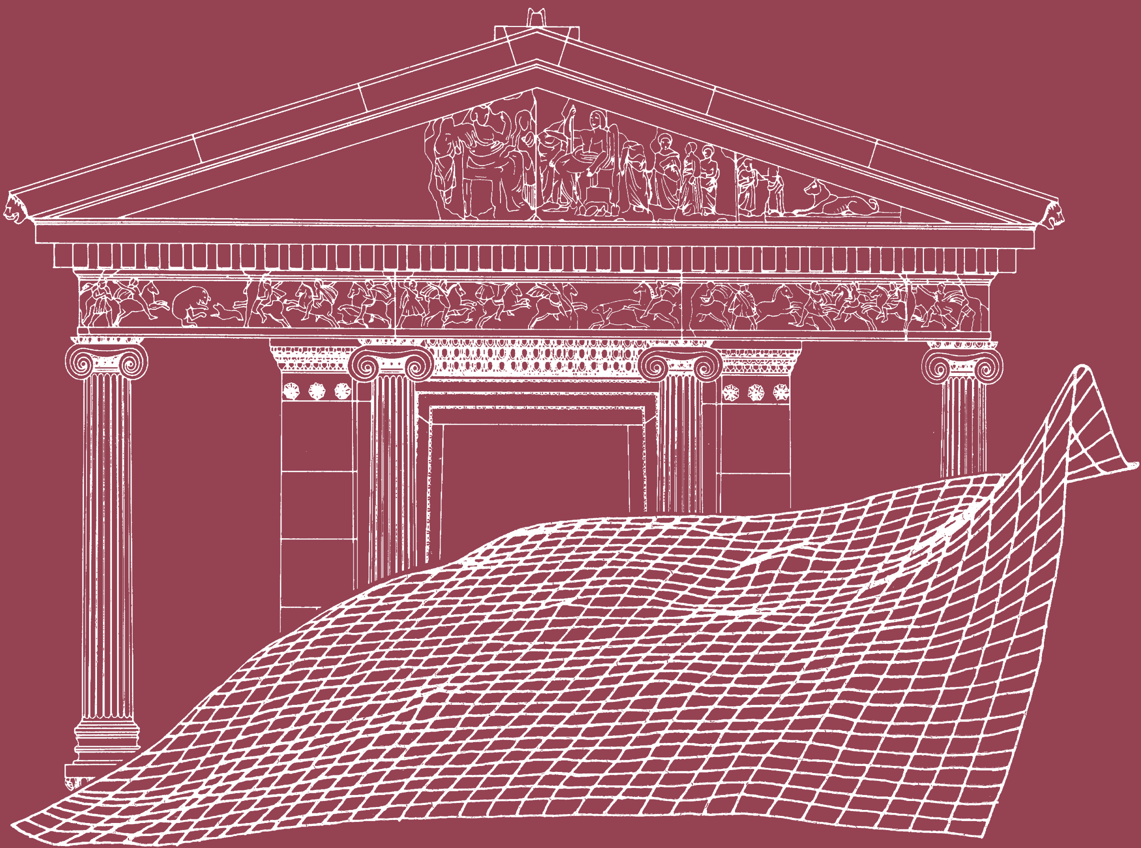

ARCHEOLOGIA E CALCOLATORI

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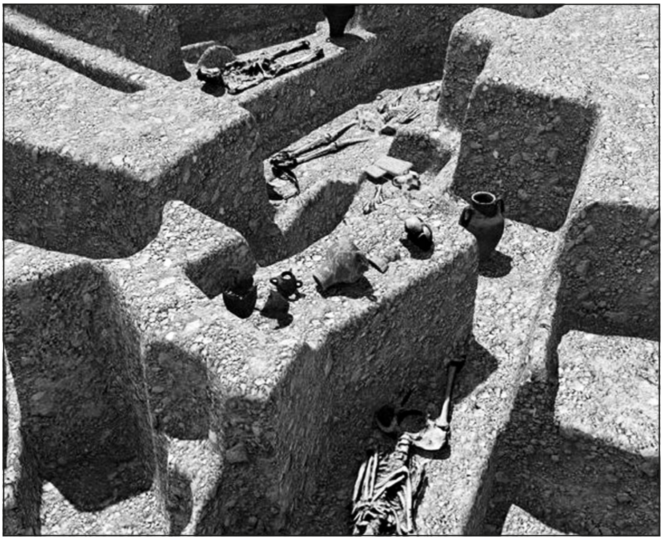
INDICE

FROM POTTERY TO CONTEXT. ARCHAEOLOGY AND VIRTUAL MODELLING

edited by
Vincenzo Baldoni



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INTRODUCTION

This concise introduction aims to take account of the variety of topics which the papers collected under the title 'From Pottery to Context. Archaeology and Virtual Modelling' focus on, and draws attention to the *fils rouges* which guided their selection. This collection is one of the main outcomes of a research project on a competitive call funded by the University of Bologna, entitled *Dal reperto al paesaggio*: *analisi archeologica e modellazione virtuale delle necropoli picene di Numana* (AN) (From Artifact to Landscape: Archaeological Analysis and Virtual Modelling of the Numana Picenian Necropolis).

The project concentrated on a sector of the Picenian Davanzali necropolis in ancient Numana (nowadays Sirolo - Numana, Ancona Province), excavated in the 20th century. Its primary aim was to experiment techniques for the acquisition of digital models of archaeological finds from funerary contexts and reconstructing the same contexts by modelling. The case study of Numana is well suited to this type of analysis, because of its complex stratigraphy and the variety of objects found in the grave goods. The attempt, completely new in this field of studies, involved the use of the typical methodologies of virtual archaeology, for the setting up of an entire funerary context, from the single object to the whole landscape. This approach stimulated the need for confrontation with the experiences of other research teams, which could provide useful comparisons. To discuss these topics the project should have included a workshop, planned for Spring 2020: unfortunately, the meeting could not take place, due to the global pandemic.

Hence, the idea of collecting a series of papers ranging from the problems of digital modelling of objects to the broader contextual issues under the title 'From Pottery to Context. Archaeology and Virtual Modelling' (which recalls directly the Numana project), giving the authors the opportunity to reflect on the relation between traditional and innovative approaches, on theoretical issues and methodologies, as well as on results and future developments of their research. These pages are therefore the alternative opportunity to present the contributions by those scholars who would have taken part in the meeting.

The essays draw attention to issues of investigation, which are now well established in scientific literature, but the purpose of their selection is primarily contributing to the broader debate with new research perspectives. This path of investigation fits perfectly in the way already paved four years ago by the KAINUA 2017 International Conference, published in «Archeologia e Calcolatori», and edited by A. Gaucci and S. Garagnani (2017), who have taken part in the Numana project. The 2017 Conference focused on urban areas, taking *Kainua*-Marzabotto as a main case study. On that occasion,

P. Moscati summed up the projects and research on this specific topic in *Archeologia e calcolatori*, underlining an epistemological aspect that should be considered as primary: «Therefore, if nowadays technical training cannot be ignored, technology should not overshadow the ultimate purpose of the historical reconstruction and interpretation of the past» (Moscati 2017, 63).

In recent years «Archeologia e Calcolatori», one of the most established journals in the discipline, published a few contributions related to the application of photogrammetric and laser-scanner survey methodologies for the reconstruction of funerary landscapes (Fariselli *et al.* 2017, where M. Silani, another researcher also involved in the Numana project, published) and funerary contexts (Putzolu, Vicenzutto 2013). However, what is currently still missing is the systematization of all the data within a digital ecosystem that virtually simulates the funerary landscape in every aspect, from the particular to the general (see A. Gaucci below for further considerations and bibliographical references).

As already mentioned, the starting point comes from the research project financed by the University of Bologna on a sector of the Picenian necropolis (Davanzali) in ancient Numana. The considerations developed in this case study by the members of the research equipe from Bologna (see V. Baldoni, A. Gaucci, E. Zampieri, M. Silani, S. Garagnani below) open the collection. Their contributions, introduced by an overview of the topics by V. Baldoni, deal with different perspectives on the several subjects of the project, which intended to obtain the virtual reconstruction of the necropolis in all its elements, from the objects of the grave goods to the funerary landscape. The complexity of the context and of its interpretative issues stimulate reflection on a multiplicity of themes, such as the processing of archival data, the modeling of objects, the reconstruction of tombs and their grave goods, the funerary rituality, the dynamics of space occupation of the necropolis and the virtual reconstruction of the landscape. The experimented methods meet the need to reconcile digital model reliability - suitable to the multiple purposes of investigation - with a fast and efficient workflow. As we might notice, that is why this variety of research perspectives encouraged a methodological dialogue with other investigations, centered on study issues and on valorization of the different constitutive elements of archaeological contexts (mainly funerary ones), and centered on the application of digital acquiring and modelling techniques to archaeological finds.

Digital models of artifacts produced by the project can effectively contribute to the diffusion of the knowledge on ancient Numana's archaeological heritage, still little known. Indeed, these models and their narrative potentialities are meant to be important tools of divulgation for a wide audience, both in exhibitions and through a dedicated web portal. Besides this remarkable outcome, theoretical and methodological issues need to be addressed in order to achieve scientific goals. First of all, in our view it is necessary to work on acquisition processes and understand to which extent it is possible to stress the acquired data and obtain a more traditional graphic documentation from them. Particularly, the latter issue has been widely discussed in various projects (see A. Gaucci below for some references), thus confirming its pivotal role in the current debate about documentation of archaeological finds.

That is why scholars were invited to contribute to the discussion on these topics with their research. Moreover, the submitted papers address two strands of research, considered to be of prime importance: figured pottery (Attic and Italiote) and serial production (here analyzed using the case study of architectural terracotta). In both cases, we are considering topics of particular interest, because of the strong knowledge potential and the challenges that such objects present, when digital modelling techniques are applied to them.

Significant space is dedicated to Greek and Italiote pottery, the subject of three contributions that deal with the in-depth analysis of the shape and decoration of the vases, with the complexity of their documentation and with the dissemination of their knowledge, considering different approaches. Largely attested in Numana, Greek or Italiote pottery are productions extensively studied, for which various methods of documenting and analyzing vase features have long been experimented; as mentioned, in recent years, various digital modeling techniques were also applied. The methods used for Greek pottery may also be useful in relation to the study of other ceramic productions, a field of investigation that could be further developed in the future.

The first contribution by I. Algrain and D. Tonglet (CReA-Patrimoine - ULB, Bruxelles) concentrates on vase shape: as demonstrated by these scholars, morphological studies have a consolidated tradition, they are still of great relevance in the scientific debate and have considerable perspectives for future development. Beginning with the historiography of the shape studies, the authors present the methods adopted in the study of some Attic vases (*alabastra* and *kyathoi*), emphasizing the importance of the comparative analysis for their profiles. This type of analysis not only proves to be of fundamental importance to deepen our knowledge of potters' activity – and consequently, of the Attic *ergasteria* – but (morphological studies) can also contribute to shed light on other relevant research topics, such as cultural exchanges and interactions.

The study of shape, style, and iconography is the topic of the contribution by A. Pace and D. Bursich (respectively, University of Fribourg and University of Salerno). The first part of the paper focuses on the digital modelling of ceramics as an important tool to know the style of Attic painters: through the analysis of 3D models of two *lekythoi* from Gela, A. Pace proposes a new stylistic framework of the vases, refining Beazley's classification. The second part of the paper (by D. Bursich) is dedicated to the working method adopted for the acquisition of the images up to the creation of the models and presents the results of their multi-year research on the digital treatment of Greek ceramics.

The following two papers converge on the analysis of serially produced objects, in particular, the possibilities of studying architectural terracotta through digital modelling techniques. This specific topic takes us away from funerary contexts. Indeed, both papers deal with the virtual reconstruction of the decorative elements of sacred architectural structures.

M. Natalucci presents her research on the fragments recently discovered in the sacred fence of the temple of *Uni* at *Kainua*-Marzabotto, excavated under the direction of E. Govi (University of Bologna). The application of archaeometric investigation methods leads to the reconstruction of the original polychromy (spectroscopy) and of the recursive decorative patterns (Visible-induced luminescence, VIL) of the architectural terracotta from the site. The research intends to retrace all the phases of the production of the architectural decorative system, from the raw pigments to the final 3D reconstructions. The study allows us to reach a philological reconstruction of the decorative system and to improve our knowledge of the local *chaîne opératoire*, but it also leads to the acquisition of new data on the activity and on cultural interactions of the craftsmen of *Kainua*-Marzabotto, who applied new pigments and techniques imported from Tyrrhenian Etruria, in the 5th century.

Another essay on architectural terracotta is presented by M. Esposito. It concerns a study coordinated by C. Rescigno (University of Campania Luigi Vanvitelli) about a conspicuous group of antefixes preserved in the Museo Provinciale Campano of Capua from 19th century excavations in the Archaic sanctuary at Curti (Caserta). The research focuses on the group called 'female heads within the nimbus', within which 30 series were recognized and catalogued in a database. It was possible to achieve 3D reconstruction of the prototypes through digital restoration of the fragments. Considering the seriality of this production, the fragments can be traced back to their archetypes: hence the possibility of obtaining reliable 3D models of the prototypes, using the laser-scanner. The paper also examines the process of acquisition and rendering of the models and, finally, discusses the aims for the knowledge, conservation, and diffusion of the mentioned corpus.

The last two contributions deal with different interpretations of the context through diverse research perspectives. Although these perspectives are antithetical, both clarify the cognitive potential of virtual context reconstruction. The first of these two papers reflects on the theme of the collection as a lost context to be traced again. The second one focuses on the funerary context, as a space already excavated and therefore to be reconstructed (similarly to what happens in Numana): the analysis leads to the study of the ancient landscape and its use in diachronic view.

The contribution by the team coordinated by M. Salvadori (University of Padua) presents a wide research project (MemO Project) on Greek and Italiote artifacts in the collections of the Veneto Region. Through a multidisciplinary approach, the research intends to 'recontextualize' these finds, reconstructing their 'memory', i.e., the set of information they carry, thus making them important resources for study. The research integrates traditional methods of archaeological analysis with the most innovative techniques of modelling: several research purposes can be achieved, such as the study of production, reception, use and many others. Among these, there is also the theme of vase falsification, a phenomenon of great interest from a social and cultural point of view. A part of the analysis is dedicated to the digital modeling of the finds: the description of the laser-scanner acquisition process offers an interesting alternative to the method used for the finds from Numana. The contribution concludes by discussing the issue of heritage valorization: the characteristics and potentialities of the tool designed for this objective are examined, a database that also allows for the sharing of a variety of information on the web and is aimed at different categories of users.

Finally, the paper presented by scholars of Pisa (University and Scuola Normale Superiore) proposes a 3D reconstruction project of the necropolis of Volterra. In this case, the starting point is the context, the opposite of what happens in the research at the University of Padua: in Volterra, the tomb structures are preserved, but, since the objects of the funerary set are no longer there, an element of great importance of the context was lost. The approach here intends to restore the integrity of the context, through the virtual reconstruction of six hypogeal tombs, in which all the lost elements (movable and immovable) are relocated, intending to offer the audience an immersive visual experience, thanks to the use of low-cost mobile devices, which allow the fruition of information and metadata. The creation of this virtual environment is the result of an interdisciplinary cooperation and, in their contribution, the authors also address the method and the tools developed in the research.

In conclusion, I would like to thank all the scholars who have contributed to this volume and the University of Bologna, whose Alma Idea grants made it possible to pursue the project on the Numana necropolis and to edit these papers. Moreover, I would like to express my gratitude to the colleagues with whom I had the privilege to work on the necropolis of Numana, hoping that this fruitful cooperation will continue in the future.

Finally, I would like to express my thanks to Paola Moscati, for giving us the opportunity to publish these contributions in «Archeologia e Calcolatori», which in 1990 established itself as the first worldwide journal dedicated to information technology and archaeology, but always looking beyond technology.

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The 'Alma Idea' Numana Project

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FROM FINDS TO LANDSCAPE: ARCHAEOLOGICAL ANALYSIS AND VIRTUAL MODELLING OF THE DAVANZALI NECROPOLIS IN THE PICENIAN EMPORION OF NUMANA (AN)

1. Recent research on the Davanzali necropolis and the 'Alma Idea' Project of the University of Bologna

The Conero area, located on the middle-Adriatic western coast, for its natural characteristics and its location has always been a privileged place for trade, settlement and meeting people of different origins. The Picenian emporium of Numana developed in the Southern part of the Conero promontory during the first millennium BC: thanks to its privileged position and its natural harbor, it became one of the few suitable landing places along the western Adriatic coast. By the end of the 9th century BC these characteristics favored the birth of a settlement which was destined to become in the following centuries the most important emporium of pre-Roman Picenum, capable of establishing relationships with the Greek world, the Adriatic area, Tyrrhenian Italy, and Northern Europe (Finocchi 2018; Baldoni 2020 with previous references).

The period of the greatest development of the emporium is between the 6th and 4th centuries BC, when Numana became one of the strongholds of Greek trade (especially Athenian) along the Adriatic coasts. During the Hellenistic period (3rd-2nd century BC) Numana, like Picenum, seems to progressively shrink, as one of the results of the new historical setting, connected to the Roman control of the Region, while it became a *municipium* in the 1st century BC (Baldoni, Finocchi, Paci 2019; Baldoni, Finocchi, Ciuccarelli 2020; Baldoni, Finocchi in press).

The topography of pre-Roman Numana is not yet known in its comprehensive perspective: our knowledge mainly depends on funerary documentation from the necropoleis spread on this territory (today's territories of the municipalities of Sirolo and Numana) and we have only scarce evidence of the settlement (Fig. 1).

Despite the abundance of more than 1500 tombs investigated in Numana, only a few isolated contexts have been published; as a matter of fact, the edition of an entire necropolis or at least of a significant nucleus of burials is still lacking. This gap concerns both the knowledge of the topographical development and the relationships of the different funerary areas, as well as the numerous locally produced and imported finds from the grave goods.

In order to address these gaps in the knowledge of the archaeological heritage of ancient Numana, a few national and international research projects have been undertaken in recent years in collaboration with the

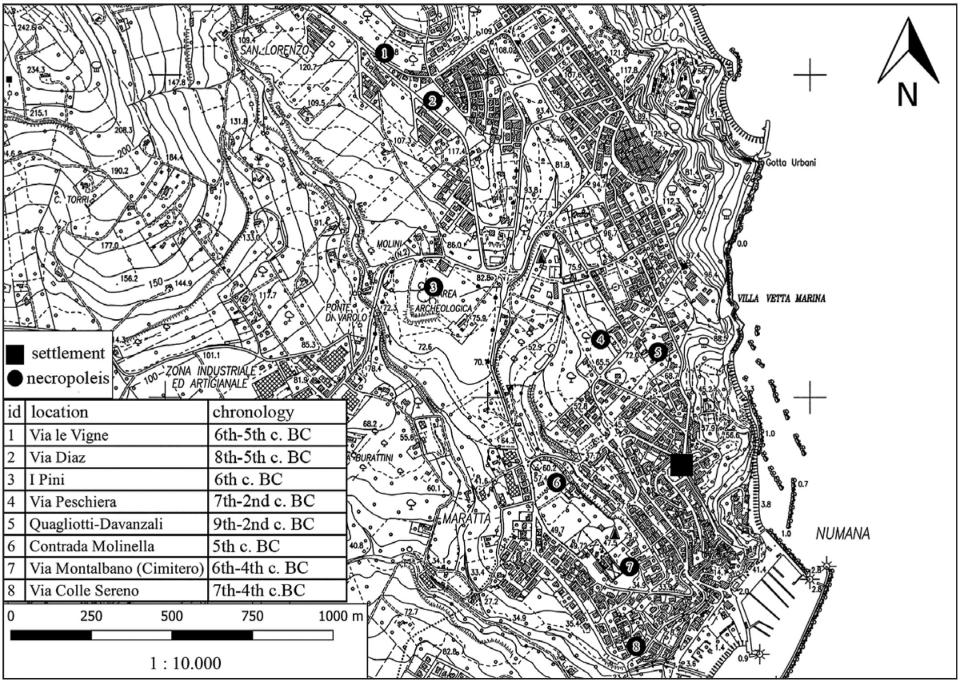

Fig. 1 – Plan of ancient Numana (Sirolo, Numana, AN): location of the settlement and necropoleis (CTR-Regional Technical Map); plan elaborated by E. Zampieri.

Superintendency (SABAP Marche) and the Direzione Regionale Musei Marche: the University of Bologna has developed since 2015 a multi-year research on the necropolis Quagliotti-Davanzali (Finocchi, Baldoni 2017; Baldoni, Finocchi 2019). The research project on the Davanzali necropolis is coordinated by V. Baldoni for the University of Bologna, S. Finocchi for the SABAP Marche, and N. Frapiccini for the Direzione Regionale Musei Marche. This research has been followed by other projects of the University of Bologna with SABAP Marche, such as the one on the necropolis in the 'I Pini' area of Sirolo, still in progress.

The study of the Quagliotti-Davanzali necropolis focused on a topographically coherent lot of more than 240 burials located in the central sector of Davanzali area (Fig. 2), extensively investigated in the 20th century; the goal is to reach for the first time in the history of studies on the Picenian *emporium* a systematic analysis of a large funerary sector and of the correlated tomb contexts.

