Archeologia e Calcolatori
32.2, 2021, 237-248
doi 10.19282/ac.32.2.2021.22

TESTING A MOBILE LABORATORY AT THE AEOLIAN MUSEUM OF LIPARI (MESSINA) FOR THE 3D SURVEY AND THE CHEMICAL CHARACTERIZATION OF ARCHAEOLOGICAL MATERIALS: PRACTICE AND FURTHER DEVELOPMENTS

1. Introduction

The technological innovation of the last decade has significantly reduced the qualitative gap between the performance achievable by traditional bench-top instruments and portable/handheld devices (Blais 2004), increasingly affordable and accessible. This has made possible many useful and effective applications in the field of Cultural Heritage survey: firstly, for urgent and rapid measurements during archaeological excavations; secondly, to perform diagnostic and digitization campaigns within archaeological areas, museums or in any situation where moving art objects or simple finds to specific laboratories can be difficult (e.g. due to fragility, large dimensions, risks of damage or lack of authorizations). Today this obstacle can be overcome thanks to the availability of high-performance portable and handheld devices that can be used on-site for special needs. For museums and archaeological sites, digitization and diagnostic campaigns may represent an opportunity to increase the information potential of collections (including not exhibited artefacts) (Gonizzi Barsanti, Guidi 2013) and to create digital archives (containing all metric data, such as 3D models, or archaeometric analysis results) to be used for remote study, restoration or dissemination.

In the museum field, the most requested approaches involve the use of technologies that allow to achieve metrically accurate three-dimensional replicas of artefacts (Hess, Robson 2012) and information about the composition and the properties of materials. The former mainly consist of range-based instruments such as triangulation laser scanners (fixed or mounted on mobile mechanical arms) or image-based photogrammetry. The latter, instead, consist of tools that allow scholars to perform non-destructive and non-invasive chemical-physical investigations (Raman spectroscopy, FT-IR, XRF, etc.) able to answer specific questions related to conservation, attributions, dating or provenance (Bitossi *et al.* 2006; Clementi *et al.* 2009). In fact, the identification of pigments, binding supports or components of materials can be linked to a specific production technology, artisan or artistic workshop and helps to determine the dating or the origin of a given artefact, as well as to identify possible false works of art. All these techniques, each with its own peculiarities, can therefore lead to the knowledge of the materials composing a certain artifact and, in combination with 3D digital models, can also be valid supports able to guarantee accessibility and to improve the visiting experience.

This work shows the main results of a measurement campaign carried out by the IPCF-CNR of Messina at the Aeolian Regional Museum of Lipari aimed at testing two different portable instruments[1] (a laser scanner arm and a Raman spectrometer) on a selection of archaeological artifacts. The campaign was a test to plan a broader and systematic survey to be carried out as part of an ongoing agreement between the two institutions. According to the different challenges associated to each artefact or to the specific request of the Museum, single or combined techniques were used, as illustrated in the following paragraph.

2. Materials and related issues

The Aeolian Museum, founded in 1954 by Luigi Bernabò Brea and Madeleine Cavalier, is located on the plateau of the Lipari Castle, an imposing volcanic rock that dominates the port area. The complex, which preserves and exhibits important finds from excavations carried out in the Aeolian Archipelago since the 1940s, is divided into six sections (Prehistory, Epigraphs, Minor Islands, Classical Archaeology, Volcanology, Quaternary Paleontology), which testify to the various settlement phases from Prehistory to the Modern Age and the strategic role of the Aeolian Islands in the context of ancient trade routes (Martinelli, Vilardo 2019).

