a) Adrasto Painter crater (i.n. 10648); (b) Maron Crater (i.n. 340bis)

The latter, in particular, has been repeatedly subjected to reassembly and restoring, the first of which in antiquity to be re-used as element of funerary equipment while the second between the ’50 and ‘70. This, specifically performed using shellac, had compromised the structural stability of the vessel, making a new intervention necessary to remove the glue. After our survey, the new restoring has been finally carried out in 2019 [9].
In addition, a projection on plane of the decorative apparatus depicted on the body of both vessels was also requested.
With the same purposes also the two lids of *lekanai* have been surveyed both by laser scanner and portable Raman.
Finally, a high precision 3D survey and generation true orthophotos with high accuracy shading system for the characterization of decorative details was requested for the *arula* in order to identify the traces of letters no longer visible.

III. TECHNIQUES AND INSTRUMENTS

A. Laser scanner

In order to fulfill the requests of accuracy, one of the most performing coordinate measuring machines (P-CMM) available on the market has been deployed: the “CAM2 Quantum M Arm” by FARO - Europe GmbH & Co. KG (fig. 3), a laser scanner arm meeting the most rigorous ISO 10360-12:2016 standards.

Accuracy:	±25 µm (±0.001 in)
Repeatability:	25 µm, 2σ (0.001 in)
Stand-off:	115 mm (4.5 in)
Depth of field:	115 mm (4.5 in)
Effective scan width:	Near field 80 mm (3.1 in); Far-field 150 mm (5.9 in)
Points per line:	2000 points/line
Minimum point spacing:	40 µm, (0.0016 in)
Scan rate:	300 frames/second, 300 fps × 2000 points/line = 600,000 points/sec
Laser:	Class 2M
Weight:	485 g (1.1 lb)

Fig. 3. Quantum^{TM} FaroArm”: Laser Line Probe Specification.

It is a portable device which can be simply used on-site as a digitizer or an advanced digital pen to measure and record the shape of an object in three dimensions.
The device, through a suitable optic is able to produce a coherent and monochromatic light blade, which is detected by two CCDs (Charge-Coupled Device) and subsequently processed through a triangulation process.
The choice of this system is justified by the morphological and dimensional features of the finds to be analyzed: this kind of point-based technique has, in fact, a wide background of experimentation for the survey of small-sized objects with irregular and/or porous surfaces (as ceramic of archaeological interest), well documented in literature [10].
The scan quality on these materials is guaranteed by the advanced components of the instrument, which include interchangeable probes (Faroblu™ laser line probe HD) and a blue laser technology. Once connected to a PC running a specific software (Geomagic Wrap), the device is ready to acquire geometric data with a speed of over 600,000 points per second, showing in real time the resulting dense cloud as graphic representation of the object (fig. 4).

Fig. 4. Measurement through the 3D laser-scanner arm

Finally, the work-flow for the reconstruction has been performed trough Geomagic Wrap, a software having good capabilities in generating mesh surfaces starting from the point clouds and in managing the texture mapping of 3d models, following several steps (filtering, alignment, meshing, editing and exporting, fig. 5).

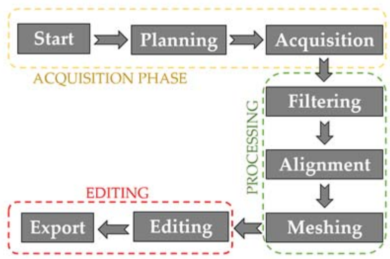

Fig. 5. Flowchart of data processing

B. Photogrammetry

Using a Canon Eos 7D Reflex Camera, a scaled *structure from motion* model of two figured calyx kraters was created in order to generate a photographic texture to be applied to 3D model (this version of laser arm, in fact, is not able to acquire RGB colors of points). In particular, the vases were entirely photo-scanned following a ‘converging axes’ schema and the photo-set processed through “Agisoft Photoscan”.

C. Raman Spectrometry

A next-generation handheld Raman Spectrometer (BRAVO – Bruker), manufactured by Duo LASER, was used to collect Raman spectra (figg. 6 - 7) in situ. The instrument uses patented technology (SSE™, Sequentially Shifted Excitation, patent number US8570507B1) [11] and is equipped with two excitation lasers (DuoLaser™) having wavelengths centered at 785 and 853 nm [12] working together to mitigate the fluorescence phenomena.

Fig. 6. The Raman Spectrometer (BRAVO – Bruker)

The Raman technique is one of the most suited non-destructive archaeometric methods to analyze work-arts and cultural heritage materials [13, 14]: as a scattering technique, it does not require a preparation or sampling of the artifacts and as an optical technique it works very well in a large wavelength range, for which a variety of optical devices has been developing for a long time. The technique is very powerful in the identification of crystalline substances, pigments and dyes, both of organic and inorganic component, as well as for the identification of restoration materials and degradation products [15]. The information obtained may represents also a great aid to restoration and conservation techniques.

Fig. 7. Measurements by the handheld Raman Spectrometer (BRAVO – Bruker)

IV. DISCUSSION

Raman analyses performed on all the clay masks preserving traces of color with the aim to identify the pigmentations, have led to important result involving the use of cinnabar; it is a brilliant scarlet mercury (II) sulfide (HgS) employed since antiquity in very important paintings and art objects. Raman spectrum of clay mask n°6766 (Fig.8) shows, in fact, only one band centered at 340 cm-1 imputable to cinnabar pigment (HgS), which is in accordance with data from the literature.