From the beginning, the research has imposed a reflection on the method and on the most suitable tools to effectively manage the large amount of data

Fig. 2 – GIS of the Quagliotti-Davanzali necropolis (author E. Zampieri).

available and to answer the many questions to be addressed in the interpretation of such a complex funerary context. If the documentation produced during the excavation of the necropolis in the last century is very abundant, on the other hand it is also lacunose, because of the methods of excavation and documentation in use at that time.

Therefore, from the beginning it seemed useful to integrate the traditional research with other methods of investigation, specifically those of Virtual Archaeology, which can offer valid answers to the documentary gaps and effective interpretative tools of the context considered.

The opportunity to conduct the investigation in this perspective was offered by the competitive funding program 'Alma Idea' of the University of Bologna (2017-2020), a program aimed at the promotion and development of basic research. Thanks to this funding, a group of researchers focused on the application of virtual modeling techniques to the Davanzali necropolis (for a first presentation of the project, see also Baldoni *et al.* in press).

The aim of this project is the reconstruction of all the elements of the necropolis: the ancient landscape on which it was set and developed over time, up to the single object laid in the grave goods, as the result of an action of the funerary ritual.

The method of virtual reconstruction had to be simple and quick and had to produce explorable and useful models for the study and the valorization of the context. Within the project it was possible to start the testing on a specific lot of tombs located in the central part of the burial ground, but the developed method could be applied in the future to the whole necropolis, in anticipation of its integral publication.

In the four following papers, the participants in the research group of the 'Alma Idea' project deal in detail with the single aspects of the work carried out.

In the first essay, A. Gaucci illustrates the theoretical and methodological framework of the research, offering an overview of some significant case studies of the application of Virtual Archaeology techniques, among which we can mention some recent projects conducted by the University of Bologna on Etruscan Po Valley contexts, such as the necropolis of Spina, Valle Trebba or the Etruscan city of Marzabotto. Starting from these examples, Gaucci evaluates the potential of digital models with respect to the case study of the Davanzali necropolis.

The subsequent contribution by E. Zampieri deepens the problems of the archaeological and topographical interpretation of the Davanzali necropolis, starting from the traditional excavation documents. Then, the potentialities and the limits of the experimented methods for the creation of digital models of the necropolis and of the objects of the grave goods are highlighted. Finally, a reflection on the first results of the project and on its future perspectives is offered.

The essay by M. Silani is dedicated to the theme of reconstruction of the ancient landscape: the geomorphological characters, the topographical and archaeological data are taken into consideration, including those coming from new survey activities carried out during the project. The contribution formulates reconstructive hypotheses of the topographical plans and offers useful elements that contribute to the achievement of a reliable reconstruction of the terrain on which the necropolis was set up and developed through the centuries.

The last article by S. Garagnani illustrates the methods and the specific phases of the workflow used to obtain the digital model of the Davanzali necropolis. As mentioned, the experimentation is aimed at the creation of digital models of elements with very different scales. Regarding the macro-scale of the burial ground, the generation of the morphology of the necropolis landscape is obtained from the plans of the different phases of the burial ground. The final product is a 3D model of the necropolis at the time of the excavation from which plans and sections can also be obtained for the archaeological analysis of the burial ground in its diachrony and of the complex relationships of the tombs. It should be pointed out that this last aspect is particularly useful in the frequent cases of concentration and overlapping of burial pits in sectors of limited extension.

As for the micro-scale of the objects of the grave goods, their modeling must respond effectively to the variety of forms, materials, surfaces and textures as in the case of ceramics, which are present in large quantities and are pertinent to different classes of production. The most effective procedure – even in the case of complex objects such as figured pottery – is that of photogrammetry, which allows the attainment of an exhaustive graphic and visual documentation which responds to multiple aims of study, cataloging and valorization of the finds.

2. Studying pottery from the Davanzali necropolis: digital models and new perspectives

As mentioned, the ceramics from the Davanzali necropolis are very abundant and varied. As a matter of fact, among the finds, there are classes of local and imported productions: these are fine pottery, figured and black-glazed (Attic, Italiote, Alto Adriatico), transport amphoras, dining, storage and cooking wares. The value of the project for the study of these ceramics is remarkable, both because the experimented method allows us to proceed to a rapid, reliable and objective documentation of a great number of finds, and because the digital models obtained offer different possibilities to deepen the analysis of the shapes and the decoration of the vases (see in this volume S. Garagnani, Figs. 1-2). Moreover, these models are explorable and interactive and can be used for their knowledge by scholars and non-specialists, as it is planned to do both through exhibitions and events and in a dedicated website (see below). Regarding the study of ceramics, digital models of the vessels are useful to deepen the analysis of form and decoration, when present. From these models it is possible to obtain both very detailed traditional images and overall views of the figured decoration: in both cases, important resources are available for the stylistic and iconographic analysis of the vases, since it is possible to explore every single element of the main and accessory decoration. For some time now, scholars have highlighted the potential offered by digital documentation and visualization techniques (laser-scanning, CT scanning, 3D photo-modelling: e.g. Trinkl 2013): as highlighted in the contribution of A. Pace and D. Bursich in this volume, it is possible to deepen the attribution of the vases and thus contribute to a wider knowledge of the activity of the painters.

Further important advantages offered by digital models of vessels concern the study of vase-shapes and the investigation on the relationship between shape and image, both central issues in the current scientific debate in this field of study. Regarding the shape, the possibility to derive precise and reliable profiles of the vessels is a great advantage for the analysis of morphological details. It is therefore possible to set up the study of the different productions from the point of view of the activity of the potters, who, like the painters, can be identified on the basis of the formal details of the vases produced, which are characteristic of the hand of each potter. As well shown in the contribution of I. Algrain and D. Tonglet in this volume, the analysis of vase-shapes constitutes one of the most-lively topics in the panorama of recent ceramics studies: this field of research has a long and consolidated tradition – starting from the pioneering studies of Bloesch 1940 and 1951 – especially in relation to Greek and specifically Athenian production.

By focusing the analysis on the potters and the painters (in the case of figured pottery), it is finally possible to broaden the view on *ergasteria* and their functioning and, more generally, on the wider phenomenon of ceramic production.

Pottery found in the Davanzali necropolis constitutes a promising case study for this type of research, which is based on the analysis of decoration and shape: the findings, in terms of quantity and variety, offer many opportunities for analysis and future prospects for in-depth study, especially if one considers the current scarce knowledge of local production of Numana. Among the vases from the necropolis only a small number is yet published, most of which are Attic imports or belonging to the local Alto Adriatico pottery production.

A very interesting field of research is, for example, black glazed pottery, attested in large quantities and probably also produced in the Picenian area. Archaeometric analyses and further deepening, starting from the analytical study of the shapes, are already being planned on the black glazed production from the contexts of the Davanzali area.

The detailed documentation obtained from the digital models of the vases is undoubtedly useful for these research purposes: as a matter of fact, extrapolating the profiles of the vases from the digital models avoids some possible errors due to the subjectivity of the designer's hand and it is therefore possible to have a reliable graphic documentation on which to set up an analytical and comparative study of the various attested forms. An example is offered by a *skyphos* (Alto Adriatico production) from tomb 220 Davanzali with geometric decoration: the comparison between the profile of the vase realized by a draughtsman (Fig. 3) and the one obtained from the 3D model (Fig. 4) shows sensible differences in the curvature of the body, as well as a more consistent thickness of the walls, thanks to the extreme precision of the measures obtained from the photo-modelling (Fig. 5).

A further area of research is the analysis of the influences among different productions: formal, stylistic and iconographical affinities between local Alto Adriatico production and Attic, Italiote and Etruscan ceramics have already

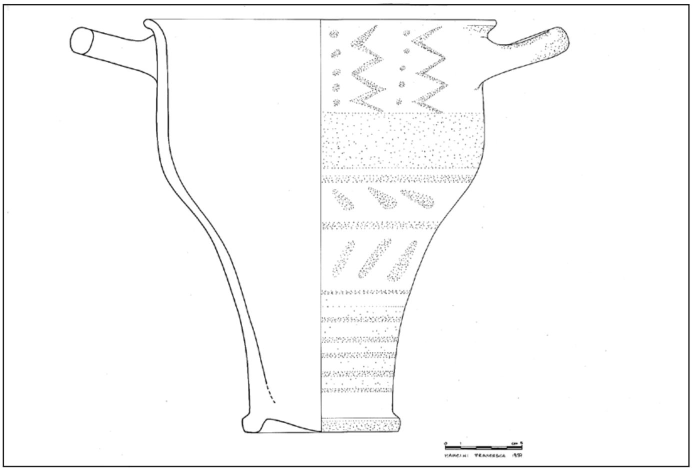

Fig. 3 – Profile of the *skyphos* from t. 220 Davanzali. Archive Sabap Marche Id. 28663 (author F. Mancini). Courtesy of Ministero della Cultura - Sabap Marche and Direzione Regionale Musei Marche.

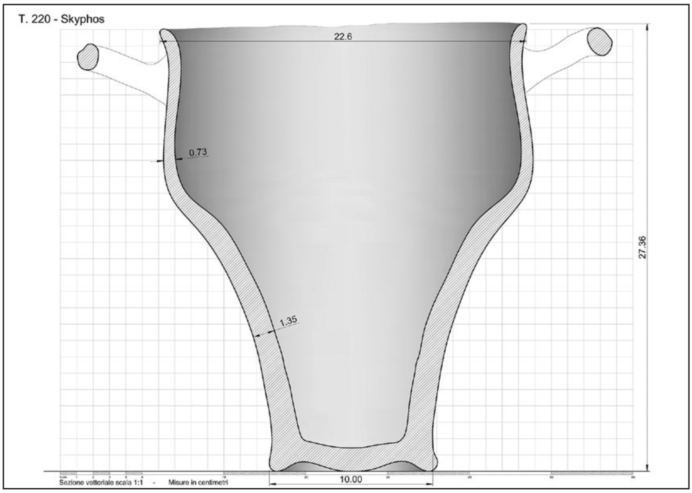

Fig. 4 – Profile of the *skyphos* from t. 220 Davanzali, obtained from the digital model of the vase (author S. Garagnani).

been highlighted by scholars, as in the case of kraters, *skyphoi*, *pelikai* and stemned plates (not to mention the similarities with the coeval red-figured and black-glazed vases produced on both Adriatic coasts). Furthermore, an articulation into groups of the picenian Alto Adriatico production was

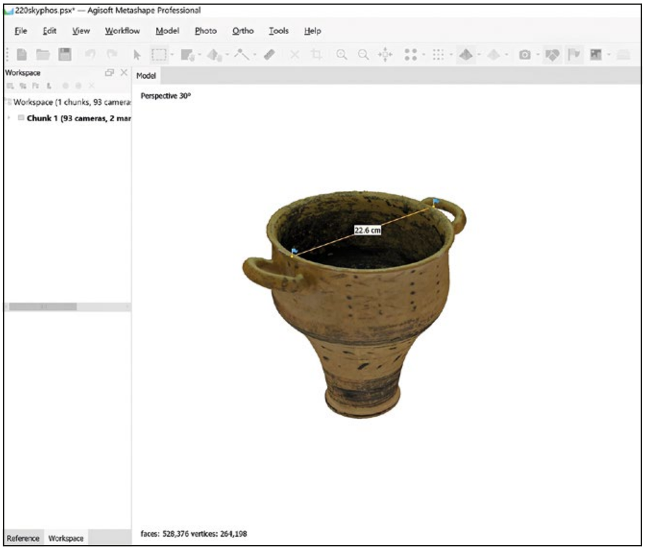

Fig. 5 – Photo-modelling of the *skyphos* from t. 220 Davanzali. Museo Archeologico Nazionale delle Marche, inv. 27428 (Courtesy of Ministero della Cultura - Direzione Regionale Musei Marche, author E. Zampieri).

proposed on the basis of the type of decoration (Landolfi 1997; 2000). The documentation methods experimented on the finds of the Davanzali necropolis can be used in the future on a larger scale for the analysis of the ceramics found in Numana in order to deepen our knowledge of local production, as in the mentioned case of Alto Adriatico pottery, where it is fundamental to consider both the characteristics of shape and decoration.

Within the limits of the project, it was possible to produce new documentation of a restricted group of objects, but in the future, thanks to the expeditive method developed, there will be the possibility of applying it to other finds. It will thus be possible to investigate important aspects, such as the development of the ateliers, the analogies and interactions between the productions, the diffusion of techniques and models and, finally, to identify possible phenomena of artisans' mobility.

3. First results and future perspectives of the project

At the end of the two-year project, we can assume that the results achieved are encouraging and that the application of Digital Archaeology methods provides effective tools for the study, dissemination and valorization of the necropolis and its findings.

From the perspective of its scientific impact, the 3D model of the Davanzali area allows us to address some of the gaps in the traditional documentation and to approach the analysis of multiple issues of funerary archaeology, such as the topography of the burial ground, the strategies of occupation of the area, the relationships between the tombs. The reconstruction of the tomb structures and of the grave goods enables to deepen the analysis of other aspects of the funerary rituality.

The digital model of the necropolis also can serve to increase the visibility of the context, which can be explored and used in different ways. This goal is in line with the policy of valorization of the archaeological heritage of the territory of ancient Numana. Very recently the valorization project 'Archeodromo' has been developed by Parco Regionale del Conero with local and national institutions (SABAP Marche and Direzione Regionale Musei Marche), in which techniques of experimental archaeology are used and infrastructures dedicated to the diffusion and promotion of the archaeological heritage of the territory to a wide public are created. This project also includes the virtual reconstruction of another important funerary context, the so-called 'Queen's Tomb' (end of the 6th century BC), discovered in the nearby necropolis 'I Pini' in Sirolo.

The digital reconstruction of the Davanzali necropolis can also be used to spread its knowledge among scholars and the wider public of non-experts through the website dedicated to the project (https://site.unibo.it/dal-reperto-al-paesaggio-numana/it). The web portal is intended to be implemented over time and it is designed to contain both the virtual model of the necropolis and of many objects of the grave goods: they are real replicas, viewable for scientific or cognitive purposes even in their smallest details. The digital models will also be used for events, exhibitions (including virtual ones) dedicated to the knowledge of the necropolis, also through immersive experiences with 3D viewers.

In conclusion, it is foreseeable that the results of the project will have an impact on different levels. On the scientific level, the models realized will allow scholars to deepen their knowledge of the funerary archaeology of the Picenian *emporium* and of its material culture, until now only in part known. For the wider public, the possibility of visiting and getting to know, from any place, the objects of the grave goods and their finding context constitute an opportunity to learn about a heritage that is largely located in museum storerooms (finds) or that is no longer currently visible on the ground (necropolis).

Therefore, the project also constitutes a great opportunity to study and valorize the copious archaeological heritage of Sirolo and Numana, a patrimony which for its richness certainly deserves to be known and appreciated more and more in the near future.

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ABSTRACT

Among the studies recently promoted by the University of Bologna on the Picenian necropolis of Numana (Sirolo-Numana, AN), a two-year research project has been dedicated to the application of digital archaeology techniques on a topographically consistent lot of tombs in the Davanzali area. Thanks to the financing of the University program 'Alma Idea', a team coordinated by the author focused on the virtual reconstruction of the necropolis, in all its aspects: from the finds to the funerary landscape. This contribution presents a synthesis of the research and introduces the articles written by the members of the team (A. Gaucci, E. Zampieri, M. Silani, S. Garagnani). The different contributions illustrate the project goals, methods and results. The conclusion of this article highlights the research potential for both the study (especially for pottery) and the context valorization.

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VIRTUAL ARCHAEOLOGY AND THE STUDY OF NECROPOLISES AS A SYSTEM: METHODOLOGY AND PRACTICE IN THE CASE STUDY OF NUMANA (AN), ITALY

1. The study of necropolises: methodology and practice

The primary aim of the *From Pottery to Context* Project is the reconstruction of the ancient funerary landscape of the pre-Roman settlement of Numana (Ancona), selecting one of the main necropolises as case study. This aim entails the effort to collect all the available data, certainly primarily archaeological, but also archival and geomorphological. The analysis has been already undertaken (see Baldoni in this volume) through methodologies more closely linked to traditional archaeological research, such as the study of the necropolis of Valle Trebba belonging to the Etruscan port-city of Spina in the Po Delta. There, the reconstruction of a funerary landscape totally lost, due to the profound changes that have taken place over 2.300 years in one of the most dynamic geomorphological environments in the world, has led the research group of the Chair of Etruscology of Bologna University to reconstruct the ancient morphology of the islands emerging from the lagoon in which the necropolis was established, starting from the maps of the 19th century and the excavation data (Fig. 1; Gaucci 2015, 118-125). Thanks to the philological reconstruction of the grave goods, it was possible to anchor the individual burials to the funeral space and therefore undertake the analysis of the dynamics of occupation. The two poles of this methodological approach, which is part of a consolidated practice, are on the one hand finds and structures that form the funerary contexts and on the other the environment of the necropolis, an exceptional diachronic palimpsest of social dynamics of a community filtered through funerary ideology.

The aforementioned practice is part of a tradition of Etruscan and Italic studies and it distinguishes the Bolognese School in particular, starting from the study of the Etruscan necropolis of Bologna (Sassatelli 1988; most recently, Morpurgo 2018). The methodological premises underlying the team work are inserted within a broader and international debate which now benefits from important analysis tools, allowing us for the integration of spatial and landscape analysis with the study of grave goods and funerary ideology (see Cerchiai 2018, with references).

Thanks to the continuous updating of funerary studies with increasingly innovative methods, the reconstruction of complex systems, such as the necropolises, currently allows scholars to probe more deeply the historical and social framework within which the funerary landscape developed. It is

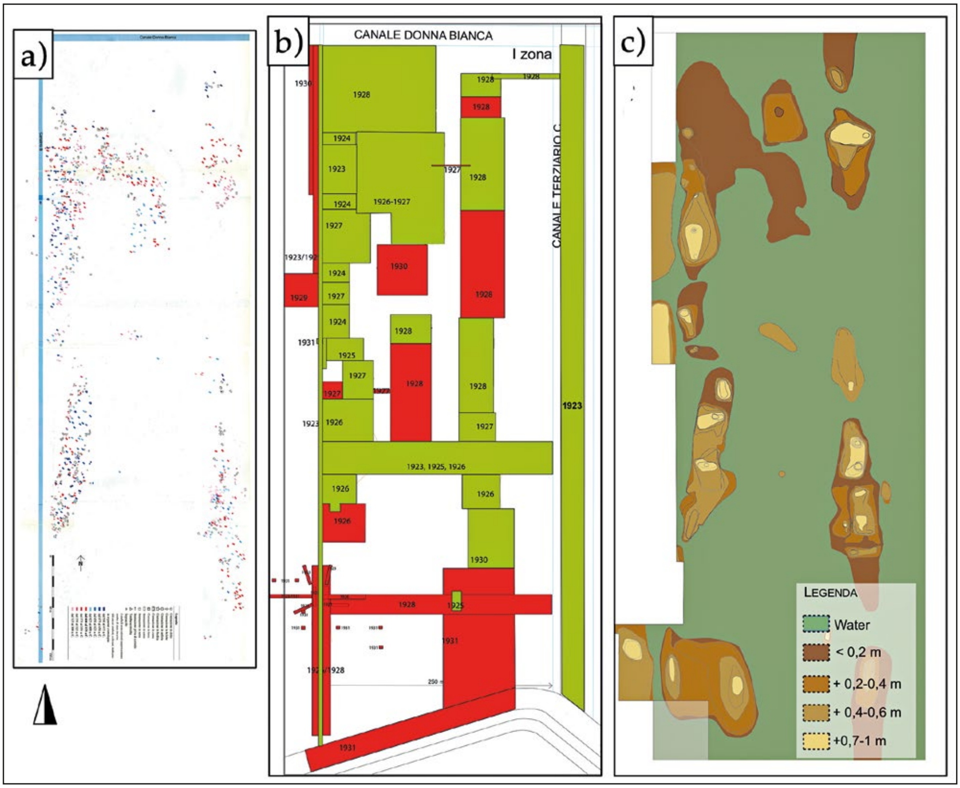

Fig. 1 – Plan of the main area of the Valle Trebba necropolis, Spina: from the plan edited in 1993 (on the left) to the reconstruction of the excavated areas and the reconstruction of its geomorphology (on the right; after Gaucci 2015, Figs. 4, 5, 9).

certainly a metaphor for the society of the living (D'Agostino 1985), but at the same time it implies planning strategies, diversified use and exploitation of spaces, as well as preservation and governance through labor (Cerchiai 2018, 156). This is not the place to deepen theoretical reflections on the funeral sphere by connecting it to a lively and very articulated debate, but it is rather important to underline how the involvement of disciplines such as virtual archaeology and the application of new methods can certainly bring a significant contribution to the reconstruction of the necropolis system (e.g. the Greek necropolis of Itanos, Crete: Ercek, Viviers, Warzée 2010).