The list of the selected objects includes the following archaeological finds preserved in the Section of Classical Archaeology:

– 12 miniature terracotta masks coming mainly from funerary contexts of the urban necropolis, whose dimensions range from 6 to 25 cm in height (Fig. 1a). They are part of a rich corpus of finds of theatrical subject, consisting of over a thousand miniature statuettes and masks (this is the most numerous of all the ancient Greek heritage) (Mastelloni 2018), all dating between the first decades and the end of the 4th century BC;
– two figured *calyx* craters dating back to the mid-4th century BC: the first one (inv. 340bis), attributed to the Painter of Maron (Fig. 2), active around 340 BC, depicting an episode from the myth of Hippolytus; the second one (inv. 10.648) attributed to the Painter of Adrasto (perhaps active in *Lipára*);
– a lithic *arula* characterized by a difficult to read Greek inscription dedicated to Artemis (4th century BC), coming from a sanctuary located close to the city walls and the necropolis;
– two decorated *lekanai* lids.

[1] This research, part of the 'IDEHA. Innovation for Data Elaboration in Heritage Areas' project (DUS.AD017.087).

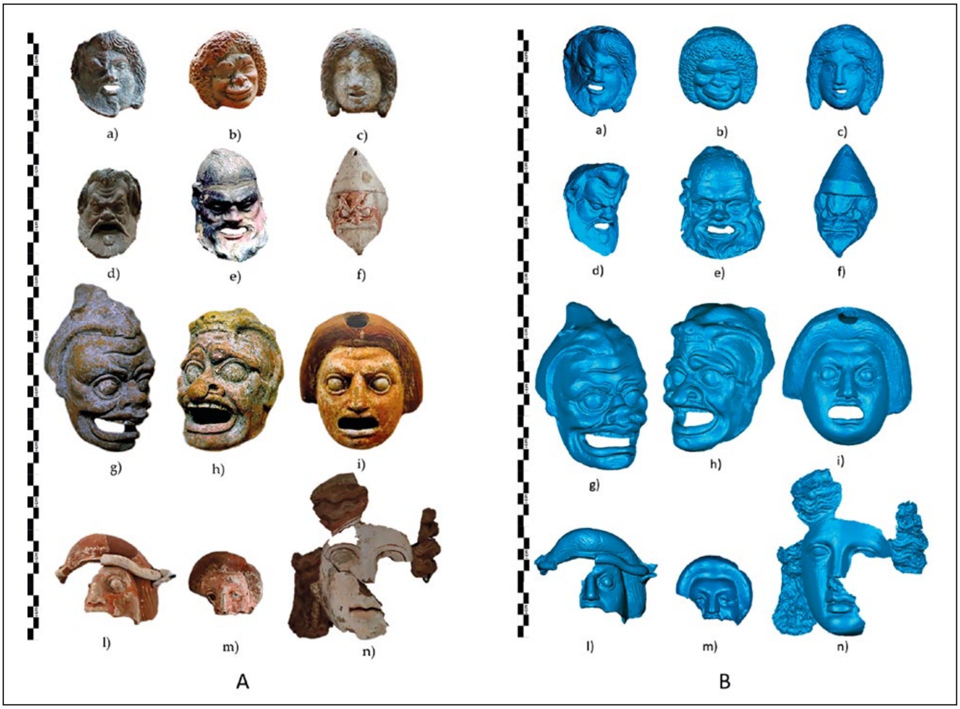

Fig. 1 – Theatrical masks taken in exam: a) n. inv. 11114-E (h. 7.8 cm); b) n. inv. 10827 (h. 6.9 cm); c) n. inv. 11114-B (h. 7.2 cm); d) n. inv. 9729 (h. 7.9 cm); e) 9219 (h. 11.5 cm); f) 13558 (h. 11 cm); g) 14585 (h. 16 cm); h) n. inv. 14584 (h. 13 cm); i) n. inv. 6766 b (h. 13 cm); l) n. inv. 11248 (h. 9.5 cm); m) n. inv. 3375 (h. 6.3 cm); n) n. inv. 9768 (h. 16.5 cm) (da Giuffrida *et al.* 2019). Image A) shows the original artifacts; image B) shows the same 3D digital copies.