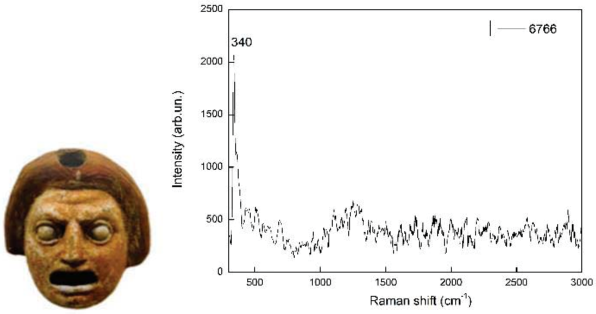

Fig. 8. Clay mask n°6766 analyzed with BRAVO Handheld Raman Spectrometer and Raman spectrum obtained.

The spectrum was acquired in the 320–3000 cm^{-1} range with integration times no longer than 60s. The identification of the contained dyes is carried out thanks to the use of database [16]

Its presence within the palette of both Lipari Painter (middle 3th cent. BC) and his followers [17] strongly suggest and identical use of materials and a local production.

Concerning the 3D reconstruction, the results obtained consist of metrically correct and high-resolution models, which have been organized in a digital archive which can be easily consulted for different study needs of study, conservation interventions, support for digital restoring, integration of lacking parts and virtual fruition via web-browser (see https://skfb.ly/6QzLw). In the case of the mask nr. 11114-E, for example, the data recorded hallowed to generate a detailed reconstruction of the two-half figures represented (fig. 9).

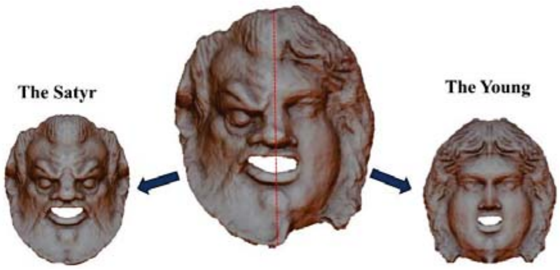

Fig. 9. 3D model of the mask 11114-E and virtual reconstruction of the two characters.

The informative potential of the digital archive created is vast, as it contain not only metric data (deriving from the geometric survey), but also information about the nature and the chemical composition of a determined pigment; as this information is appropriately recorded within modular and independent metadata, it is possible to use the final 3D model at multiple levels of depth, ranging from a simple display, to metric or information query.

Although the laser-scanner is the most accurate methodology in defining the geometry of objects, it is very

poor in photorealistic rendering, in relation to the high cost of equipment and elaboration software, which require long processing times and high modeling skills.
Another element of discussion concerns the management of high poly digital models, i.e., the meshes characterized by a high number of vertices and faces, so it is often necessary to decimate the models to get faster visualizations.
The results of the photo-scansion of the two calyx craters, have been also used to generate a projection on plane of the decorative apparatus depicted on the body of both vessels: this solution can certainly improve the reading of the scenes represented (fig. 10).

(a)

(b)

Fig. 10. Projection on plane of the iconographies depicted on the body of the two calyx craters: (a) Adrastus settles the dispute between Polynices and Tydeus; a female figure offers a large phiale to a young. (b) Hyppolytus and chariot horses.

The combined use of both techniques can provide an efficient way for executing drawings of painted vases, thanks to stylistic analysis from which it is possible to identify, in some cases, painters and workshops: only a meticulous fine documentation of details may reveal the particularities and characteristics of a painter and can help to recognize these on other vessels.
In the case of *arula*, instead, the laser survey did not lead to significant results in the reading of the epigraph, due to the bad conditions of preservation of the surface of the stone.

V. CONCLUSIONS

All the examples reported want to show the potential of creating mobile laboratories inside museums by portable instruments for the purpose of study, survey and characterization of finds of historical-archaeological interest. These new technologies, in fact, are an opportunity for both scholars and museums to perform complex measurements *in situ* and simplify the management and analysis of scientific data.
If, on one hand, 3D models become an effective tool supplementing and supporting traditional study activities (mainly when physical access to materials is not possible), on the other hand, its use hallow anyone to better understand the past thanks also to their integration into interactive applications, personalized presentations and virtual environments [8], with considerable repercussions on the visiting experience.
In addition, the association between digital models and the information deriving from diagnostic survey can strongly help users/visitor to deepen their knowledge about a given question and museums to make collections more appealing.
Another issue that should not be underestimated concerns the accessibility to findings not selected for exhibition, often banned to common users: the creation of digital archives containing 3d models of objects preserved within the storehouse allows to increase the range of objects publicly available and it can foster new narrative suggestions by enhancing the meaning of the objects physically exhibited and, in general, the entire design of the display arrangement.
Regarding this aspect, we have to finally underline how the use of technologies has now become essential in the process of re-evaluating the role of Cultural Heritage, no longer seen as exclusive domain of specialized scholars, but as an economic resource to be exploited for the growth of local communities and regions.

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