In the case of Numana, the possibility of accessing an accurate and copious excavation documentation and the incentive to work on a site where different Universities and Research Institutes operate at different levels and with an effective synergy (in addition to Bologna, the Sapienza University of

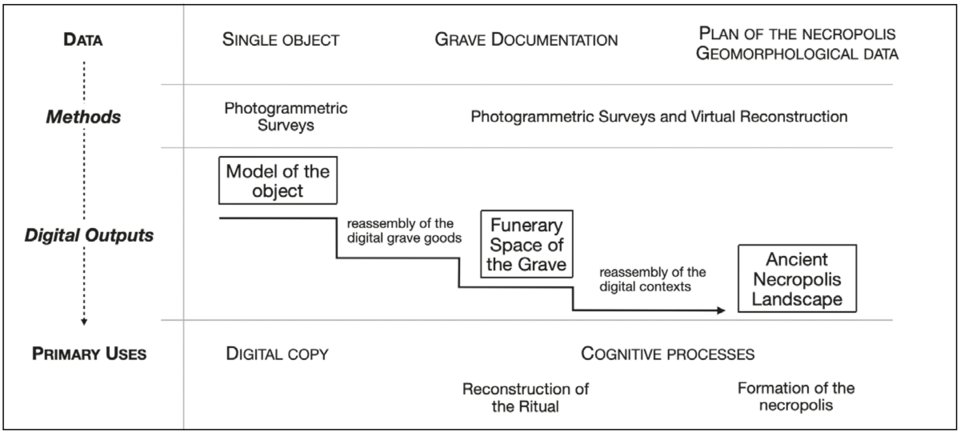

Fig. 2 – Scheme of the process adopted during the project, from the data to the primary uses of the digital outputs.

Rome and the Zentralmuseum of Mainz), thanks to the farsighted work of the local Soprintendenza and the Direzione Musei of the Marche Region, have favored the integration in research of the most recent and innovative methodologies of archaeological informatics (see Moscati 2019, 21-24) and in particular of virtual archaeology (for an overview on the discipline and its main issues, see A. Gaucci in Garagnani *et al.* 2021).

In order to achieve the primary aim of the project, the funerary area is limited, in order to test the potentiality of the virtual environment and whether it is possible to operate interactively within it or not (see Forte, Beltrami 2000, *passim*). Ultimately, the development of the virtual environment should be an opportunity to reconstruct and understand the formation process of the archaeological deposit and how it interacted with the environment during centuries.

This ambitious goal can only be achieved if we work both on grave goods of funerary contexts of the area and on the relationship between the Digital Terrain Model as an ancient geomorphological structure and the arrangement of the graves within it. Indeed, this is the twofold research front on which the team has focused his efforts (Fig. 2).

2. The grave goods: from objects to digital models

Regarding the grave goods, it should be emphasized that in the field of archaeological researching the acquisition of digital models is a step felt to be increasingly important, currently resulting a very lively and fruitful field of investigation and increasingly integrated into theoretical and methodological reflections. In fact, it is now established that the digital model has a triple function: it is a tool for conservation, dissemination and research (see Garagnani, Gaucci 2020; on the topic, also Reilly 2015, focused on the role of 3D printers).

The life cycle can trivially include the production and use phase, that of burial and then move on to that of archaeological record. In this sequence (which could be much more complex), the digital model can take on the dignity of a life phase, as demonstrated for example by the virtual heritage projects relating to the reconstruction of lost monuments due to conflicts in the contemporary age, such as the recent *Million Images Project* concerning the Triumphal Arch of the temple of Bel di Palmira destroyed by ISIS in 2016 (Khunti 2018). Indeed, we can assume that the authenticity of cultural heritage is a process of social mediation that varies over time and this assumption can also be applied to replicas, whether physical or digital (Di Giuseppantonio Di Franco, Galeazzi, Vassallo 2018b, 2). With respect to the concept of 'aura' of authentic objects and the loss of it in replicas, to date scholars are arguing about the possible migration of the aura from the formers to the latters (Latour, Lowe 2011; Di Giuseppantonio Di Franco, Galeazzi, Vassallo 2018b, 2, with references). In a broader perspective, the scientific community has thus started a debate on the complex relationships between the original object and its digital copy (see Di Giuseppantonio Di Franco, Galeazzi, Vassallo 2018a).

As already stated, from the point of view of the biography of objects (Kopytoff 1986), the digital model can be claimed as a new phase of its life cycle. However, besides more intuitive conservation and dissemination purposes (e.g. portability and access: digital models are extraordinary source of information for persons who may not have access to originals; safety: working on models allows authentic objects not to be damaged; manifold usability: 'copy' has the same etimology of 'copious', i.e. abundant; etc.), the digital model also plays an important role in archaeological analysis.

First of all, a fundamental field of investigation is that of the digital acquisition of the artefact for its study. From this point of view, it seems not very fruitful to recall the experimentation of many methodologies (see the recent review of computer methods for the reconstruction of ceramic sherds offered in Eslami *et al.* 2020), from those of great detail on individual objects, such as the works on Attic figured ceramics, a complex production from many points of view (see the contribution of D. Burisch and A. Pace in this volume), up to the attempt to standardize the acquisition process (Santos *et al.* 2017). These are only a few examples of the variety of methodologies and techniques used in order to achieve different objectives. In our point of view, it is clear that the acquisition process is strictly bound by the aims of the project itself in which it operates. In the case of Numana, the goal has been to develop a system for creating a digital model of the objects that balances accuracy and speed both in the acquisition phase and in the post-production phase, thanks to a 'light' instrumentation which allows at the same time satisfactory results in terms of documentation. The underlying reasons are the high number of finds, their variety in terms of material and technology (e.g. within pottery, Athenian figured and local hand-formed vessels) and the need not to stop at the single object but to reconstruct entire grave goods.

As will be seen, if this allows us the acquisition of satisfactory digital models, it should not be underestimated that the goal is to have a model that is not only the bearer of geometric information (and possibly textures), from which to extrapolate more traditional documentation, but it should be the repository of all information on the object (material, historical, archival, etc.), thus resulting its digital copy and so fulfilling its entire biography. This process is currently satisfactorily pursued within Architecture using the Building Information Modeling (BIM) method (amongst others, see Scianna *et al.* 2020 and the overview in Garagnani *et al.* 2021), where a deep and dynamic cognitive interaction enhances the archaeological analysis process.

3. Zooming out: from the scale of the object to the scale of the landscape

Within the project, the development of digital models of all the objects of a single assemblage and the reconstruction of its burial structure lead to the digital restitution of the funerary space of a single grave as a result of the organization and arrangement of the objects resulting from a ritual. Regarding this very last topic, in past years important projects focused on this field of study using Virtual Archaeology methodologies. An interesting case study is *Etruscanning* (Hupperetz *et al.* 2012; Pietroni, Adami 2014), a project focused on the virtual restitution of two Etruscan monumental tombs of the 7th century BCE. The reconstruction of the funerary space as it could have been at the time of its closure required careful examination and verification of the various documentary sources available. This case is an excellent example of how 3D reconstruction is primarily a tool of analysis and interpretation. Moreover, the model thus created is also a product for dissemination. Therefore, *Etruscanning* effectively represents the cognitive process deriving from the reassembly of the grave goods, as an action of rewinding time until the reconstitution of a closed environment, namely that of the tomb at the time of its closure.

The process outlined so far in its theoretical features leads to the restitution of the entire landscape, thus achieving a complex digital environment that can be investigated in every single part and in its diachronic formation process (cfr. § 1). The potentialities of this analytical approach (including organization of spaces and paths) have been tested in the *Kainua Project* regarding the cityscape of the Etruscan *Kainua*-Marzabotto (Gaucci 2017, 106-107; Govi 2017, 94; Gaucci, Govi, Pizzirani 2020). Furthermore, as already mentioned, the process of populating the graves will constitute an important moment of reflection, because the insertion of these virtual spaces according to the correct chronological sequence allows us to grasp the occupation strategies (see Taccola *et al*. in this volume).

As already mentioned, the digital products thus obtained, in addition to an advancement of knowledge and methodologies and an important basis for conservation, also represent effective dissemination tools. In particular, the latter aspect is primary in the perspective of communicating the results of the project to an increasingly wider audience, according to the principles of virtual museums as defined by François Djindjian (2007). In the case of Numana, the exhibitions of the recently renovated Antiquarium and the National Archaeological Museum of Ancona will be able to use tools such as tablets and viewers that allow visitors a more direct interaction with the finds and their location within the graves. The use of Internet will make it possible to disseminate these products to an increasingly broader public and also to aspire to virtually return the ancient landscape in the archaeological area, as already experimented for the project of virtual restitution of the Etruscan city of *Kainua* in the archaeological area of Marzabotto (Gaucci 2017; Garagnani 2017).

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ABSTRACT

The paper briefly introduces methodologies and practices of Virtual Archaeology applied to the pre-Roman funerary contexts of Numana (Ancona). Starting from the traditional approach and the concept of necropolis as a system, we will focus on the methodological issues and potentialities related to the use of digital models for the archaeological analysis of grave goods and their contexts.

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THE DAVANZALI NECROPOLIS OF NUMANA (AN): FROM THE ARCHAEOLOGICAL CONTEXT TO THE VIRTUAL ENVIRONMENT

1. Introduction: the archaeological context of the Davanzali necropolis

The Quagliotti-Davanzali necropolis is the largest funerary area of ancient Numana and includes more than 500 graves datable between the 9th and 2nd centuries BC (Finocchi, Baldoni 2017; Finocchi, Bilò 2020, 163-167). It is actually only one sector of a large funerary complex extending on the slope located North of the ancient settlement (Finocchi 2018, 262). The necropolis was extensively excavated between 1965 and 1975 (Lollini 1985); the southernmost sector was brought to light by G. Spadea in 1976 (Spadea 1977) and is the only one still accessible in the entire area: this allowed the Soprintendenza ABAP of Marche to carry out a recent maintenance operation, during which our research group carried out a new survey of the sector, of great importance also for the research included in the project whose results are presented here (Baldoni, Paci, Finocchi 2019, 3-6; see Silani in this volume).

As already mentioned by V. Baldoni in this volume, the Davanzali area, in particular a sector occupied by over 240 burials, has been the focus of a study project of the University of Bologna since 2016. The progress in the study of the grave goods has already allowed us to acquire a large amount of new data on the funerary rituals and the dynamics of occupation of the necropolis (Baldoni, Finocchi 2019; Natalucci, Zampieri 2019). However, the study also highlighted the critical aspects of the available documentation and the difficulties in the interpretation of the burial ground and in the topographical analysis: the tombs, as already pointed out, cover a vast chronological span and, during the different phases, often insist on the same areas, leading to overlaps that complicate the philological reading of the context.

These difficulties have led us to experiment, within the framework of the project presented here, with some of the methods of virtual archaeology, in the conviction that the three-dimensional reconstruction of the necropolis can be a concrete tool to support the interpretation of the archaeological context, as well as obviously a means for its dissemination.

The ultimate aim of this experimentation, which will continue beyond the time limits of the project presented here, in anticipation of the overall edition of the necropolis, is the creation of a virtual environment in which, through the interpolation of all possible documentary sources, it is possible to analyze the various constituent elements of the context at different viewing scales: the ancient funerary landscape, the single burial context or a group of burials, and the object inserted within the grave.

The first of these sources is undoubtedly the archival documentation produced during the excavation phase: the processing of this data, which is quite substantial for the Quagliotti-Davanzali necropolis, led to the creation of two-dimensional cartographic products in a GIS environment, from which the subsequent three-dimensional processing was based. At the same time, the autoptic analysis of the finds preserved in the deposits of the National Archaeological Museum of the Marche in Ancona provided further insight into the Picenian material culture and its peculiarities in the various chronological phases attested in Numana. The wide range of objects present (mainly pottery and, to a lesser extent, metals and other types of objects) led to the consideration of different acquisition methods for obtaining three-dimensional models. The desire to focus primarily on the study of ceramic vascular forms led the research group to adopt photogrammetry (see Baldoni and Garagnani in this volume).

At the same time, the topographical study of the necropolis and of the ancient landscape of Numana was initiated, with the aim, once the chrono-typological study of the grave goods had been completed, of placing the burial area in the broader context of the relative settlement, a fundamental aspect for better understanding the appearance of the site and the relationship between the necropolis and the neighbouring areas. To this end, a number of field activities have been carried out and a geomorphological study has been initiated, which lays the foundations for future developments of the project, as will be highlighted in the following paragraphs.

The aim of this contribution is therefore to describe the key points of the archaeological analysis that guided the various phases of the project, from the processing of the archaeological record to the creation of the three-dimensional models of the necropolis and the grave goods obtained following protocols that are as expeditious and replicable as possible, in the conviction that our experience can find analogous applications in different contexts.

2. The archaeological record: elaboration and interpretative issues

During the excavation campaigns carried out in the Quagliotti-Davanzali necropolis, a large amount of graphic and photographic documentation was produced: in addition to some general plans of the funerary area, a detailed plan was realized for each grave and, for the more complex clusters of tombs, some sections, unfortunately small in number compared to the total amount of evidence excavated. Furthermore, at least two pictures were taken for each tomb and a good series of panoramic photos, useful for a more accurate overall reconstruction of the necropolis.

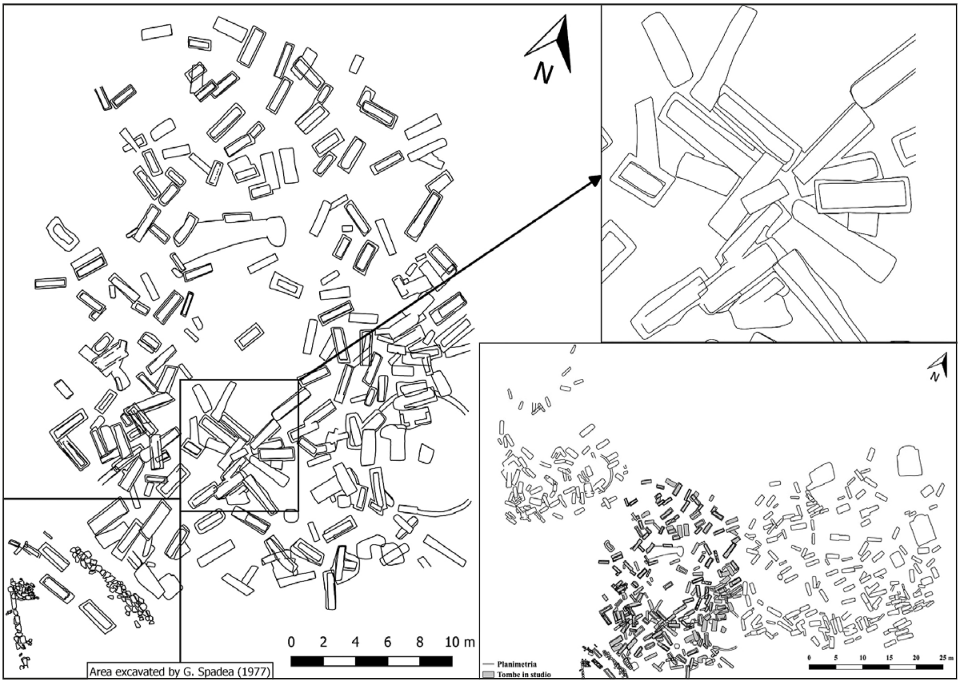

Fig. 1 – In the box on the lower right, planimetry of the Quagliotti-Davanzali necropolis; on the left, detailed plan of the Davanzali plot under study; in the box on the upper right, the tombs in which the three-dimensional modelling was initially experimented are highlighted (elaboration by E. Zampieri).

As detailed as it generally may be, the documentation of the excavations has some remarkable limits: for instance, the general plans lack the reference points necessary for their correct positioning. In addition, all the elevations reported in the excavation diaries and sections refer to a 'zero point' no longer recognizable in the area, which is also characterised by a not negligible N-S slope.

The complexity and quantity of the available documentation made it necessary, right from the start of the necropolis research project, for the implementation of a GIS platform associated to a PostgreSQL/PostGIS geodatabase, containing all the data on the grave goods, in order to correlate the information on the tombs (position, structure, etc.) with the individual objects they contain: the structure thus set up proves to be a useful tool not only for organizing the data, but also for a wide range of spatial analyses (Natalucci, Seccamonte, Zampieri in press).

The general planimetry of the necropolis has been properly georeferenced also thanks to the new measurements conducted in the field. For the sector of the Davanzali necropolis currently being studied it has been possible to achieve a high level of detail by georeferencing the plans of each single burial and subsequently vectorizing all the structural elements that made up the tombs, such as ditches, perimetral steps and, when present, covering elements.

The result was the creation of a new planimetry (Fig. 1), containing information on each individual tomb structure, which is the basic starting point for a more accurate philological reconstruction of the context in a three-dimensional environment.

3. From the analysis of the context to the virtual environment

Excluding two cremation tombs, referable to the most ancient phase, all the burials in the Quagliotti-Davanzali necropolis consist of inhumations in simple ground pits, sometimes marked with a perimetral step; the sole exceptions are the so-called 'monumental' tombs 64, 178 and 185 Quagliotti, which are not included in the lot we consider, comprising 241 graves of the Davanzali area. In the contexts already studied within the research project on the Davanzali area, almost all the phases of occupation are represented: it could thus be argued that the area has been employed as a burial place from the 9th to the 2nd century BC, with a significant hiatus during the Orientalizing phase.

Through the study of the grave goods, still ongoing, it has been noticed (Baldoni, Finocchi 2019, 636-637) how the necropolis was originally occupied, between the 9th and 8th centuries BC, by separate burial plots. There is

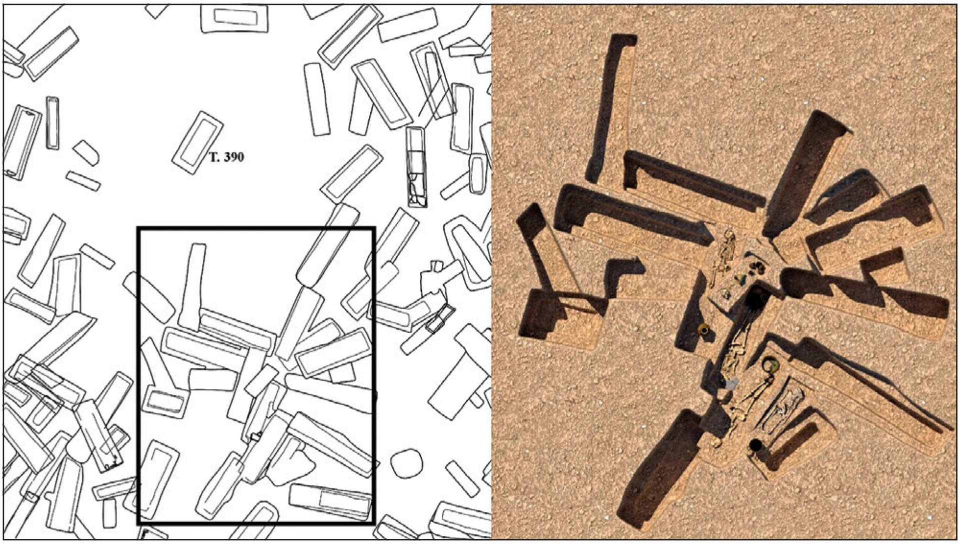

Fig. 2 – Zenith view of the 3D model realized for a sector of the Davanzali necropolis and its positioning with respect to tomb 390 (elaboration by S. Garagnani and E. Zampieri).

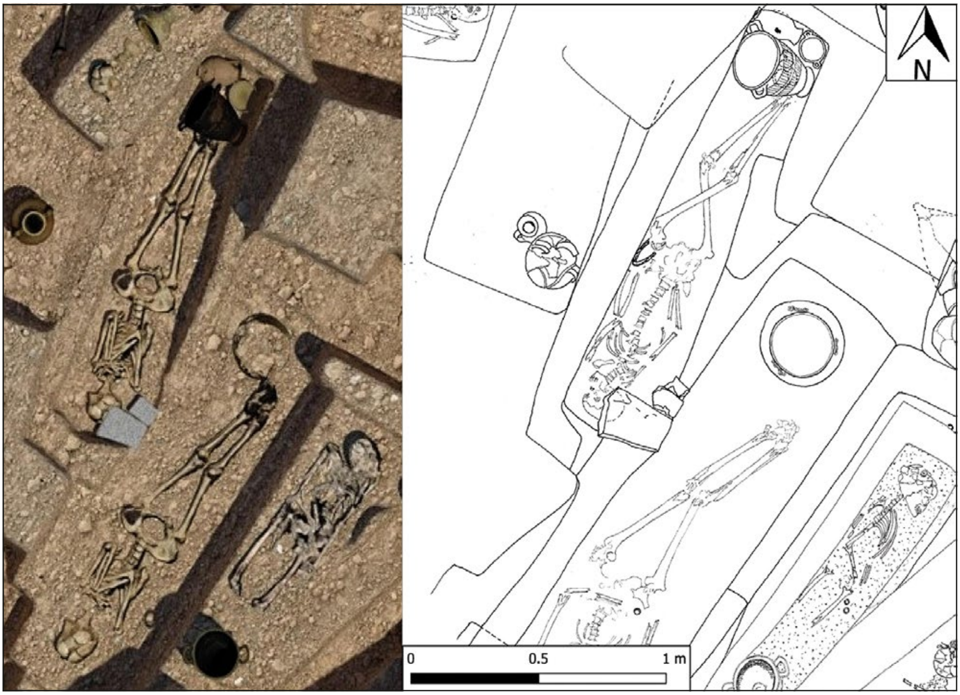

Fig. 3 – Comparison between 3D model and planimetry elaborated in GIS environment (model elaboration: S. Garagnani and E. Zampieri; planimetry elaboration by E. Zampieri on the basis of the drawing SA 16210 - Courtesy of Ministero della Cultura - Sabap Marche).

no record of the Orientalizing phase (yet, well represented in the surrounding areas), while an extensive occupation can be seen from the 6th century BC, when the burials maintain a certain regularity in their orientation and topographical arrangement. Especially from the 4th century BC there had been an increase in graves: in this final phase, which lasts until at least the first half of the third century BC (with sporadic attestations until the 2nd century BC), the graves are concentrated above all in the southern sector of the Davanzali area, very frequently intercepting previous burials while significantly respecting some of the most ancient graves of the whole necropolis.