In relation to the specific historical-archaeological problems characterizing each class of artefacts, the museum has specified various needs and goals: for the theatrical masks (Giuffrida *et al.* 2019), chemical analyses on the composition of the pigments preserved in traces on some samples were required, in order to obtain information about attribution, dating or origin. This analysis will be of fundamental importance in the choice of materials to be used for future conservation and restoration interventions. In addition, a high-resolution 3D geometric survey was required to obtain a digital 3D replica of each artifact. The registration and systematization of all these data have led to the creation of a digital archive (a database of 3D models complete with chemical-physical information) available for the study and comparison of materials, conservation and restoration interventions, digital integration of the missing parts and for a future project of virtual use in augmented reality (Barrile *et al.* 2019).

Fig. 2 – a) *Calyx* crater attributed to the Painter of Maron (n. inv. 340bis).

A particular study focused on the mask n. 11114-E (Fig. 1a, mask a) (Giuffrida *et al.* 2021), the only sample in the collection featuring a singular iconography that combines a half-face with a Silenic appearance to another youthful one. Considering the peculiarity of the find (discovered only in 2018 after the removal of a hard concretion that covered most of the surface of the mask), a laser-scanner survey was requested to improve the reading of the young face, not clearly visible autoptically due to the bad state of conservation, and generate a virtual reconstruction of both characters.

An accurate 3D geometric survey was also required for the two important *calyx* craters exhibited in the Classic section of the Museum: the first one is attributed to the Painter of Adrasto, while the second one to the Painter of Maron (340 BC). The latter, in particular, has been restored several times: the first restoration, carried out in ancient times, was functional to the reuse of the vase as an element of funerary equipment; the second one, carried out between the 1950s and 1970s, had the aim of restoring the unity and solidity of the vase for display purposes. In the latter case, however, the use of shellac had compromised the structural stability of the vessel in the long term, making it necessary a new intervention to remove the resin. Since the restoration was carried out few months after our investigation (Bavastrelli *et al.* 2019), it will be possible to metrically compare the new asset of the vessel with respect to the previous one. In addition, an orthographic projection of the decorative apparatus depicted on the body of both vases was also requested. With the same purpose, the two *lekanai* lids were both measured by laser scanner and portable Raman. Finally, a high-precision 3D survey was required for the *arula* together with the exporting of high-precision 3D shaded-models and orthophotos in order to identify the traces of letters that are no longer visible.

3. Methodology and instruments

3.1 *Laser-scanning*

The morphological and dimensional characteristics of the selected finds led to the choice of a triangulation laser scanner, which is the most accurate and metrically precise among portable measurement systems. Laser scanning is an active and non-contact survey technique, based on the measurement of distances using electromagnetic waves. Specifically, a monochromatic light beam is used to measure the distance between a sensor system and a target, thus obtaining three-dimensional coordinates (x, y, z) in the scene, defined by the instrumental range of action. Among the point-based measurement systems, the triangulation has a vast background for the digital survey of small-sized artifacts characterized by irregular and / or porous surfaces such as ceramics (White 2015).

The instrument used for this purpose is one of the best performing coordinate measuring devices (P-CMM) available: the FARO - Europe GmbH & Co. KG laser scanner FARO Quantum M Arm. It is a tripod-mountable mechanical arm that meets the most rigorous ISO 10360-12:2016 standards. The instrument, easily transportable, can be used in situ as a digitizer or advanced digital pen to measure and record the shape of an object in three dimensions. The device works through a special optic, by emitting a coherent and monochromatic blade of light, which is detected by two CCDs (Charge-Coupled Device) and subsequently processed through a triangulation process. Scan quality on these materials is guaranteed by the instrument's advanced components, including interchangeable probes (Faroblu HD laser line probe) and a blue laser technology. Once connected to a PC running specific software (Geomagic Wrap), the device is ready to acquire geometric data with a speed of over 600,000 points per second (Fig. 3), showing real time the resulting point cloud.

The data processing was performed using Geomagic Wrap, a software designed to generate mesh surfaces from point clouds and to manage the texture of 3D models. The processing has been carried out through several steps: 1. Acquisition (starting, planning, carrying out); 2. Processing (filtering, alignment, meshing); 3. Editing; 4. Exporting.

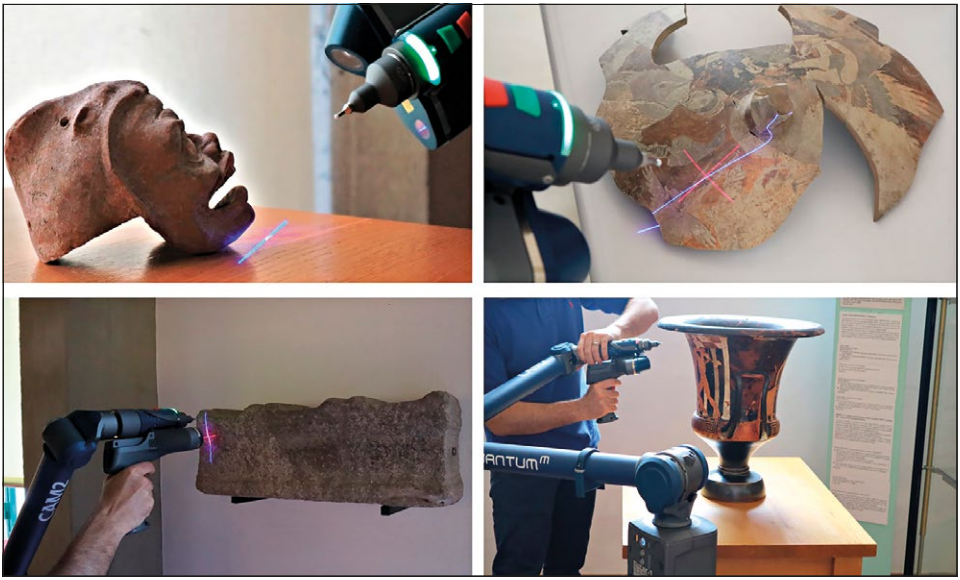

Fig. 3 – Laser arm scanning in progress.

3.2 *Photogrammetry*

Since the laser arm used is not able to acquire the colorimetric data (RGB) of the points recorded, the *calyx* craters were also documented through digital photogrammetry, in order to obtain a photorealistic 3D model, which subsequently has been scaled on the laser-scanner model. Photogrammetry is an image-based passive detection technique by which ordinary camera photos are turned into 3D models thanks to the use of specific algorithms (e.g. structure from motion) capable of collimating homologous points from a set of overlapping photos belonging to the same scene and to define the position, shape and size of the object under consideration (Historic England 2017). Using a Canon Eos 7D reflex camera, the craters were entirely photo-scanned according to a 'convergent axis' scheme and the resulting photos were processed using Agisoft Photoscan. The image-based model was also preparatory for the orthoimages of their iconographic apparatus.

3.3 *Raman Spectroscopy*

A new generation handheld spectrometer (BRAVO), produced by Bruker (Fig. 4), was used to acquire the Raman spectra of the pigments preserved on the surfaces of the artifacts. The instrument uses a patented technology (SSE, Sequentially Shifted Excitation, patent number US8570507B1) (Conti