The selected area for our first trial of 3D reconstruction is located in this specific sector (Fig. 2). The group of burials analyzed is located immediately to the South of a major area of respect related to one of the most ancient graves of Numana; it is also characterized by a remarkable continuity in occupation from the 6th to the 3rd century BC, a condition which has led to frequent cases of overlapping or partial obliteration of the burials. The tombs dating to the beginning of the 3rd century BC were excavated in the same ground already occupied in the 6th and 5th centuries BC, but they still keep respecting the northern area pertaining to the tomb 390, dated to the 9th century BC. If on the one hand the insistence of the tombs in this sector may be explained by assuming the will to emphasize the belonging to the same social group, on the other hand it seems clear, given the disposition of burials in the surrounding areas, that in some way the tomb 390 influenced the topography of the necropolis even at very later stages (Natalucci, Zampieri 2019, 645-646).

This sector effectively shows the potential of a 'virtual' approach: the 3D model allows us to read the stratigraphical relationships between the tombs in a more immediate and intuitive way, as well as facilitating their analysis. From the model, in fact, new sections can be extracted: this operation allows us to easily correlate tombs excavated in different archaeological campaigns. Moreover, once the digital reproductions of the grave goods are inserted, it is possible to actually recreate the context at the time of the excavation and analyze, with the aid of the third dimension and following an accurate study of post-depositional dynamics, the funerary ritual.

In extreme synthesis the virtual environment described here (obtained through the interpolation of archival documentation, traditional study of the grave goods, new field surveys and digital products, whose implementation process will be illustrated in the following sections of this paper) makes it possible to create a new archaeological documentation, more accurate than the one originally produced, yet at the same time clearly inseparable from the excavation, therefore constituting the first context to be reproduced in the process of constructing the virtual environment (Fig. 3).

4. Further developments

As already pointed out, the first detailed model (Fig. 4) opens up new perspectives for the analysis of the funerary context. It is a faithful 3D reconstruction of the sector at the time of the excavation, which does not, however, provide a hypothetical graphic representation of the burial at the time of its closure. This choice is dictated by a lack of data that probably not even the completion of the study on the grave goods will be able to fill.

However it is clear that, even considering the information derived from the use of the third dimension, the sector maintains some of its criticisms, mainly due to the overlap between the graves. It is therefore necessary to attempt, for a better understanding of the context, a virtual reconstruction that separately displays the different phases of the necropolis, starting from the objective but necessarily incomplete data of the excavation.

For this reason, the same 'quick' approach implemented for the reconstruction of the first detailed sector was applied to the entire area of the necropolis, starting from phase maps on the same model of the one in Fig. 4. In

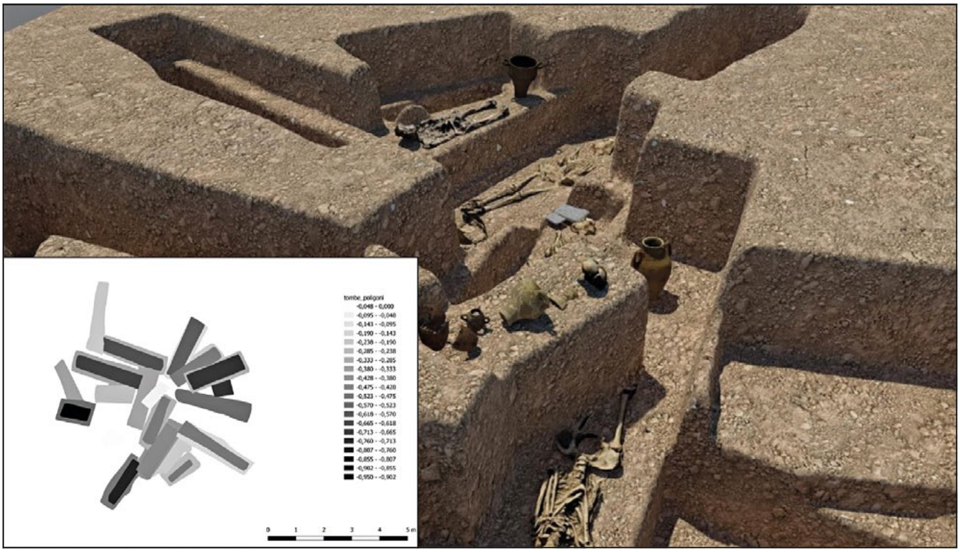

Fig. 4 – Perspective view of the detailed 3D model. In the lower left box, the planimetry with indication of the heights in relation to the marly soil (elaboration by S. Garagnani and E. Zampieri).

these plans, the gaps present in the tombs cut by successive burials have been integrated through drawing in GIS environment: the limits of the pits have been reconstructed when they were only partially incomplete; in the absence of sufficient data, instead, only the preserved portion has been represented. This method, which implies an interpretation process of the lacunar tomb structure, allows us to obtain reliable models of the necropolis on the basis of a bidimensional cartographic product, without having to hand-model the walls of the burials affected by the overlapping.

Considering the current state of progress of the research, it is possible to define four 'macro-phases' to be rendered graphically in three dimensions; these phases are based on the periodization of the Picenian material culture carried out by D.G. Lollini (1976). The first phase of attendance, which is defined by a few small burial plots dated between the end of the 9th century BC and the first half of the 8th century BC, falls within the periods known as Piceno I and Piceno II. A substantial number of burials show the traditional Piceno IVA and IVB phases, covering the entire 6th century up to the first decades of the 5th century; then comes the Piceno V phase, which lasts until the first decades of the 4th century BC. Finally, it is possible to include in a single graphic representation the later stages of attendance of the necropolis, corresponding to the Piceno VI phase until the romanization of ancient Numana.

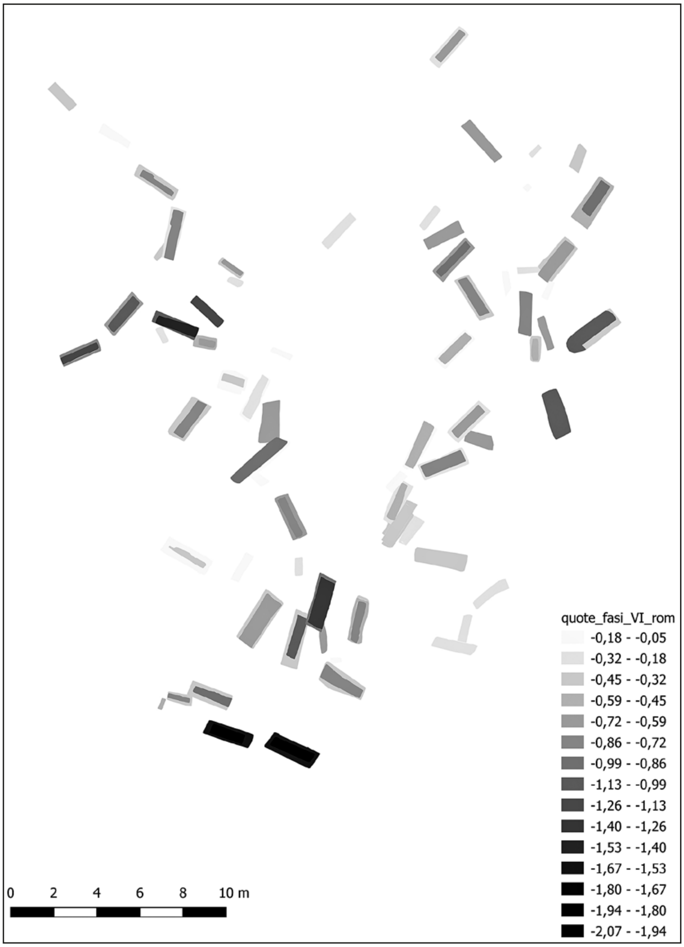

Fig. 5 – Plan of the necropolis including the tombs attributable to Piceno VI and those of the 'Hellenistic-Roman' phase, with indication of the heights in relation to the marly soil (elaboration by E. Zampieri).

A first attempt of quick 3D modeling on a wider scale was conducted precisely in the latter phase, in which the burials cover most of the area considered (Fig. 5). In fact, about 25% of the graves located in the Davanzali area are attributable to Piceno VI phase (385-268 BC); to these we can add a small number of burials representative of the romanization phase of the Picenian center (Baldoni, Ciuccarelli, Finocchi 2020, 101-103).

The model obtained (for the realization of which see Garagnani in this volume, Fig. 4), despite being characterized by a lower level of detail compared to the model of the sector proposed in Fig. 4, can be a useful tool for a diachronic analysis of the context and its ancient topography. However, only once the study of the grave goods has been completed will it be possible to fully explore the potential of this method. For example, it could be possible to understand, taking into consideration the volumes of all the burials attributable to each phase, the criteria behind the spatial arrangement of the burials themselves, or identify the presence of internal paths or other elements which influenced the organization of the necropolis in the different periods.

Once the study of the grave goods has been completed and the 'phase models' refined accordingly, these will be related to the DTM (see Silani in this volume, Figs. 1-2), in an effort to recreate a proper ancient digital terrain model, which will allow us to analyze the diachronic development of the necropolis with a novel 3D approach.

The realization of such a model introduces some critical issues dictated by the lack of preserved paleosols, with the exception of a portion of a gravel embankment, datable within the first decades of the 4th century BC, identified during the excavation led by G. Spadea in 1976; it is therefore impossible to reliably rebuild a paleosol in the rest of the necropolis. It can reasonably be assumed that this lay at an elevation very similar, if not equal in certain sectors, to the current ground level, placed at an elevation varying between 1 m (as attested in the adjacent 'Ex-Frontalini' necropolis) and 2.5 m (in the area excavated by G. Spadea, in the southern part of Davanzali necropolis: see Silani in this volume, Fig. 5) above the marly soil in which the graves have been identified. This information can be deduced by analyzing the depth of child burials, often discovered poorly preserved: especially in the tombs attributable to Piceno VI phase located nearby the central sector of Davanzali area (Fig. 5), the elevation in relation to the marly soil is often about -10 and -60 cm, which is certainly too small a depth even for the tomb of an individual of subadult age.

This is a preliminary hypothesis that certainly deserves to be further explored as the studies progress. However, it is certainly an effective example of how the results achieved within the framework of our project open up new research perspectives, in some cases filling or at least integrating the gaps in the excavation documentation. Once again we can see the potential of the virtual environment created for the Davanzali necropolis in Numana, which still needs to be enriched and therefore 'explored' in its entirety, but which is undoubtedly a useful tool for the topographical and essentially archaeological analysis of the context.

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ABSTRACT

The paper focuses on the issues of archaeological interpretation of the Quagliotti-Davanzali necropolis of Numana (AN) in relation to the virtual reconstruction of the context. The first step of this process is the reconstruction of the necropolis at the time of the excavation. This reconstruction is realized through the analysis and elaboration of the wide archival documentation produced during the archaeological campaigns. The study then focuses on the archaeological analysis of some specific sectors of the necropolis and on how digital models can effectively support this investigation. The limits and the potentialities of the experimented methods for the creation of the models are subsequently highlighted. Finally, a reflection is proposed on the future perspectives of the project in relation to the overall study of the necropolis, with a preliminary application of 3D modelling on the entire funerary area, in particular in its last phase of attendance. Indeed, for this last stage an optimal interpolation between the excavation data and the new research carried out in the field can be achieved, with a view to an integrated reading and a consequent virtual representation of the ancient funerary landscape.

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RECONSTRUCTING THE FUNERARY LANDSCAPE: NATURAL ENVIRONMENT AND TOPOGRAPHY OF THE NECROPOLIS

It is well known that the definition of landscape can have multiple declinations depending on the aspects considered by a given discipline. Generally speaking, we could describe the landscape as «the part of the territory that is embraced by the eyes from a given viewpoint» (https://www.treccani.it/vocabolario/paesaggio). Inherent in the definition of landscape is therefore a visual meaning, the view from which we look at and the recognition of certain features that characterize the landscape we are observing. These specific aspects are represented by a series of features, geological, structural, geomorphological, climatic, to which modifications due to human action are necessarily intertwined.

The interaction between natural elements and human settlement structures determines the shape of the landscape that is observed.

If we introduce the chronological aspect and thus shift our point of view, observation will then necessarily have to take into account different sources of information in order to 'look at' that landscape. It is essential to analyze the modifications of the natural and anthropic forms of a given territory, the former being studied by the earth sciences (in particular geomorphology) and the latter by landscape archaeology (Dall'Aglio 2011).

Finally, the reference to a 'historical' or 'ancient' landscape implies the concept of reconstruction, a reconstruction that will obviously be hypothetical and therefore virtual. The potential offered today by Virtual Reality and Augmented Reality makes it possible to visualize this ancient landscape and to recall the visual perception at the basis of the very definition of landscape (Pescarin 2009).

Even for the reconstruction of the landscape of the Picenian necropolis Quagliotti-Davanzali, before defining and detailing techniques and procedures of modelling and three-dimensional reconstruction at site scale (spatial scale) and single burial/object scale (object scale) (see in this volume S. Garagnani) starting from the archival archaeological documentation and recent excavations (see in this volume E. Zampieri), the integration of the information deducible from the archaeological investigations with the geomorphological analysis was evaluated.

It was immediately deemed necessary to extend the topographical analysis to the landscape surrounding the entire necropolis. The first step was the creation of an initial Digital Terrain Model (DTM) starting from the Regional Technical Map at a scale of 1:10000 with a 10 m pitch, through the interpolation of the contour lines and the current hydrography, using the

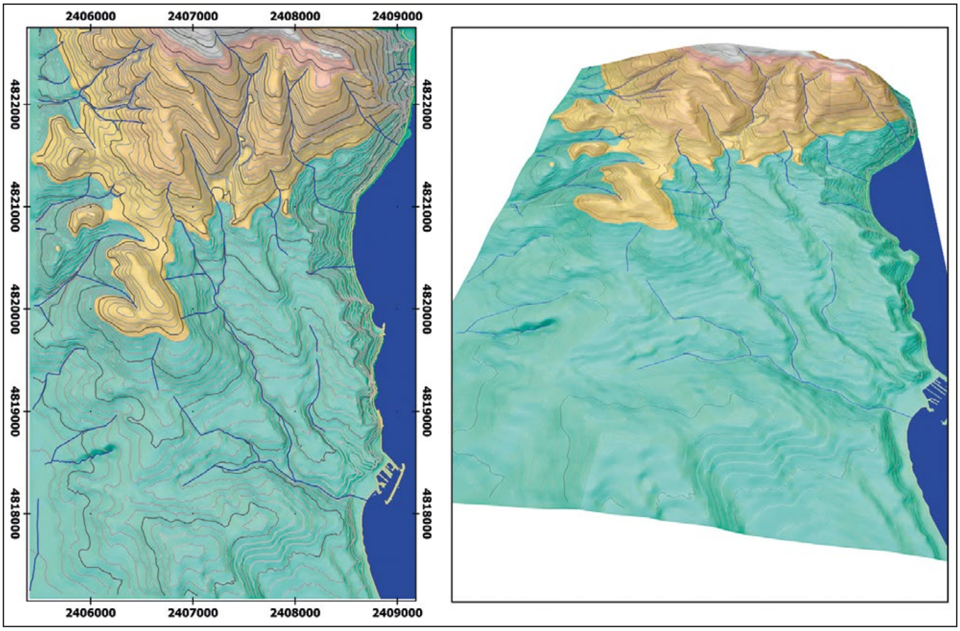

Fig. 1 – DTM of the Numana area extracted from the CTR (Regional Technical Cartography) (elaboration M. Silani).

Topo to raster algorithm (see *Using Topo to Raster in 3D Analyst* in *ArcGIS* online help) (Fig. 1).

In order to obtain a more detailed DTM, a stereoscopic pair of aerial photographs from the 1955 G.A.I. flight (11095-11096, Sheet 118, Stripe 13D, Flight altitude 5000 m, scale 1:33000) was subsequently acquired. These photograms immortalize a territory devoid of the incisive changes due to the mechanization of agricultural practices and the urban densification phenomena of the last sixty years, or in other words, a morphology more similar to the historical landscape. The digital photogrammetric processing (with Agisoft Metashape software) was supported by a measurement campaign of different GCP (Ground Control Points) by differential GPS (see below), visible in the frames and still recognizable on the ground. The classification of the evidence related to the elements on the ground surface (buildings and vegetation) present in the frames finally allowed the extraction of a detailed DTM (0.5 m cell sizes), which describes with good accuracy the morphology of the site (Fig. 2).

At the same time, the collection of geomorphological data of the area currently published began, to which it is hoped to add data from direct surveys.

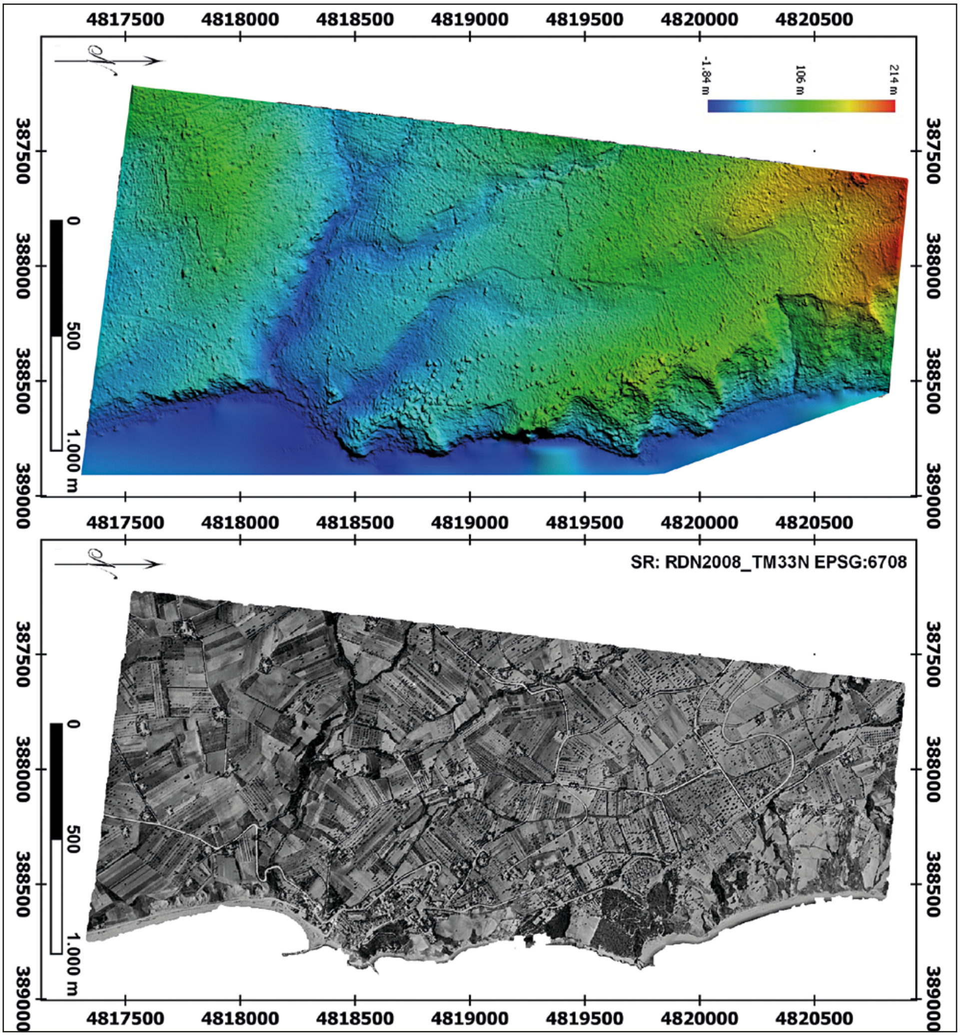

Fig. 2 – Detailed DTM (0.5 cell sizes) and relative orthophoto of the Numana area: photogrammetric elaboration of the 1955 G.A.I. flight (elaboration E. Zampieri, M. Silani).