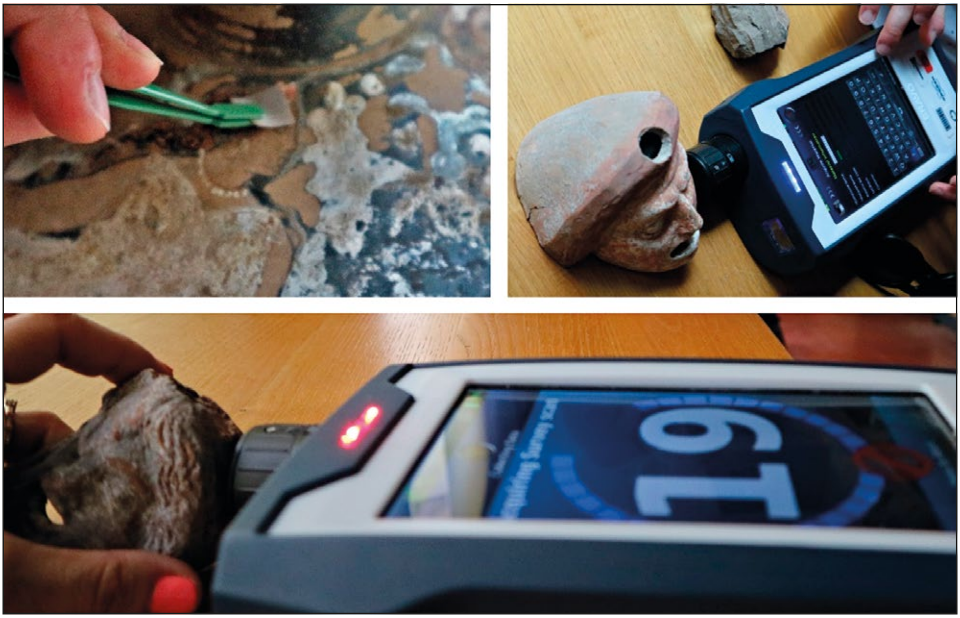

Fig. 4 – Measurement through Raman spectrometer.

et al. 2016) and is equipped with two excitation lasers (DuoLaser) having wavelengths centered at 785 and 853 nm (Pozzi *et al.* 2019) that work simultaneously to mitigate the fluorescence phenomena.

The Raman technique is one of the most suitable non-destructive archaeometric methods for analyzing works of art and historic materials (Vandenabeele *et al.* 2014, 2016). Its use has a double advantage: as a scattering-based technique, it does not require preparation or sampling of the artefacts and as an optical technique it works very well in a wide range of wavelengths, for which a variety of optical devices have been developing for a long time. The technique is very powerful in the identification of crystalline substances, pigments and dyes, both organic and inorganic, as well as for the identification of restoration materials and degradation products (Bellot-Gurlet *et al.* 2006). The information obtained can also represent a great help to restoration and conservation techniques.

4. Results and discussion

Raman analyses, performed only on masks preserving traces of color in order to identify pigmentations, have led to important results regarding the use of cinnabar in antiquity. Cinnabar is a bright scarlet (HgS) mercury (II)

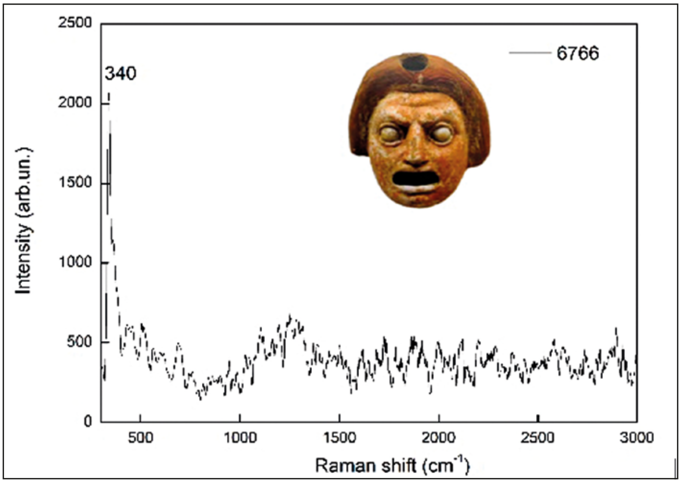

Fig. 5 – Raman spectrum of the clay mask No. 6766.

Fig. 6 – Mask No. 11114-E: data acquisition, modeling and results.

sulphide used since ancient times in very important paintings and art objects. The Raman spectrum of the clay mask No. 6766 (Fig. 5) shows, in fact, only a band centered at 340 cm^{-1} attributable to the cinnabar pigment (HgS) that is coherent with the literature data. The spectrum was acquired in the range 300-3000 cm^{-1} with integration times not exceeding 60s. The identification of the dyes contained is carried out thanks to the use of databases (Burgio, Clark 2001).

Fig. 7 – Projection onto a plane of the iconography depicted along the body of Maron's crater.