Although the analysis is still at a preliminary stage, interesting indications and problems for the reconstruction of the ancient landscape have immediately emerged. As it is well known (Finocchi 2018), the town of Numana lies on the top of a coastal cliff subject to strong erosion, characterised by Holocene landslide deposits in evolution belonging to the Musone synthema (Fig. 3). Towards the hinterland, the hilly relief is furrowed by modest valley incisions,

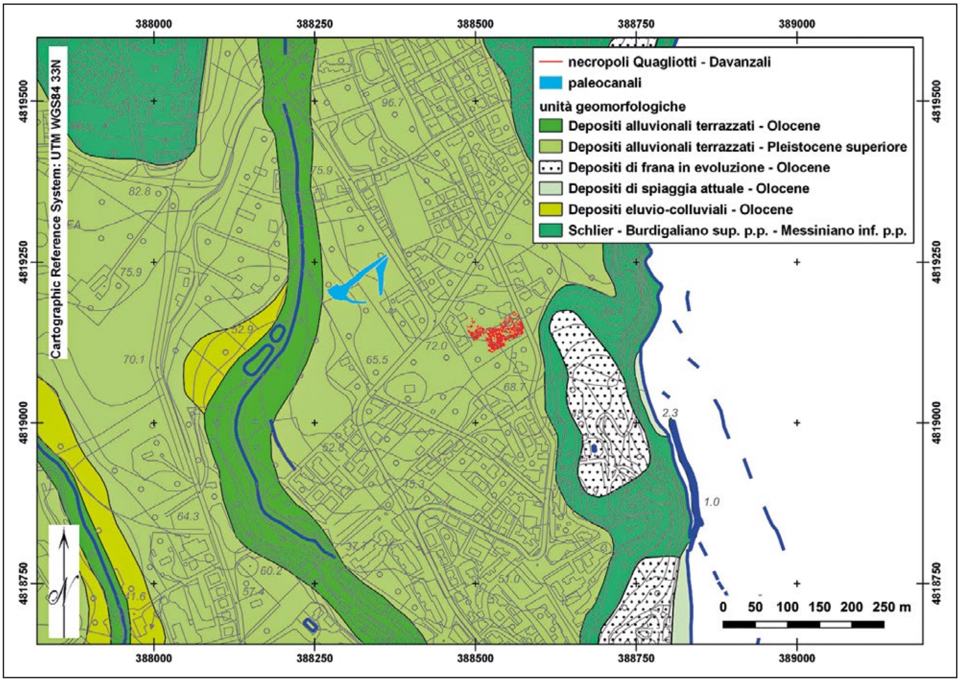

Fig. 3 – Extract of the geomorphological map of the Numana area: in evidence the funerary areas under study (elaboration by M. Silani).

where there are numerous streams, today as in ancient times, which feed the main collector of the Fosso dei Mulini that flows 100 metres south of Numana. With a course parallel to the previous one, but more shifted towards the coast, the Fosso della Fonte, today partly entombed, borders the slope that limits the settlement of Numana to the west and therefore also the necropolis sector. The latter are located in a more stable area than the coastal sector, i.e. on the alluvial terraced deposits of the Matelica synthema, with a predominantly sandy matrix, datable to the Upper Pleistocene. Of particular interest are the data from the recent excavations of the necropolis of Via Peschiera (Baldoni, Paci, Finocchi 2019), about 250 m from the Davanzali necropolis, in a terraced sector sloping down towards the Fosso della Fonte. The area, during the phase of use between the 3rd-2nd century BC, was crossed by wide and deep active paleochannels, with direction NE-SW and EO, converging on the Fosso della Fonte. The fills of the paleochannels, between 7 and 20 m wide and more than 5 m deep, consisted of alternating colluvial deposits with post-antique ceramic materials inside. This information is of particular interest, as it testifies to the geomorphological dynamism of the area, which may also have conditioned the choice of location of the necropolises and, above all, may have modified the height of the original paleosols in ancient times.

In order to put forward some initial hypotheses for the reconstruction of the different phases of occupation of the necropolis and to identify the relative topographical planes (paleosols), it was necessary to define a sort of 'zero elevation' from which to begin in order to understand the choices implemented by man in the realization of the funerary area.

From a procedural point of view, the definition of a single altimetric reference system for the entire necropolis made it possible to relate the information deduced from previous investigations to the only portion of the excavation area still partially accessible (Baldoni, Paci, Finocchi 2019).

A new topographical documentation activity was therefore set up through the systematic use of geomatic techniques (photogrammetry, photo-modelling, laser scanning, DGPS), to document the archaeological evidence and form the starting point for the virtual model.

The starting point was the materialization of a new network of topographical vertices using differential GPS, not only as a support for future archaeological research and geophysical surveys, but also for the georeferencing of the laser scanner and photogrammetric surveys. The acquisition was carried out with NTRIP real-time differential correction on the basis of the Leica Smartnet Italpos network, subsequently re-processed in post-processing on the basis of the IGM grids of the area and related to the national network for the restitution of coordinates in the reference system RDN2008 TM 33N.

The network of strongholds materialized on the ground also constituted the reference base for the acquisition of further notable points by means of Total Station, in particular of some modern structures visible in the historical photos and still visible today among the vegetation, which are fundamental for relating the heights present within the documentation of the previous excavations with the mean sea level and therefore the current topography.

While the new survey campaigns made it possible to determine the absolute heights of the topographical planes reached by the previous excavations, the archaeological evidence still visible was documented by means of a laser scanner survey (with Phase-Shift TLS Faro Focus 3d Cam2, 4 station points, step of 6 mm at 10 m and final resolution of 1-2 mm) integrated with a photogrammetric survey (created using image based technique from 135 shots), in order to obtain the best result in terms of metric reliability and radiometric quality (texture) of the 3D model. This three-dimensional modelling provided a first reference for the reconstructive hypothesis of the topographic plans of the main phases of the necropolis' life (Fig. 4).

In particular, this is the fragment of a gravel ballast, datable within the first decades of the 4th century BC on a stratigraphic basis (Baldoni, Paci, Finocchi 2019), which constitutes a fixed point for the definition of the

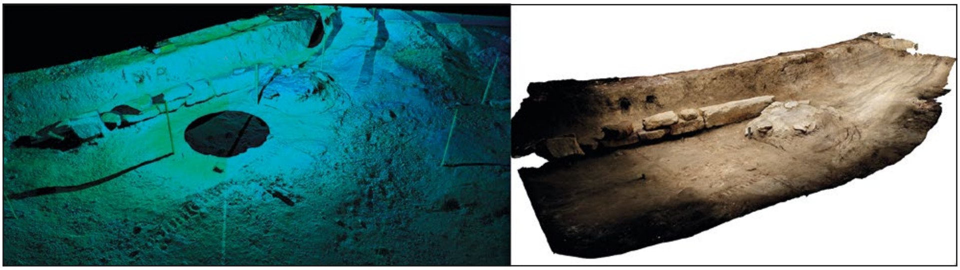

Fig. 4 – Laser scanning and photogrammetric survey of the still visible evidence pertaining to the necropolis (Courtesy of Ministero della Cultura - Sabap Marche, elaboration E. Zampieri, M. Silani).

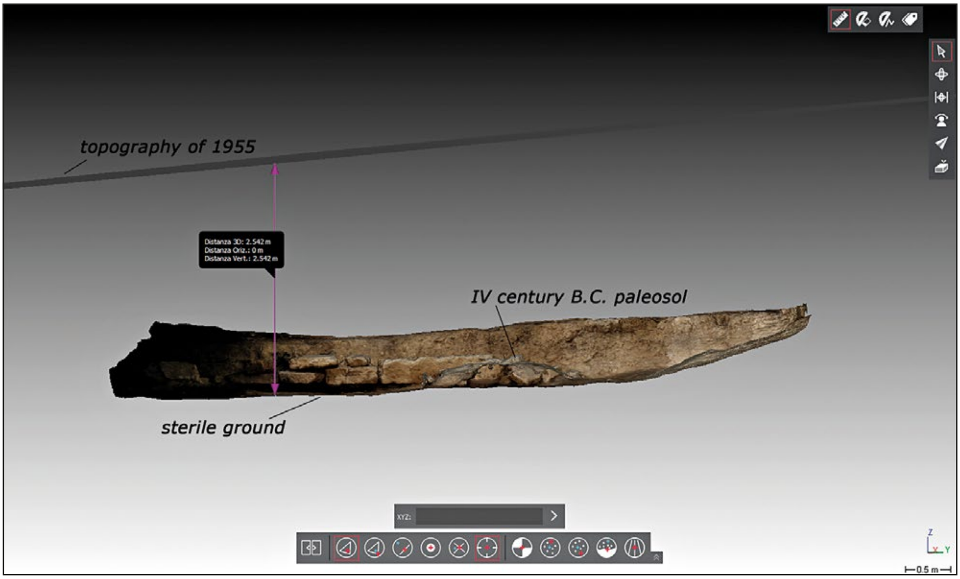

Fig. 5 – Topographic plan of 1955 in relation to the paleosol of the 4th century BC (elaboration M. Silani).

walking surface of the necropolis in this phase of its life. The possibility of relating this paleosol to the DTM of the entire area of the necropolis extracted from the aerial photographs of 1955 represents a significant starting point for the analysis and reconstruction of the modifications of the ancient landscape, including the visual aspect (Fig. 5).

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ABSTRACT

The short note illustrates the activities carried out within the 'Alma Idea' project of the University of Bologna for the reconstruction of the ancient funerary landscape of the Davanzali necropolis in Numana. While waiting for new geological-geomorphological research aimed at the acquisition of data at a territorial scale, the landscape shapes, reconstructed so far on the basis of published data, are recalled for the contextualization of the necropolis sector under study. Attention is focused on geomatic techniques for the documentation of the different ancient topographical plans, the starting point for subsequent topographical reconstructions of the evolution of the landscape of the necropolis over the centuries.

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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.

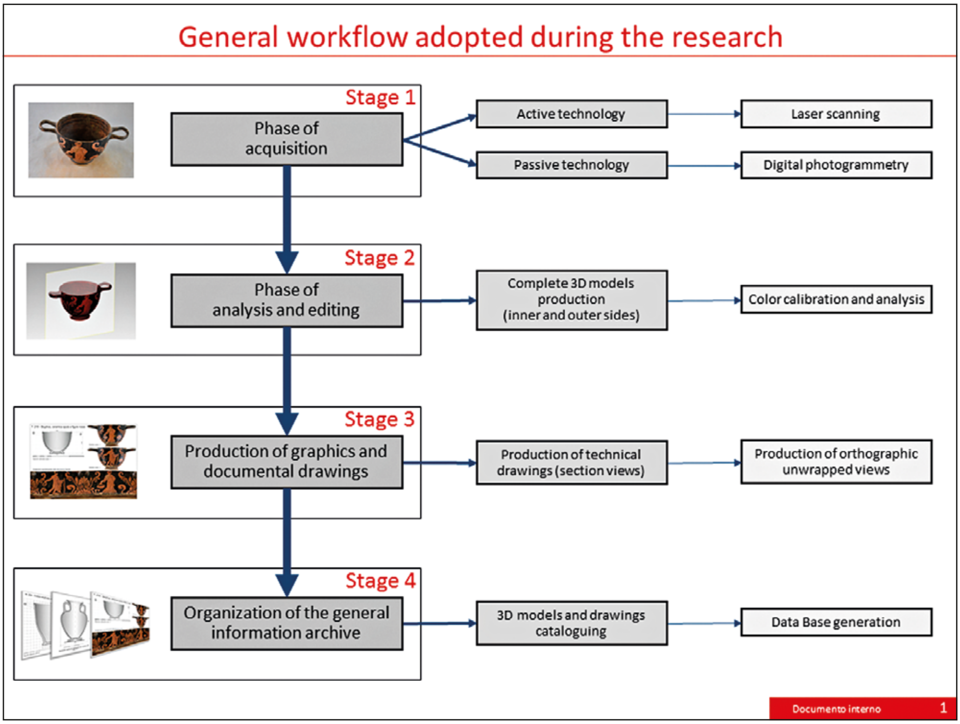

Fig. 1 – General scheme of the workflow applied to digitalize, analyze, document and organize all the artifacts investigated during the research work.

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

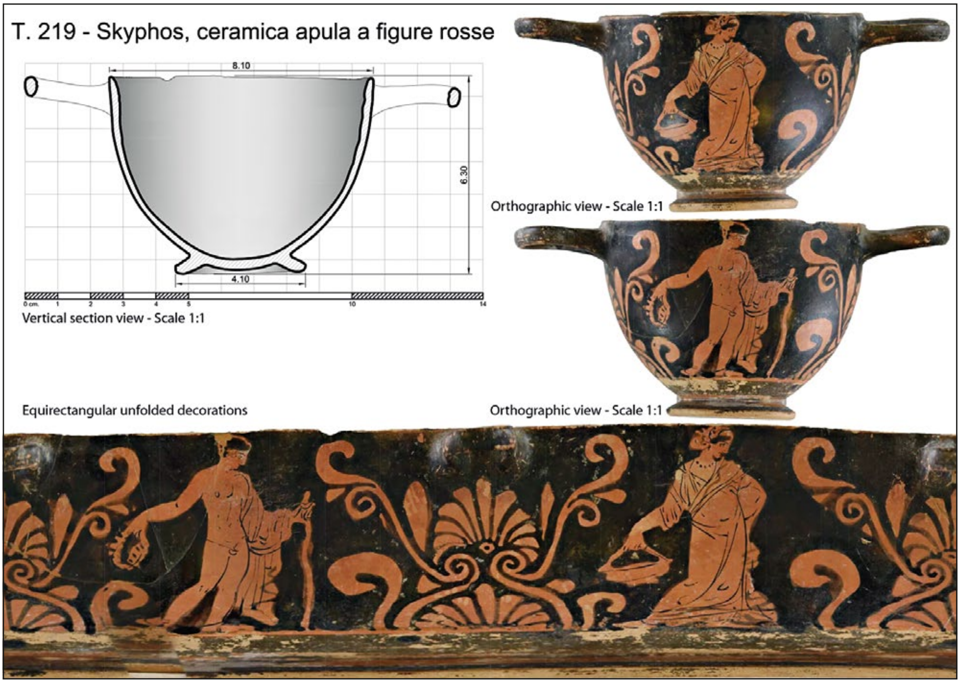

Fig. 2 – An example of section view and 2D representations of a ceramic artifact inferred from the 3D digital model. 3D representations were used to replicate the thickness of the ceramics studied and unfold the decorations on the object's lateral surface (Museo Archeologico Nazionale delle Marche, inv.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

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

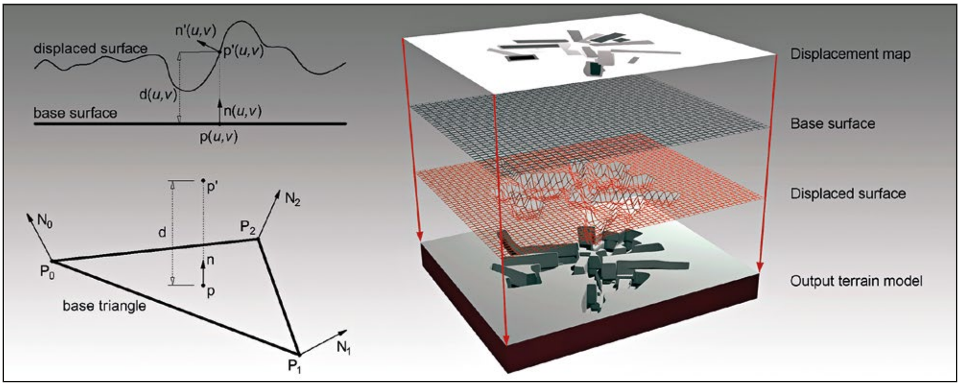

Fig. 3 – Geometric representation of the mathematical approach behind the displacement mapping technique adopted: a general base surface is proportionally deformed according to different weights expressed by a 2D map.

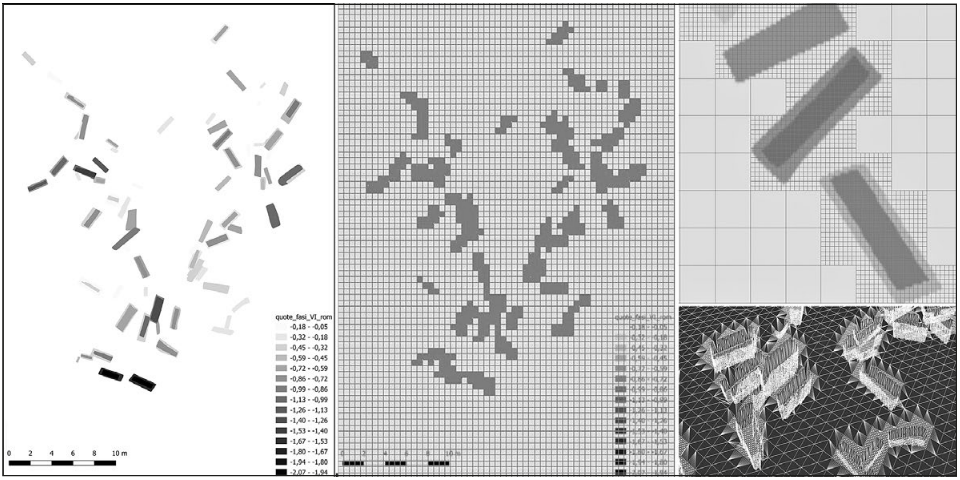

Fig. 4 – The displaced surface was triangulated to reach a better layout, in order to cover the edges of the 2D reference bitmap generated by GIS maps produced in different times. Even if this is not an accurate metric representation, it proved to be useful in 3D documentation of excavation levels, determining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

From Pottery to Context:
Methodologies, Practices, Case Studies

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STUDYING THE SHAPES OF GREEK VASES: HISTORIOGRAPHY AND NEW METHODOLOGIES

1. Introduction

«Now that the painters of nearly all important Attic vases, and most of the less important, have been determined, the whole material must be re-studied from the point of view of potters; and this time we must be prepared to hold the painters at arm's length. It will not be enough to note the general proportions of the shape: the eye must become accustomed to perceive minute refinements of curve and line. Then it will be possible not only to write the history of Attic vases from the point of view of the potters, but, in the long run, to shed fresh light on the painters with whom they collaborated» (Beazley 1944, 42).

The fact that these thoughts were Beazley's, and were published as early as 1944, highlights a paradox which is still mostly valid in the historiography of research in Greek figured pottery. While this branch of Classical studies focused for decades on the development of Beazley's lifework, i.e. the attributions of Greek vases to anonymous painters, the study of the potter's work, i.e. the variations in vase shapes and their connections with craftsmen's habits as well as workshop practices, remained broadly neglected and were never systematically analyzed. Yet, Beazley was perfectly aware of the necessity to pursue these avenues.

In spite of this negative assessment, it is important to stress that some scholars developed frameworks and methodologies to approach what we might call 'micro-typologies' of Greek vases. This paper offers a synthesis of the various and somewhat disparate works on the shapes of Greek vases and their attributions to anonymous potters. Building on this historiography, the paper also presents the methodological guidelines followed by the authors in their works on Greek shapes.

This article might appear somewhat *at odds* with the other contributions in a volume on the virtual modelling of ancient pottery. If virtual 3D modelling might soon replace drawings made by hand, the systematic and large-scaled study of the potter's work of ancient vases – in combination with the stylistic studies of the figured decoration – remains necessary and methodologies will have to follow similar steps. The methods discussed here are fundamental, not only for a better understanding of the organization of potters' workshops but also to appreciate their local interactions and intercultural relationships with other Greeks and non-Greeks.

2. Studying the work of Attic potters: a short historiography

2.1 *Pioneering studies*

The pioneering studies on Greek shapes were developed between the 1930s and the 1950s and are mainly represented by C.H.E. Haspels, J.D. Beazley and H. Bloesch. These early approaches, like most of the more recent studies they inspired, strongly depended on a first classification based on *epoiesen* signatures (interpreted as potters' signatures) and on the stylistic analysis of figured decoration. Beazley would attribute unsigned vases to a specific painter by studying his manner in representing certain anatomical details – such as the ears, hands and muscles – or the folds of clothes. Besides the identification of single hands, Beazley also assembled vases under anonymous *Groups* of painters (Robertson 1989, xvi-xvii), consisting in more nebulous clusters where individual hands could not be distinguished. The goal of early researchers – heavily relying on painted decoration – was to apply the same methodology to the potters (Hemelrijk 1991, 251).

Haspels' book on Attic black-figured *lekythoi*, published in 1936, is the first of these pioneering studies (Haspels 1936). Still highly relevant today, this work is more than a simple typo-chronology of *lekythoi*. Haspels organized her corpus according to morphological types and workshops' specific characteristics: she divided the entire *lekythoi* production into seven groups according to shape and chronology and by acknowledging the synchronicity and chronological overlaps of various profiles manufactured in different workshops. The last group she discussed, *From About 500 onwards*, was a worthy attempt to identify workshops and their development, collaborations between potters and painters, the characteristics of leading craftsmen and groups of vases they were related to, but probably potted and painted by other minor workers. The second part of the volume, the *Appendices*, reinforced Haspels' workshops analysis by shedding further light on seventeen groups of vases that share additional morphological and stylistic traits. The influence of Beazley, who was Haspels' professor and who probably carefully reviewed the manuscript (Audiat 1938, 292), is especially strong in this section, as the seventeen groups are mostly named after painters. In a 1938 review, Audiat, though praising Haspels' work, regretted her limited focus on vases that were well-painted, but disregarding «l'armée innombrable des lécythes sommairement décorés». Haspels' methods and knowledge might have been able to shed some light on the vast quantities of neglected vases for which Beazley's methods are of no use (Audiat 1938, 293-294). This remark is of the utmost importance, since it is one of the major claims of the present article that studies of shapes may lead to a better understanding of the huge amount of poorly painted vases.

As noted in the introduction, Beazley should also be considered as a pioneer in shape studies, although this aspect of his research is often overlooked.

As he laconically wrote in his seminal work on stylistic attributions of Attic vases to painters (*ARV*[2], xliii): «'Class' refers to shape». This means that vases grouped by Beazley under a *Class* present the same shape with a further range of specific morphological details (Robertson 1989, xvi). The term is therefore connected with the potter's work, but it lacks precision since it is not always clear if a determined *Class* refers to a sub-type crafted by several workshops, a single workshop or a single craftsman.

However, Beazley carefully observed the potter's work, for instance, in his grouping of black-figured *lekythoi* attributed to the Sappho and Diosphos Painters. These two distinct hands worked on the same shapes and shared the same techniques as well as many stylistic and iconographic features. Building on these observations, Beazley considered this workshop to be a collaboration of two painters with a single potter – the Diosphos Potter – identified by recurring morphological details on his *lekythoi* (*ABV*, 507; *ARV*[2] 1963, 300-304; *Para*, 246). Unfortunately, Haspels' and Beazley's morphological approach was never theorized nor systemized.

In 1940, Bloesch published what R.M. Cook defined as «the first serious attempt to do for the potters who made Attic vases what has been done for the painters who decorated them» (Cook 1945, 122). For his project, Bloesch studied the morphology of about 900 Attic cups dated between 530-430 BC, starting from Exekias' work (see also Bloesch 1951, for a similar study on amphorae and *hydriai* connected with Andokides). He went further than Haspels by using profile drawings as a method to compare small morphological details and tiny variations between vases. Although he still relied on stylistic attributions and signatures, he grouped the productions of various potters by observing the features of the cups' bowl, rim, handles and foot, defining the characteristics of each potter and their connections. However, as noted by Cook, Bloesch's attributions are difficult to validate given the very limited number of illustrations compared to the total of studied vases (Cook 1945, 123). There is a further problem: in his drawings of cups, amphorae and *hydriai*, Bloesch mostly published small parts – mainly the foot and rim of the vases – to save space in the plates. This choice makes it difficult for the reader to analyze shapes that s/he can never study directly. According to our experience with *kyathoi* and *alabastra* (see *infra*), one analyzes a shape visually faster and more effectively when comparing complete profiles of vases. Partial drawing should therefore be discouraged in publications for the sake of morphological studies.

Despite this last issue, it is important to remember that Bloesch's most significant contributions to the studies of shapes are the systematic drawing of large corpora of vases sharing a same shape and type, and the use of photography to complete the corpus when drawing is not possible (Katharıou 2017, with bibliography, proposes a continuation of Bloesch's work for the workshops of the Meleager and Jena Painters).

2.2 *Recent developments: from the 1980s onwards*

After Bloesch's publications, research focused on painters and, to the best of our knowledge, no significant work on Attic potters was published before the 1980s.

For instance, in 1984, B.F. Cook studied a particular Class of *lekythoi*: Class 6L (Cook 1984, 149-152). He defined two variations in the shape of these vases, located on the foot. However, faced with the difficulty of interpreting these morphological variants, Cook specified that it was impossible to determine whether there were one or two potters. If the identification of different Classes (or coherent typological groups) and consequently of different workshops is a simple process, it is far more difficult to distinguish a potter's hand among the vases in a same Class, because of the close links uniting the potters of a workshop.

The same year, Mackay proposed to work, like Bloesch, on the basis of profile drawings and her work on Exekias' amphorae (Mackay 1984; 2010, see Fig. 1) was very innovative. She compared the profiles of vases of the same type by reducing proportionally all the drawings to the same height, using a

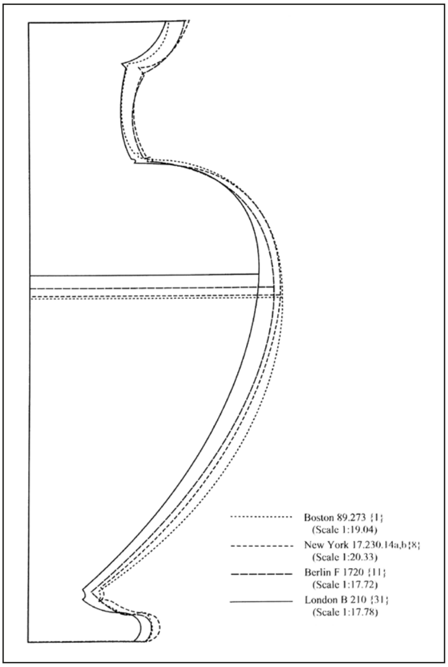

Fig. 1 – After Mackay 2010, 390, fig. 3. Superposition/envelope of profiles (brought to the same height) of amphorae made by Exekias.

complex mathematical formula. Her method also gives an average profile of each vase and reduces occasional distortions of the potter's work, by combining several profiles of a same vase. Mackay started her work with four profile drawings for each amphora, then continued with only two drawings, as she realized that Exekias' work was very precise.

Based on our experience of *kyathoi*, we confirmed that reducing the similar profiles of two vases of very different sizes can be very helpful (see *infra* Fig. 5; Tonglet 2018, 182-184). Thanks to today's technology, this graphic operation is easier and faster to perform and laborious calculations have become unnecessary. Mackay's tendency to reduce distortions of the original vase by producing a kind of 'average profile' is less convincing. First of all, outside the field of Classical studies, anthropological studies regarding the standardization of pottery productions have shown a broad tendency among potters to place his/her pride and proof of talent in his/her capacity to reproduce identically the same shapes (e.g. Arcelin-Pradelle, Laubenheimer 1983, 131). This way of thinking clearly applies to Attic potters, and their proven ability to reproduce exactly the same shapes (and sizes, if necessary) was demonstrated by M. Langner in a seminal study of late red-figured Attic pottery from the potter's perspective (Langner 2013). It is also our opinion that we should work with the actual profile of a vase without trying to 'correct' it, as proposed by Mackay. When different craftsmen might

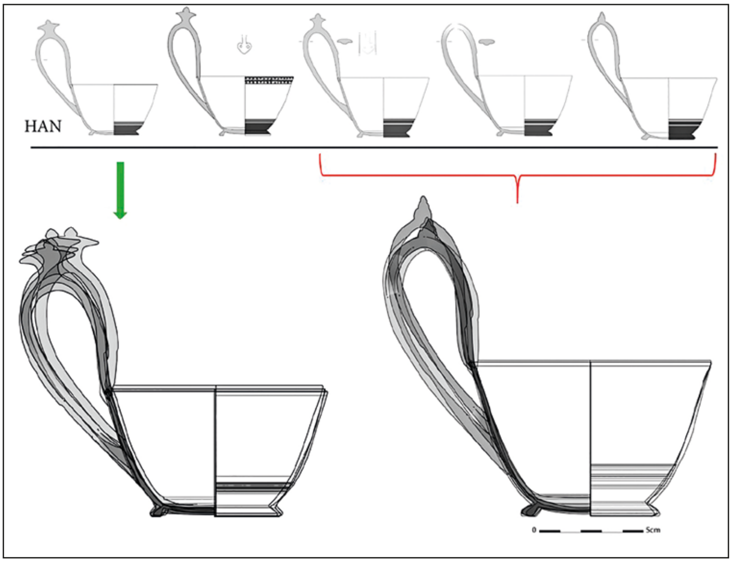

Fig. 2 – Serialization of potter han's work. Above: five chronological variants. Below left: envelope of the first variant. Below-right: envelope of variants 3-5.

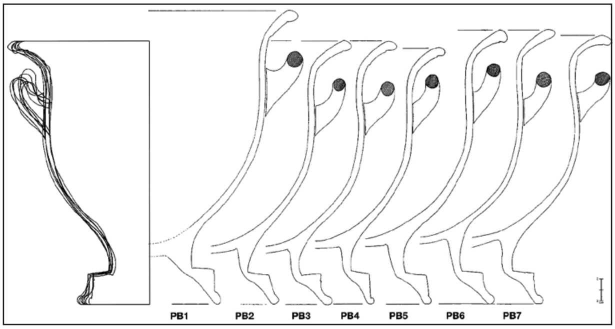

Fig. 3 – After Langner 2013, 138, fig. 13. Comparison of the profiles of various bell kraters made by one potter.

be at work, it is particularly important to stick to the physical reality – and therefore imperfections and variations – of every single piece. In fact, while some potters like Exekias were able to approach perfection, others did not: and this is where and how we find them (e.g. Euwe 1996, 70-71; Tonglet 2018, 149, fig. 52c, 180-181, fig. 57). Inconstancy and imperfections can be a potter's mark.

Finally, it is important to note one capital contribution of Mackay's work to the field of Greek pottery studies: bringing the drawings of various vases on the same vertical axis (Fig. 1). Comparisons and identification of variations are deeply eased by the graphical superposition of these images. This technique, called 'envelope' was theorized in another archaeological field (Delft pottery) by C. Orton in the 1980s (Orton 1987). While this serialization by superposition was followed by some scholars like Tonglet (Fig. 2, below), other researchers, e.g. Jubier-Galinier (1999; 2003) and Algrain (2014) continued to use the serialization by juxtaposition (Fig. 2, above). In his above-mentioned work, Langner (2013) proposed a most interesting visualization of profile comparisons: his figures show both an envelope presenting the left profiles of different vases reduced to the same height and, on the other side of the axis, the right profiles of these same vases presented side by side in their actual scale (Fig. 3). This might be the best visual presentation for vases of large sizes (containers), as opposed to smaller drinking or perfume vessels that do not need to be systematically reduced to the same height.

One last important matter must be evoked before closing this very brief synthesis: the importance of secondary decoration, i.e. the scheme of black lines, bands and ornamental patterns framing the main figured decoration and sometimes decorating the foot and handle(s). This topic will be developed below but, we must already stress the significant role played by Dutch scholars – several monographs published in the *Allard Pierson Series* of

Amsterdam (Tonglet 2018, 22 note 60 for a bibliography) – in the study of these elements in combination with the analysis of potters' work. Among the works of the 'Dutch School', H.A.G. Brijder's books on Komast and Siana cups are illustrated by plates presenting the drawn cup-profiles combined with their secondary ornamentation (e.g. Brijder 1983, one of the earliest). It is our opinion that every study of Greek shapes and potters should provide a similar illustrative apparatus.

3. Further methodological developments in Brussels

At the Université libre de Bruxelles (CReA-Patrimoine), the interest in shape studies was triggered by research programs about the distribution, production and uses of ancient pottery in the Mediterranean world (Tsingarida 2009; Tsingarida, Viviers 2013). The study of shapes, contexts and markets shed new light on cultural interactions between Attica and other regions such as Eastern Greece, the Near East, Egypt and Etruria. It also highlighted a need for a deeper understanding of the potters' practices and their attitude towards outside influences (e.g. Tsingarida 2008a; 2008b). In this framework, two monographs, written by the authors of the present paper, offered solid results: a book on the Attic *alabastron* – a perfume container the shape of which originated in Egypt – published by Algrain in 2014, and two volumes on Attic *kyathoi* and their Etruscan models, published in 2018 by Tonglet. In the line of previous works on shapes, and with the conscious desire *to hold the painters at arm's length*, those two books focused on a shape rather than on a specific painter or group.

The methodology consists of three stages: shape study, analysis of the secondary decoration and re-evaluation of Beazley's (and his followers') stylistic groupings. In practice, these three stages do not always follow each other in that order. Researchers must often juggle between them, going back and forth. If the purpose of the corpus is to study the work of potters, scholars cannot of course disregard the broad chronological classification of Attic vases and previous attribution works: they can start the morphological study within stylistic groups but they must move beyond this. Stylistic attributions might be a starting point for initial morphological groupings. However, in the early stages of research, they should not influence researchers nor discourage them to link or isolate vases on morphological grounds.

3.1 *Setting aside the main figured decoration and organizing series*

An extensive study of ancient shape requires numerous drawings. As we will see later, each drawing must include not only the profile but also the decorative scheme of the vase. When studying a potter's work, we soon try to define typological criteria to distinguish one potter from another and to group vases within the same workshop. The most straightforward method is the serialization of vase profiles. Serialization by juxtaposition of drawings (Fig. 2, above) must anticipate any work on 'envelopes' (e.g. serialization by superposition, *supra*; Fig. 2, below), which can be an additional step in the process. Serialization helps to determine morphological criteria which are specific to each potter. Obviously, these criteria will be more similar between potters who work in the same workshop and who often collaborate than between potters from different workshops. Particular attention must be given to the:

– General proportions of the body.
– Height of the vase, since for the same shape, a potter can work with identical quantities of clay.
– Width of the body and the lip: since the potter is looking down when throwing a vase s/he can therefore appreciate its diameter and that of its lip easily, which is why diameters are often more standardized than heights on the same shape.
– Profile of the foot and the lip.
– Position and shape of handles/lugs.
– Plastic decoration, if present, adds important clues when a same mould or manual shaping technique is used on different vases.
– Recurrences in the decorative scheme: position and type of secondary decoration framing the figured area.

After a first classification of the drawings, morphological groups can be enlarged to include vases for which only photographs are available. The advantage of the serialization process is that, thanks to drawings (and photographs), vases that are not stylistically attributed may be regrouped on the basis of morphological criteria. It is important to compare the profiles that have been attributed to the same painter or group, by juxtaposing (series), then – if needed – by superposing (envelope) them. This first comparison can confirm attributions based on style as well as exclude wrongly attributed vases.

3.2 *Secondary decoration*

While the figured decoration is not included in the drawing, the profile must clearly show the secondary decoration, made of different kinds of black bands and lines, floral friezes or geometric patterns, that frame the main figured decoration. Structuring the decorative scheme of the vase was likely to be the work of the potter: black lines and bands were traced while the vase was turning on the wheel (Mertens 2006, 186). The secondary decoration also includes the way the handles are painted (outside face or entirely) or the bands and circles decorating the outside parts and underfoot of cups. All these are often specific to a painter or a workshop.

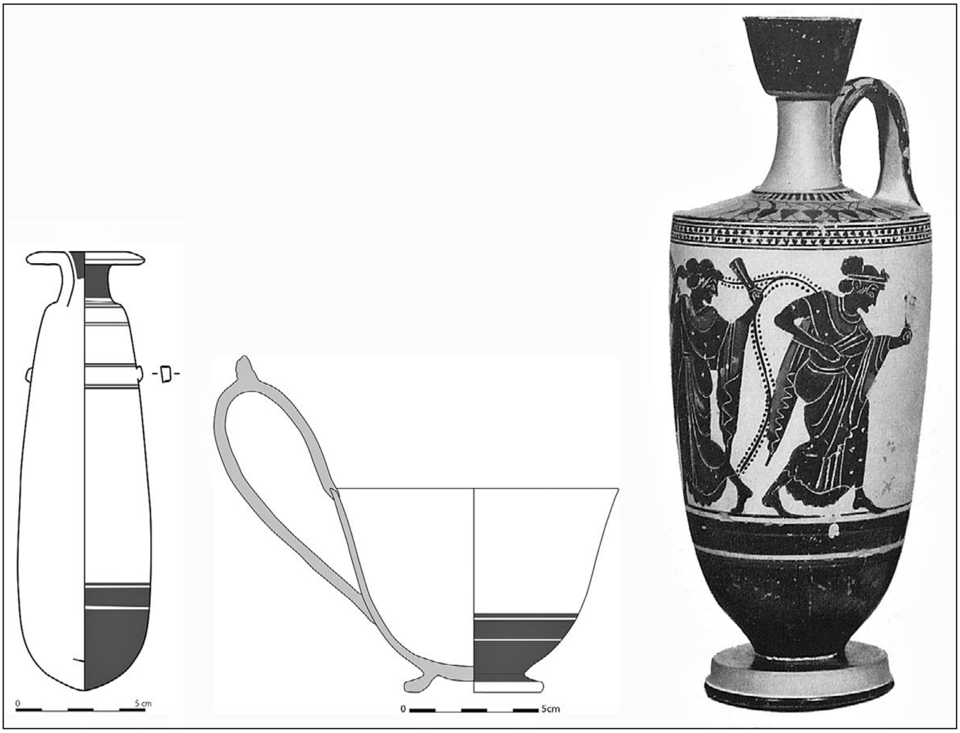

Fig. 4 – The workshop of the Sappho-Diosphos potter-painters. Left: *alabastron* attributed to the Diosphos potter-painter (Algrain 2014, cat. dio 11); centre: *kyathos* attributed to a potter of the workshop (Tonglet 2018, cat. oxf.10); *lekythos* attributed to the Sappho potter-painter (Zurich, private collection).

Let us turn back to the case of the Sappho and Diosphos workshop, which – as proved by Jubier-Galinier (e.g. 1999; 2003) – was eventually based on two craftsmen, two potter-painters, working side by side, who were both potting and painting their own vases (and not two painters with one potter, as Beazley previously suggested). The two potters-painters used mostly the same secondary decoration on their *alabastra*, decorating the upper part of the vases with a decorative frieze located on the shoulder and separated from the main decoration by two or three black lines including one that is sometimes quite wide. The decorative pattern on the shoulder usually consists of an ivy branch with small leaves. The lower secondary decoration is generally made up of a thin black line, a black band and a black bottom (Fig. 4). These different elements are separated by two reserved lines, a configuration that will occur repeatedly on the Diosphos potter-painter's *alabastra*. Regarding the Sappho potter-painter's work, the organization of the lower secondary decoration is not limited to his *alabastra* since it is identical not only on his *lekythoi* (Haspels 1936, 101; Algrain 2014, 98) but also on the *kyathoi* recently attributed to the workshop (Tonglet 2014, 10). The organization of the secondary decoration, despite possible variants, is therefore specific to one craftsman and is identified on different types of vases that he decorates. Among the production of the Sappho-Diosphos workshop, morphological similarities clearly connected the bottom parts of *kyathoi* and *lekythoi*, as on Fig. 4, raising new problems on the difficult attribution of different shapes to one potter (Tonglet 2014, 9).

3.3 *Returning to the figured decoration*

Serialization is not complete until the painter's work has been considered. The vase is an entity comprising both shape and decoration: all its elements must be taken into account to justify an attribution. Besides stylistic attribution, one must assess the general organization scheme of the figured decoration. For instance, Attic *kyathoi* were sometimes decorated with large eyes (of different types), with or without figures facing the handle, with or without ivy or vine patterns (with different recurring types). These schemes are consistent with morphological variants and secondary decoration and help to classify stylistically unattributed vases within a workshop.

The process must then be completed with a re-evaluation of the stylistic classifications of the painted work, as proposed by Beazley and his followers, through the prism of the potters' work. This fundamental step results in the groupings of associated potters and painters (workshops). The basic stylistic groups known for *kyathoi* and *alabastra* were thus reorganized with new attributions/exclusions and new connections between workshops. Obviously, as for the figured decoration, not all vases – and especially fragments – can be attributed to a potter, or even to a workshop, but cross-checking stylistic and morphological attributions may help reduce the bulk of unclassified vases. In the case of *alabastra*, for instance, Algrain was able to identify a group of vases which were probably the work of the same potter (*Potter of the checkered alabastra*) and which had not been grouped together previously on stylistic bases because of hasty and dispersed attributions (Algrain 2014, 127-132).

This aspect of our investigation provided a better understanding of the workshops' organization, and we were able to confirm and develop theories made by other scholars on other shapes. This was the case for the Sappho-Diosphos, then Haimon, workshop, completing the studies of its *lekythoi* by Jubier-Galinier, with its *alabastra* and *kyathoi* (Algrain, 2014, 95-113; Tonglet 2014; 2018, 176-233). These combined studies demonstrate that pre-existing stylistic attributions made after Haspels and Beazley for such late black-figure workshops, especially to the Haimon Painter, were anarchic and should be reassessed (Algrain 2014, 111-113; Jubier-Galinier 2016).

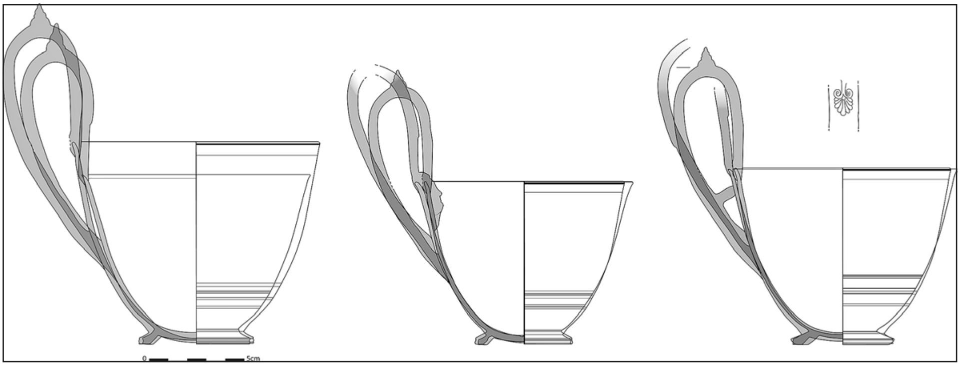

Fig. 5 – Comparisons of potters HAI and BRU. Left: envelope grouping *kyathoi* made by potters BRU (the tall one) and HAI1, normal scale. Centre: envelope grouping *kyathoi* made by potters BRU (the tall one) and HAI1 proportionally brought to the same height. Right: envelope grouping *kyathoi* made by potters BRU (the tall one) and HAI2 proportionally brought to the same height.

Indeed, the Haimon Painter had become a sort of 'label' for most late 'poorly' painted black-figured vases.