Its presence in the palette of both the Lipari Painter (mid-3rd century BC) and his imitators (Barone *et al.* 2017) strongly suggests an identical use of materials and local production. As for the 3D reconstruction, the results obtained consist of metrically correct and high-resolution models, which have been organized in an easily accessible digital archive for different study needs, conservation interventions, support for digital restoration, integration of missing parts and virtual use via web browser (https://skfb.ly/6QzLw) (Giuffrida *et al.* 2021). In the case of mask no. 11114-E, for example, the recorded data made it possible to generate a detailed reconstruction of the two half figures represented, effectively improving their reading and the possibility of making stylistic comparisons with other samples (Fig. 6).

The informative potential of the digital archive thus created is vast, as it contains not only metric data (deriving from the geometric survey), but also information about the nature and the chemical composition of a determined pigment. Since 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. The results of the photo-scanning of the two *calyx* craters were used to generate a projection on the plane of the decorative apparatus depicted on the body of both vases: this solution can certainly improve the reading of the scenes (Fig. 7).

The combined use of both techniques can provide an efficient way for executing drawings of painted vases, thanks to stylistic analysis by 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 them 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 stone surface.

5. Conclusions

The measurement campaign with portable instrumentation carried out in Lipari served as a test to plan broader and systematic analyses on other materials preserved in Lipari, as part of an ongoing agreement between the Museum and the IPCF-CNR of Messina. Moreover, all the examples reported show the potential of creating mobile laboratories inside museums with 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 the one hand, 3D models are becoming an effective tool supplementing and supporting traditional study activities (mainly when physical access to materials is not possible), on the other hand, their use allow anyone to better understand the past thanks also to their integration into interactive applications, personalized presentations and virtual environments, 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.

Dario Giuffrida, Viviana Mollica Nardo, Rosina Celeste Ponterio
Istituto per i Processi Chimico Fisici – CNR
dario.giuffrida@ipcf.cnr.it, mollica@ipcf.cnr.it, ponterio@ipcf.cnr.it

Oreste Adinolfi
FARO Europe GmbH & Co. KG, Glabeck
oreste.adinolfi@hotmail.it

Maria Amalia Mastelloni
Polo Parco Archeologico e Museo “L. Bernabò Brea”, Lipari
mariaamalia.mastelloni@regione.sicilia.it

REFERENCES

Barone G., Di Bella M., Mastelloni M.A., Mazzoleni P., Quartieri S., Raneri S., Sabatino G. 2017, *Pigments characterization of polychrome vases production at Lipára: New insights by noninvasive spectroscopic methods*, «X-ray Spectrometry», 47, 1-12.

Barrile V., Fotia A., Ponterio R.C., Mollica Nardo V., Giuffrida D., Mastelloni M.A. 2019, *A combined study of art works preserved in the Archaeological Museums: 3D survey, spectroscopic approach and augmented reality*, in *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences (ISPRS Archives)*, XLII-2/W11, 201-207.

Bavastrelli S., Gambino R., Capostagno F., Martinelli M.C., Vilardo R. 2019, *Museo Archeologico Regionale di Lipari Luigi Bernabò Brea: i restauri del cratere di Ippolito e l'evoluzione delle metodologie d'intervento*, Poster in *XVII Congresso Nazionale IGIIC- Lo stato dell'Arte, Chiesa di Cristo Flagellato dell'ex Ospedale San Rocco (Matera 2019)* (unpublished).

Bellot-Gurlet L., Pages C.S., Coupry C. 2006, *Raman spectroscopy in art and archaeology*, «Journal of Raman Spectroscopy», 37, 962-965.

Bitossi G., Giorgi R., Mauro M., Salvadori B., Dei L. 2006, *Spectroscopic techniques in Cultural Heritage conservation: A survey*, «Applied Spectroscopy Reviews», 40, 3, 187-228.

Blais F. 2004, *A review of 20 years of range sensor development*, «Journal of Electronic Imaging», 13, 1, 231-240.

Burgio L., Clark L.H. 2001, *Library of FT-Raman spectra of pigments, minerals, pigment media and varnishes, and supplement to existing library of Raman spectra of pigments with visible excitation*, «Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy», 57, 1491-1521.