In a few cases, the confrontation of Beazley's workshop organization, based on painted style, with new morphologic classifications, led to stunning reconsiderations. Here is one example regarding the Haimon Painter and his Group. The *kyathoi* of this workshop were mainly attributed to one potter, conventionally named HAI (for 'Haimon'). The characteristics of these *kyathoi* show that this potter HAI previously worked in another workshop with another group of painters. Therefore, in this first workshop, we named him HAI1, and in the Haimonian workshop, we named him HAI2. He was a good craftsman; his vases are large, fine and balanced; the black glaze is of excellent quality and the secondary decoration is applied with care. This contrasts with the 'bad reputation' of the Haimonian painters and their sketchy figured style. In his first workshop – when he is HAI1 – there is also a limited group of seven red-figured large *kyathoi*. These vases were attributed to Onesimos, the Oinophile and the Brygos Painters and were thrown by a single potter, conventionally called BRU (for the example in Brussels). Thanks to the fine comparison of the envelope method, we could safely identify this potter BRU as potter HAI1-2 (Tonglet 2018, 182-183, 242). Like Mackay, we brought proportionally the drawn profile of a big BRU *kyathos* to the height of several HAI1-2 *kyathoi*. The envelopes of these manipulations speak for themselves and confirm this identification (Fig. 5). Without the morphological study, who would have connected a craftsman from the Haimon Painter's workshop with good red-figure cup-painters like the Brygos Painter? Thus, if late black-figure is often neglected, a very good potter actually worked in the Haimon Painter's workshop (HAI/BRU could even have been the Haimon Painter). Aesthetic judgement by modern scholars may blur our understanding of the actual organization and aims of ancient workshops and mask the mobility and career trajectories of their potters.

4. Conclusions: the potter's workshop and beyond

The benefits of morphological studies are manifold. They offer valuable information about the vase-making operating chain, some of which may lead to identify specific characteristics of a potter. For instance, most of the *alabastra* potted by the potter Pasiades present the morphological peculiarity of having a pointed and thick-walled bottom, which is probably due to the technique he used. Indeed, there were at least two different ways of making an *alabastron*. The first, often used by Pasiades, consisted in throwing the vase *from bottom to top*, with a thick-walled flat bottom on the wheel. The vase was made in one piece and after a period of drying, the potter scraped the excess clay from the bottom to give it a rounded or pointed shape (Schreiber 1999, 69-70). This technique explains why the bottom of vases in this group have a very thick wall and are slightly pointed (Fig. 6). As the lip is made last, the variation of the excess of clay left to make the vase explains

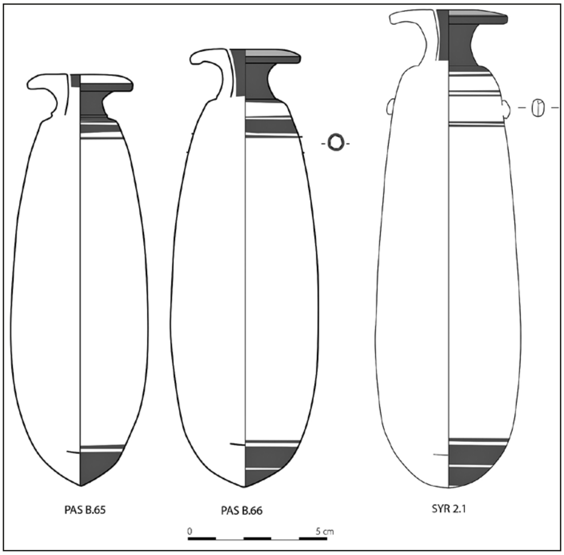

Fig. 6 – Profiles of two *alabastra* (left) attributed to the potter Pasiades and one *alabastron* attributed to the potter Syriskos 2 (right). Drawings by Algrain, including secondary decoration.

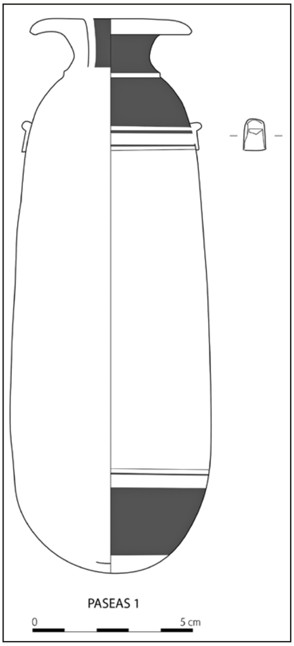

Fig. 7 – Profile of an *alabastron* made by the Paseas potter with a thin-walled bottom (Algrain 2014, cat. PASEAS 1).

why we may find a wide range of shapes and lip widths in the production of a single potter. The second technique, which Algrain witnessed in a potter's workshop in Tarragona in 2007, was used to make vases with a thin bottom and consisted in throwing the vase in one piece but upside down, *from the lip to the bottom*. The bottom was gradually rounded and closed. The bottom wall had thus the same thickness as the body. In this case, we can notice that the shape of the lip has less significant variations within the work of the same potter (Fig. 7; Noble 1965, 25-26). As most of the Attic *alabastra* were potted upside down, Pasiades' technique is one of the strong criteria to attribute vases either to him or his workshop (Algrain 2014, 68-73).

Our approach, combining morphological and stylistic criteria with schemes in the secondary decoration and figured scenes, led to the elaboration of a constellation of recurring characteristics which we organized as systems (for each potter and workshop). Indeed, simple elements found on small *kyathoi* fragments – the way a handle is painted, the shape of a plastic element, the underside of a foot – sometimes suffice to attribute the fragments to a workshop, or even to a potter. The method is thus useful in the archaeological field or in museums' shard collections and helps to refine relative chronology.

Morphological studies may also help us better understand the organization of a workshop by identifying different hands at work, although the method has its limits. As the study of the painters has shown, it is sometimes difficult to trace the career of a potter on a series of vases. Some potters are very consistent with their work while others introduce over a period of time a lot of variations on the same shape. Thus, the main difficulty is not to distinguish the production of different workshops, but to determine the number of potters at work in the same workshop. In several workshops, Algrain has highlighted the existence of a large group of *alabastra* which can be attributed to a single potter, and one or more variants, which were usually attributed to one or more potters. For example, the potter Pasiades made many *alabastra* for the Syriskos Painter. Within the same workshop, a few vases have morphological characteristics that differ too significantly from the vases potted by Pasiades to be attributed with certainty. They were therefore attributed to a second and a third potter, conventionally called the potters of Syriskos 1 and 2 (Fig. 6). However, it is quite possible that these two variations are in fact the work of Pasiades, at a later stage of his career, and that we cannot recognize it because our vision of his work is inherently fragmentary (Algrain 2014, 85-90).

Furthermore, shape studies of *alabastra* showed that 'workshop units' – a group of potters and painters working side by side during the same period – numbered two to three potters. As is the case with Beazley's groups of painters, which include followers and pupils, it is impossible to demonstrate in all certainty that this estimate corresponds to what really occurred in Athenian workshops of the late Archaic period. Nevertheless, it can serve as a basis to reconsider the organization of Athenian workshops. The very notions of 'painter', 'potter', 'workshop' and 'time' ('time unit') and the way we want to define these notions deserve further theoretical research. A first attempt was proposed elsewhere by Tonglet (2018, 93-97) and could not be developed in the present paper which focuses more on practical methodology.

Many studies focus on one painter and unconsciously place him/her at the center of a network of potters and students who collaborated with him/her. However, the study of a character like Euphronios shows that, while he started out as a painter, he ended his career as a potter (Williams 1990). The potter's position therefore seems to be more important in the hierarchical organization of the workshop. This situation is, after all, logical. Furthermore, it has already been demonstrated that the same workshops produced both figured and black-glaze pottery (Sparkes, Talcott 1970, 13-14). Undecorated pottery, easy to make and requiring much less

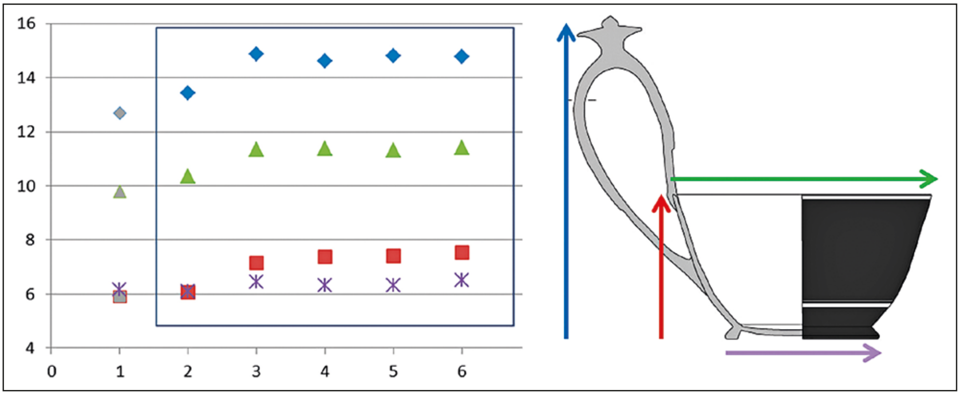

Fig. 8 – Graph comparing the averages of measurements (cm) taken on various *kyathoi* groups. Col. 1: Etruscan bucchero model; col. 2: first variant of potter HAN; col. 3-6: later variants of potter HAN.

man-hours, was arguably the most important part of a workshop's output. It is thus, in turn, important to develop studies which place the potter at the center of the workshop and of a network of collaborators (potters and painters), pupils and followers.

The interest of shape studies goes well beyond the attribution of a vase to a potter, or a better understanding of the organization of Athenian workshops. The study of shapes, even carried out on a small scale, can shed light on cultural exchanges between different regions. In the case of *kyathoi*, charting average measurements of vases (diameters of rim, cup and foot; height with and without handles; Fig. 8, right), specific to potters and workshops, helped us to visualize the arrival and impact of new Etruscan bucchero models (Fig. 8, col. 1) on the Athenian production of that shape (Fig. 8, col. 2). The first Attic series were close to the foreign model, but soon evolved into more elongated versions, quite opposed to the 'squatness' of the Etruscan pottery repertoire (Tonglet 2018, 112, 140-150, 317). Some of the earliest *kyathoi* attributed to potter 'HAN' were in fact unstable because of their heavy handle (Fig. 8, col. 2); a problem that the potter corrected in later variants (Fig. 8, col. 3-6) by lengthening the bowl (see also Fig. 2).

Furthermore, Algrain's most recent morphological study (Algrain 2020) on the Greek *kantharos* demonstrated several interesting points linked to interregional exchanges and influences. Firstly, the Etruscan *kantharos*, at the origin of the Greek *kantharos*, did not arrive first in Athens but in Boeotia and it is therefore not Athens which influenced Boeotia in the creation of this shape but the other way around. Secondly, although Boeotia's role in ceramic production is often overlooked in publications, the study showed that Boeotian potters had a lasting influence on the production of Attic *kantharoi* and their variants. These facts mean that the networks in which Boeotia was included and the distribution of its pottery during the 6th century ought to be reassessed.

Data on the operating chain, reassessment and new proposals for attributions, information on the organization of workshops, on interregional exchanges and on modes of transmission of shapes: the contributions of morphological studies are varied and multi-faceted. Considering only a small part of the figured vases from ancient Greece have been studied from this perspective, a huge field of research is thereby open for future scholars.

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ABSTRACT

While the branch of Classical studies on Greek figured pottery focused for decades on the development of Beazley's lifework – i.e. attributions of Greek vases to anonymous painters – the study of the potter's work, the organization of workshops, their networks and relative chronology (although sporadically studied by several scholars, e.g. Haspels, Bloesh, Mackay, Jubier-Galinier) remained broadly neglected and were never systematically analysed. Yet, Beazley was perfectly aware of the need to restore the potter and his/her wheel to the centre of the workshop. In this paper, we first outline the history of the research on the shapes of Greek vases and their attributions to anonymous potters, showing why this work is fundamental to understand the organization of potters' quarters (in Greece and elsewhere) and describing the most recent methodologies which we developed in this regard. In the second part, we build on case studies to move past stylistic attribution in order to show how the study of vase shapes in general can help archaeologists understand broader questions like the mechanisms of intercultural exchanges in the ancient Mediterranean.

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NEW PERSPECTIVES ON DOCUMENTING ATTIC POTTERY

1. Attic figured pottery and connoisseurship: 'instruction for use'

This paper aims to show how new technologies, and particularly 3D modelling, can be applied in the study of Attic figured pottery. Their use allows a better recording of this kind of items, enhancing their potential for interpretation. It is well known that Attic figured pottery is a valuable tool to interpret archaeological contexts, especially when it is found in a primary deposit or in a closed context.

This is primarily due to the intrinsic dating value of this type of finds, often enclosed within a narrow chronological range. We owe it to John Beazley for the opportunity to fully exploit the value of Attic figured pottery; the Scottish scholar identified hundreds of painters by adopting a Morellian stylistic approach (*ABV*, *ARV*[2]; *Para*).

Beazley's method is based on the analysis and identification of recurring stylistic elements in a painter's production (for example, the way of representing anatomical details); these elements, as a whole, make up what is defined as the painter's style (Beazley 1917; 1922; Sapirstein 2013a, 193; 2013b, 1; 2014, 175; Pace 2019, 149-150). Therefore, all vases characterized by a specific style, constitute the *corpus* of a painter.

This approach allows us to date a vase within a 25-year range, and, sometimes, with even more accuracy (up to a 5-year range).

Nonetheless, we need to pay attention in using Attic pottery as an interpretative tool; there are pitfalls and issues. Difficulties are both theoretical and practical. Beazley's work itself is problematic; many scholars have challenged and criticised some aspects, questioning its theoretical basis and its value for the scientific community (Sparkes 1996, 90-113; Arrington 2017, pp. 21-23; Pace 2019, 149-154).

In other words, connoisseurship has been accused of being a dangerous and useless practice because it drained resources from other fields that might have been much more useful in the study of the past (Arrington 2017, 21). Instead of 'wasting time' attributing a vase to a painter, it would have been best fully developing its potential as a tool for archaeological research, promoting its technological, commercial and cultural value.

After an initial phase of rejection of Beazley's work, the positive aspects of connoisseurship are now being proposed again, avoiding throwing the baby out with the bathwater (Sparkes 1996, 112). We are aware that Beazley's work, with its limits, is still useful, but it needs to be employed into a wider horizon as a stepping stone to study other aspects of the ancient world (Marconi 2004, x).

Other issues concern more 'prosaic' aspects, but are crucial to the debate on the study of Attic figured pottery. The attribution process works through comparison; to incorporate a new vase into the lists provided by Beazley, it is necessary to identify those style-defining figurative elements and provide strict correlation between them and the production of an already known painter. When there are the necessary conditions, the new vase can be added to a painter's *corpus*. The process appears pretty straightforward; but anyone who has tried to do it, can testify that it is not so easy.

One of the main problems is the difficulty of obtaining pictures that can adequately be used from a stylistic viewpoint in the already published material. Often, shape or size of a vase does not allow, when published, to get images that can be adequately analyzed from a stylistical point of view (Bursich, Pace 2017; 2018; Pace 2018; 2019, 41; 2020).

Generally, to overcome this problem, the main published *corpora*, such as the issues of *Corpus Vasorum Antiquorum*, show panoramic photos accompanied by images of details, but this solution cannot permit an analysis of the whole-figured frieze.

In this paper, we aim to illustrate how the application of new technology to Attic pottery, especially 3D modelling, can offer to the scientific community a useful tool to overcome these obstacles.

2. From theory to practice. Some case studies

As mentioned before, the shape of some objects constitutes an obstacle to get images that can be really analyzed from a stylistic point of view. Kraters, for example, are necessarily published showing a panoramic view in order to show it as a whole. These kinds of images, generally, do not allow a probative analysis of the style due to the small size of the details. Even the morphology of the vase can be a problem; the convex and rounded shoulder of a column krater distorts the subject depicted. In a calyx krater the figures are represented all around the body of the vase; a disposition impossible to reproduce with only one picture.

A calyx krater, attributed to the Group of Polygnotos, is stored at the Museo Archeologico Regionale Paolo Orsi of Syracuse; the vase is already published in an issue of the *Corpus Vasorum Antiquorum* (Arias 1941, III I, 7, pl. 11, nos. 2-3; Pace 2018, 89, no. C81, figs. 34, 116). Here, only two photographs of the main sides are published (Fig. 1). It would be ideal to unroll the whole decoration in a single picture, transporting it from the convex surface onto a flat one, translating it from three to two dimensions.

Thanks to the 3D photo-modelling process, it is possible to get a single image with the whole decoration, an image that can be really analyzed from a stylistic point of view (Pace, Bursich 2018, 550, fig. 4; Pace 2019, 193, fig. 116) (Fig. 2).

Fig. 1 – Calyx krater attributed to the Group of Polygnotos (Arias 1941, III I, 7, tav. 11, nn. 2-3).

Fig. 2 – Calyx krater attributed to the Group of Polygnotos (Pace, Bursich 2018, 550, fig. 4).

Another 'problematic' shape is the *lekythos*; its cylindrical body often provides support for a figurative frieze that develops on most of its surface. Its morphology greatly increases the difficulty of providing a complete documentation. For this reason, *lekythoi* are often published with a single photograph, providing only a partial view of the decoration. The possibility of obtaining a whole, continual representation of the decorative frieze in a single picture would be very useful, such in the case of a *lekythos* depicting the escape of Aeneas from Troy, attributed to the Edinburgh Painter and recently re-published (SR inv. 19882) (Pace 2019, 166, fig. 97) (Fig. 3).

This technique of documentation can, therefore, provide new insights to the debate on Attic pottery; new perspectives of research have stimulated some reconsiderations about certain aspects of Beazley's method, especially regarding the historical plausibility of the hundreds of *ateliers* and painters

Fig. 3 – *Lekythos* attributed to the Edinburgh Painter (Pace 2019, 166, fig. 97).

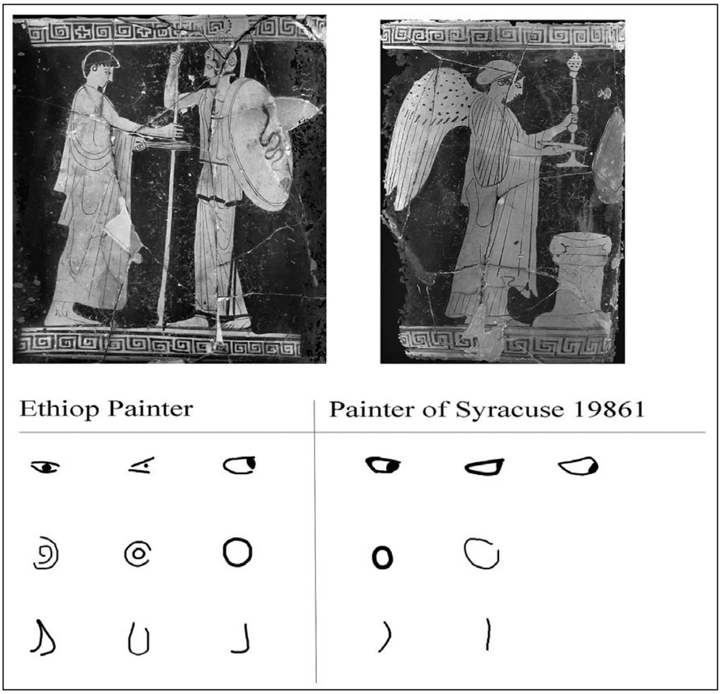

Fig. 4 – *Lekythoi* attributed to the Painter of Syracuse 19861 (Bursich, Pace 2017, fig. 5-6).

that the scholar has identified only on a stylistic basis (Sapirstein 2013b, 1; Id. 2014, 185; Bursich, Pace 2017, 82-83; 2019, 150).

Many painters have only a few objects attributed, but a low amount of attributed vases does not necessarily equate to the historical inconsistency of a painter. Random factors, such as lack of documentation, or the productive profile of the artisan – who might have been a potter-painter more heavily involved in shaping vases rather than in their decoration – can explain short attribution lists (Sapirstein 2013b, 3-9; 2020, 82-83).

Sometimes, when there are the conditions, it is possible to proceed with a 'rationalisation' of Beazley's lists, joining smaller painters to others' productions, especially when there is a clear affinity in style (Sapirstein 2014, 185; Bursich, Pace 2017, 82-83).

It is the case of the Painter of Syracuse 19861, a painter whose style recalls that of the Ethiopian Painter (*ARV*[2] 672). Only two *lekythoi*, to date, are attributed to the Painter of Syracuse 19861: they are both found in Gela, and now stored at the Museum of Syracuse (Bursich, Pace 2017; Pace 2019, 78, nos. C58-C59, figs. 28, 109-110).

The analysis of these two objects, however, shows how in reality there is no difference in style with the production of the Ethiop Painter, especially in its late phase (Fig. 4). This close stylistic relationship is not limited to anatomical details but also concerns the space in which the figures are inserted. What is, then, the reason that led Beazley to separate these two *lekythoi* from the rest of the Ethiop Painter production?

Since there are no other *lekythoi* attributed to the Ethiop Painter, it is reasonable to think the shape must have been the discriminating reason. Is it then possible to hypothesize that the Ethiop Painter could have collaborated occasionally with potters coming from outside from his workshop, or using internal resources (perhaps himself, being a potter-painter) to realize a batch of products specifically targeted to the Sicilian market, or more specifically for the Geloan market, where *lekythoi* were highly sought after (Bursich, Pace 2017, 83-89).