Clementi C., Miliani C., Romani A., Santamaria U., Morresi F., Mlynarska K., Favaro G. 2009, *In-situfluorimetry: A powerful non-invasive diagnostic technique for natural dyes used in artefacts*, «Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy», 71, 5, 2057-2062.

Conti C., Botteon A., Bertasa M., Colombo C., Realini M., Sali D. 2016, *Portable Sequentially Shifted Excitation Raman spectroscopy as an innovative tool for in situ chemical interrogation of painted surfaces*, «Analyst», 141, 4599-4607.

Giuffrida D., Mollica Nardo V., Adinolfi O., Mastelloni M., Ponterio R. 2021, *A theatrical double-faced mask preserved at the Museum of Lipari (Messina): Study and 3D reconstruction through portable equipment*, «Virtual Archaeology Review», 12, 24, 39-48.

Giuffrida D., Mollica Nardo V., Giacobello F., Adinolfi O., Mastelloni M.A. Toscano G., Ponterio R.C. 2019, *Combined 3D surveying and Raman Spectroscopy techniques on artifacts preserved at Archaeological Museum of Lipari*, «Heritage», 2, 3, 2017-2027.

Gonizzi Barsanti S., Guidi G. 2013, *3D Digitization of Museum content within the 3dicons project. ISPRS Annals of the Photogrammetry*, in *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences (ISPRS Archives)*, II-5/W1, 151-156.

Hess M., Robson S. 2012, *3D imaging for museum artefacts: A portable test object for heritage and museum documentation of small objects*, in *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences (ISPRS Archives)*, XXXIX-B5, 103-108.

Historic England 2017, *Photogrammetric Applications for Cultural Heritage. Guidance for Good Practice*, Swindon, Historic England.

Martinelli M.C., Vilardo R. 2019, *Through the theatrical mask. The Archaeological Museum of Lipari*, «Mediterranean Journal of Clinical Psychology», 7, 1, Suppl.

Mastelloni M.A. 2018, *Le maschere fittili di Lipari: nuove riflessioni sulle espressioni artigianali liparesi di IV e III sec. a.C.*, in *Dialoghi sull'Archeologia della Magna Grecia e del Mediterraneo,* Paestum, Pandemos Editore, 709-720.

Pozzi F., Basso E., Rizzo A., Cesaratto A., Tague T.J. 2019, *Evaluation and optimization of the potential of a handheld Raman spectrometer: in situ, noninvasive materials characterization in artworks*, «Journal of Raman Spectroscopy», 50, 861-872.

Vandenabeele P., Donais M.K. 2016, *Mobile spectroscopic instrumentation in archaeometry research*, «Applied Spectroscopy», 70, 27-41.

Vandenabeele P., Edwards H.G.M., Jehlička J. 2014, *The role of mobile instrumentation in novel applications of Raman spectroscopy: Archaeometry, geosciences, and forensics*, «Chemical Society Reviews», 43, 2628-2649.

White S. 2015, *Virtual Archaeology. The next engine desktop laser scanner*, «Archaeology International», 18, 41-44.

ABSTRACT

In the last decade portable devices for the analysis of Cultural Heritage (e.g. laser-scanners, spectroscopes, XRF) have reached levels of reliability that can replace benchtop instruments and enable *in situ* survey. One of the most effective application is the digitization and diagnosis of artworks preserved inside museums. Indeed, moving art objects or finds from the place of preservation to specific laboratories can often be difficult for several reasons such as fragility, large size, 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 creating a 'mobile laboratory' for chemical analysis and 3D digitization of artefacts presenting different challenges. The activities have been carried out using two high-performing and non-contact tools: a laser-scanner arm by Faro (sometimes in combination with an external camera) and a handheld Raman spectrometer by Bruker. The test was performed to plan more extensive and systematic analyses of other materials preserved in Lipari, which will be soon examined as part of an ongoing agreement between the two institutions. The results of this test clearly demonstrate the advantages, both in terms of scientific results and dissemination, that can be achieved when science and the humanities dialogue for a common goal.