3D photo-modelling can be used, also, to better define the production profile of a painter; it is the case of a *lekythos* attributed to Nikon Painter (*ARV*[2] 651.28), coming from Gela and stored at the Museum of Syracuse (Pace 2019, 76, no. C54, figs. 27, 108) (Fig. 5).

The Nikon Painter is a minor figure within the crowded workshop of the Berlin Painter, where many important figures of the following generation were trained, for example the Achilles Painter (Oakley 1997, 99; 109). Generally speaking, the proof to attest to the existence of the student/master relationship between two painters is to identify a stylistic debt at the beginning of the career of the first and compare it with the later works of the second (Sourvinou-Inwood 1975, 108; Arrington 2017, 30-32). The analysis of the Syracuse *lekythos* proves how this relationship can be much more fluid and less schematic.

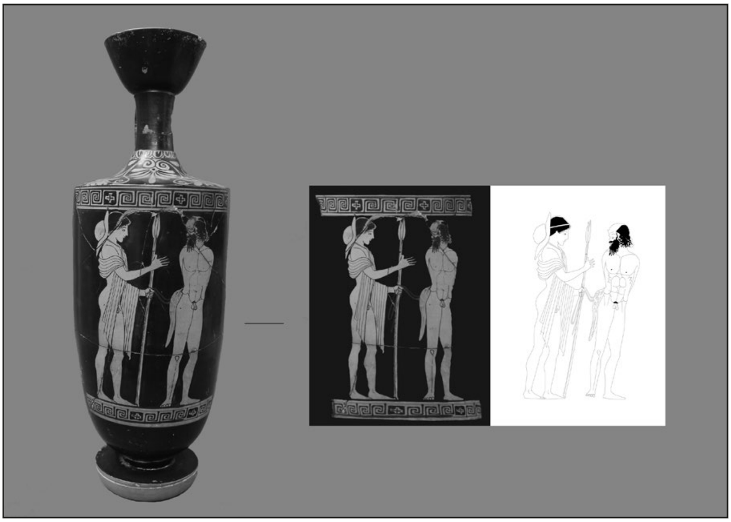

Fig. 5 – *Lekythos* attributed to the Nikon Painter (Pace 2019, 76, n. C54, figg. 27, 108).

It is important to underline how the image of the figured frieze obtained through 3D photo-modelling can be further elaborated with other graphic software applications, in order to obtain a simple drawing, thus overcoming the limitations of a traditional hand drawing (Fig. 5).

Analyzing the peculiar scene with Silenus on the Geloan *lekythos* by the Nikon Painter, it is possible to recognize a series of anatomical details that can be found in the Berlin Painter's first phase of production (Beazley 1911, 286; Kurtz 1983, 23, pl. I, no. 2; Smith 2006, 444, tab. 1); it seems therefore possible to infer that the Nikon Painter trained in his master's atelier while it was newly established. The rendering of Sileno's clavicles is peculiar; these are not welded to the handlebars but are bent forming a hook, as often happens in the early part of the production of the Berlin Painter. This solution was never again adopted in later productions of the Berlin Painter, and it allows us to attribute the Geloan *lekythos* amongst the first objects decorated by the Nikon Painter, therefore around 480 BC (Pace 2018, 96).

A.P.

3. 3D scanning for Beazley's system

As stated before, the application of 3D modelling to Attic figured pottery presents a variety of methodological advantages; firstly, the possibility to obtain an image of the figured frieze without using the traditional technique of drawing, avoiding many problems related, for example, to the vase's morphology or to the skills of the person who drew it (Bursich, Pace 2017; Pace, Bursich 2018).

At the moment, many indirect techniques of surveying are available for the creation of a three-dimensional record to scale. In the past few years one of these, photo-modelling, a technique which allows to obtain 3D models with a precision up to one millimeter, and rendered with photo-realistic texture, has come to be highly employed and widespread in the archaeological field (Arbace *et al.* 2012; Ranzuglia *et al.* 2013). There are many advantages in using these technologies: firstly, the speed of obtaining data and resulting reductions of costs: it needs only a digital camera and a personal computer. Moving from theory to practice, we show here the potential of 3D modelling by applying it to a black figure *lekythos* attributed to the Edinburgh Painter (500-475 BC). The vase was discovered in Gela at the beginning of the 20th century and is now stored at the Regional Archaeological Museum Paolo Orsi of Syracuse (inv. 19882) (Pace 2019, 57-58, no. C23) (Fig. 3).

D.B.

4. Workflow

The procedure that will be shown here, is not the only way to achieve the final outcome, but it is shown as a case study. Every phase of the workflow, synthesized in the flowchart (Fig. 6), is divided in two moments of execution: data acquisition phase (Fig. 6, point 1 - Digital Photo) and data elaboration. The whole process is carried out using only freeware or open source software (Fig. 6, points 2-5). The final output of this procedure is to obtain an image of the entire vase's figured frieze (Fig. 6, point 6 - Photo Survey).

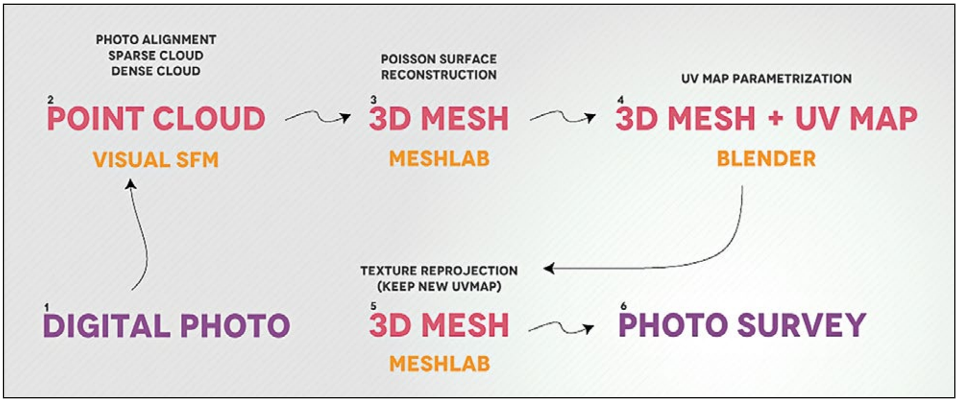

Fig. 6 – 3D modeling flowchart.

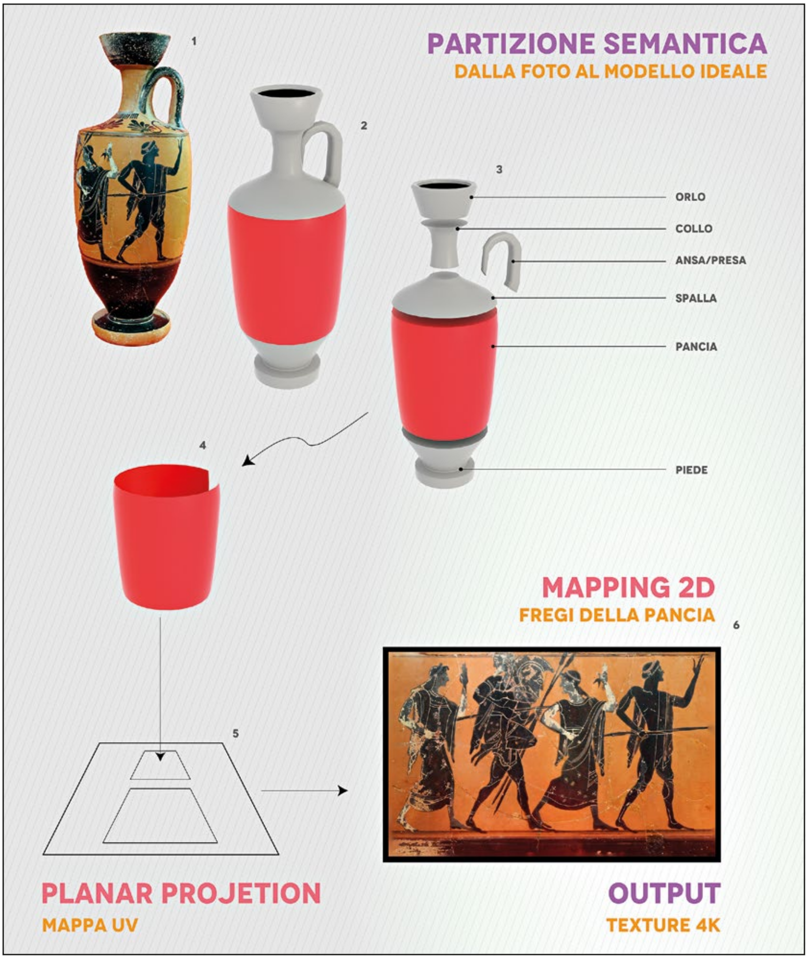

Fig. 7 – Planar projection of a *lekythos*.

With the survey, it is possible to create a 3D photorealistic model of the artefact that can be projected onto a plane surface. This procedure was already described for other applications but almost never employed for this specific kind of documentation.

It is fundamental for the correct execution of this survey to deeply ponder the semantic interpretation of the artefact (Fig. 7), which leads to ideally dividing it based on its elements; in fact, each element of the vase can be represented as a geometrical solid (cylinder, cube, etc.) and can be related to a two-dimensional projection. For example, the decoration portrayed on

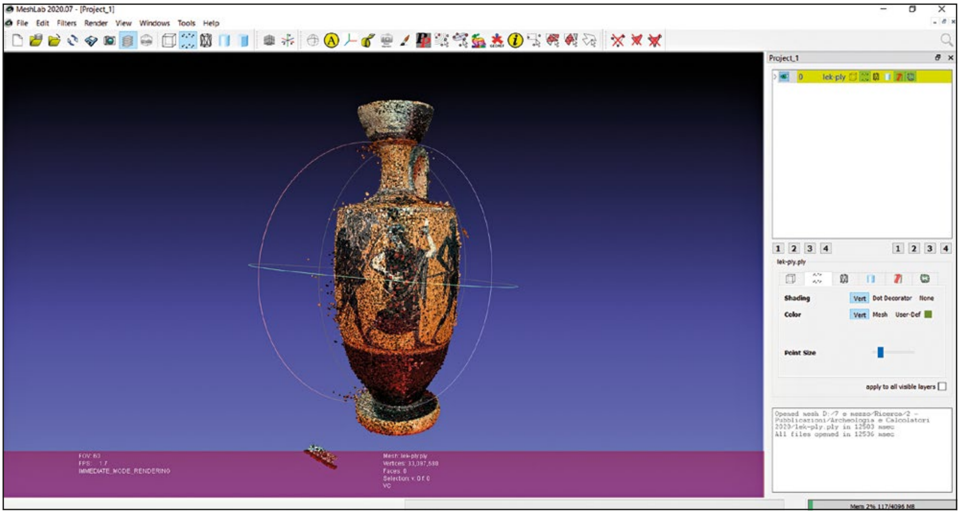

Fig. 8 – 3D modeling with Meshlab software.

the body of a *lekythos* can be translated on a plane using a planar projection, while a cylindrical projection could be employed for the accessory decoration of the shoulder (Fig. 7).

Digital imagery was imported in the photogrammetry elaboration VisualSFM software to be aligned and utilised to create a point cloud which can be exported in multiple formats (Fig. 6, Point 2 - Point Cloud). This software, unlike others, can acquire the placement within the space of each photo in real time, as well as their preview and the position from which it was taken. Once the point cloud is obtained it can be exported in .ply format, highly compatible with numerous other software and therefore very versatile for insertion in other workflows. The chosen software to elaborate the point cloud and process its 3D model was Meshlab (Fig. 8). This software can turn the point cloud into a mesh (3D shape) using the 'Poisson' filter, onto which the digital photos of the vase can be applied. Using the 'Raster Layers' function it is possible to import 2D images (raster) into a project, which can be used not only to project color data onto the 3D model, but also to save specific viewpoints or record an entire 3D photogrammetry procedure, including the pictures used to elaborate the final model.

The texture is automatically generated by Meshlab and exported to a very high resolution in graphic format (.jpg, .tga, .tiff). Since the texture creation process (UV mapping) is automated, it does not take into account the semantic approach to the 3D model previously described. To overcome this issue, it is necessary to introduce a further step to parametrise the texture based on the

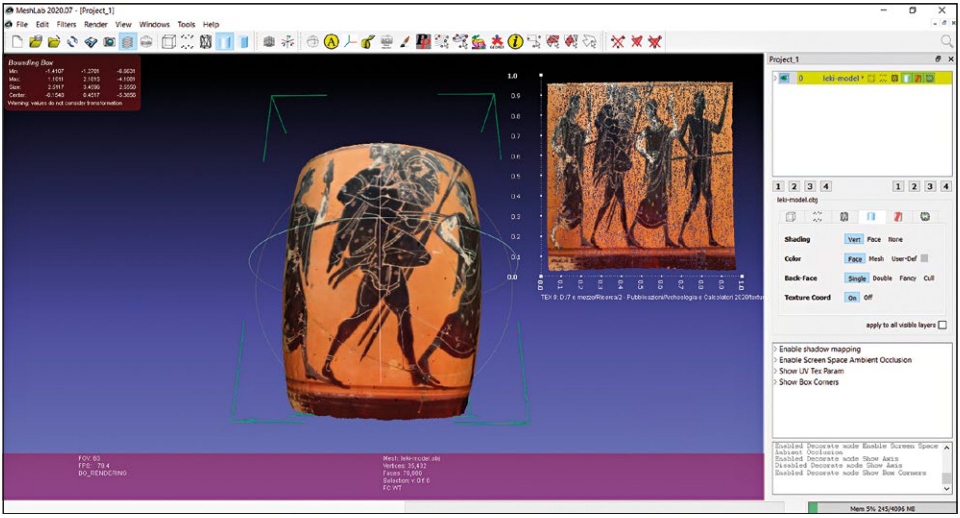

Fig. 9 – 3D modeling with Meshlab software.

morphology of each specific part of the vase. For this reason, the 3D model is subsequently exported from Meshlab and imported into Blender, a software that can modify the UV map and then be imported again into Meshlab with the new UV map (Fig. 9), making it possible to export the texture in order to obtain the required portion of the vase.

At the end of the workflow, it is possible to obtain, without employing any kind of direct survey, the graphic representation of the entire figurative apparatus, with a photo of realistic quality, without the limitations that a traditional approach would imply. It has already been suggested the vital importance of being able to provide, in publishing Attic artefacts, pictures which can really be stylistically analyzed; to overcome the limits imposed by the contemporary connoisseurship, it would, in fact, be necessary for future publications to provide adequate images. For this reason, only open source software applications have been employed, in order to allow access to this new technology to the widest possible demographic of scholars.

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ABSTRACT

The study of the Attic-figured pottery is closely connected with the 'Beazley method', which consists in the possibility of recognizing a painting 'hand' exclusively based on the style of the work; the Beazley method, despite having suffered some criticism, is still considered substantially valid. The need to have images which can be analyzed from a stylistic point of view, has suggested to combine the use of some open-source programs of 3D photogrammetry (such as VisualSFM and Meshlab) and 3D modeling (such as Blender), in order to shift the figured frieze from the pot to paper, avoiding the limitations associated with traditional direct drawing.

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THE REDISCOVERY OF COLORS AT *KAINUA*-MARZABOTTO

The city of *Kainua* (Marzabotto) near Bologna, which was inhabited between the end of the 6th century BC and the beginning of the 4th century BC, is one of the most important and best-preserved Etruscan centers in the Po Valley. During the excavations that took place between 2013 and 2019, the University of Bologna[1] team discovered a Tuscan temple consecrated to *Uni* (Roman *Iuno*) and dated between the end of the 6th and the beginning of the 5th century BC (Garagnani, Gaucci, Govi 2016; Garagnani, Gaucci, Gruška 2016; Govi 2017). In the areas located to the E and to the N of the temple (Fig. 1), masses of rare red and blue pigments (Fig. 2) have been found (Baraldi, Natalucci, Rossi 2017), probably inside the sacred *temenos*. In the 2015-2019 campaigns, around 27 samples of blue and red pigments were collected. Because they were discovered together with production scraps, it is likely they came from a nearby production area (Govi 2017, 163). Moreover, it is interesting to note that similar findings occurred also in other sacred contexts in Etruria, such as the sanctuaries of Gravisca (Torelli 1971, 299; Bordignon *et al*. 2007, 32-33), Vigna Parrocchiale in *Caere* (Bellelli 2001, 130; Trojsi 2001, 131), and *Pyrgi* (Melis 1970, 84, note 3), probably because those pigments were used to decorate the architectural terracottas of the temples. In particular, the finding of a pyx, which contained remains of blue pigment (Mattioli in press), finds comparison with two bucchero-ware bowls with Egyptian blue traces from Vigna Parrocchiale at *Caere* (Cristofani 2003, 123-126; Guidi, Trojsi 2003, 260-265).

The archaeometric analysis, carried out by Professor Pietro Baraldi (Università di Modena e Reggio Emilia), confirmed the composition of those pigments as red ochre and Egyptian blue (Baraldi, Natalucci, Rossi 2017). The colors previously attested in the Etruscan Po Valley were only black, white and red (Baraldi 2011; Rossi 2011); this discovery has thus increased our knowledge of the color palette that was used in this period. Therefore, the aim of this study has been to investigate the rediscovered polychromy and the use of Egyptian blue pigment on some architectural terracottas conserved in the National Etruscan Museum Pompeo Aria of Marzabotto. The Visible-Induced Luminescence technique (VIL; Verri 2009) has been applied by Dr. Andrea Rossi (Diar, Modena), while Prof. P. Baraldi has examined samples from

[1] I would like to thank Professor E. Govi for the chance to study these unpublished materials from the excavation of *Uni*'s temple; the Soprintendenza Archeologia dell'Emilia Romagna, particularly Dr. P. Desantis and Dr. T. Trocchi, for the authorisation to study the materials in the museum and in the storage rooms; Professor P. Baraldi and Dr. A. Rossi who did the archaeometric analyses.

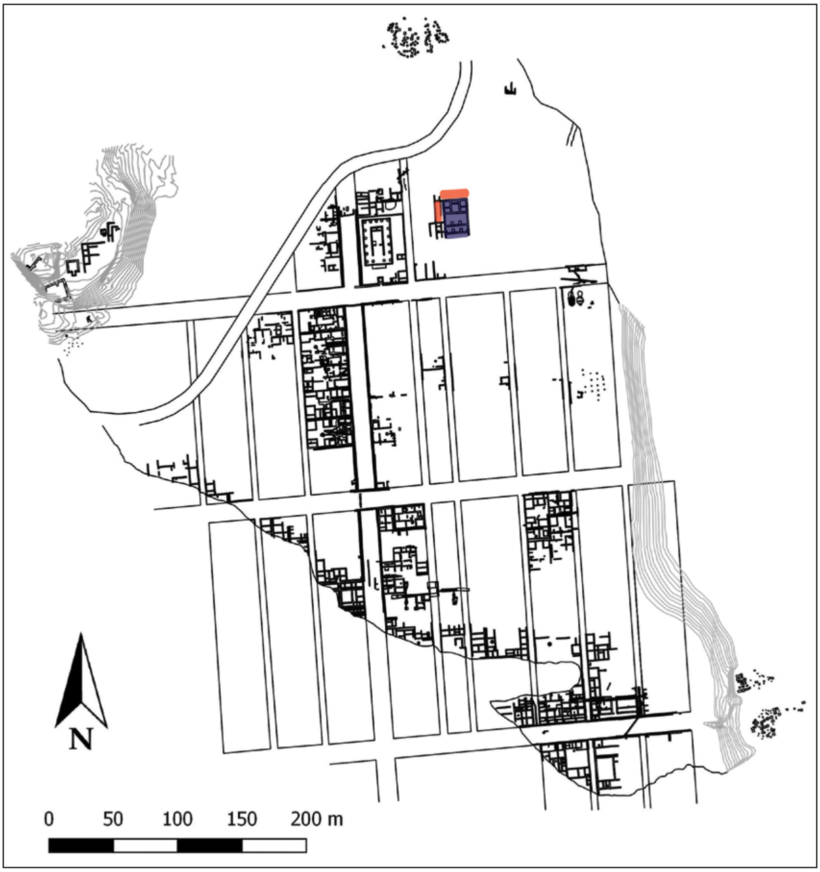

Fig. 1 – Map of the city of *Kainua*-Marzabotto with the placement of the temple of *Uni* and the zones (striped areas) where pigments were found (picture M. Natalucci).

painted tiles with XRF, FT-IR, and micro-Raman[2]. The analyses confirmed that the tri-color decoration is the most applied in Marzabotto. Indeed, black, white and red were detected by means of a Celestron microscope on the palm-shaped antefixes of the temple of *Uni* (Garagnani, Gaucci, Govi 2016, 259,

[2] The VIL technique detects and maps the presence of the Egyptian blue pigment, exploiting its property of absorbing visible radiation and reemitting it as infrared radiation. The X-Ray Fluorescence spectroscopy is a non-invasive technique that identifies and quantifies the elements of the material analysed. The Fourier transform infrared spectroscopy provides information about the molecular spectrum that reveals the presence of synthetic and organic materials in the sample. It is useful to identify the mineral salts and the organic binders. Lastly, the Raman spectroscopy is a technique that identifies the chemical and crystallographic characterisation of each granule in a mixture. Further information about the archaeometric analysis can be found in Baraldi *et al.* 2017.

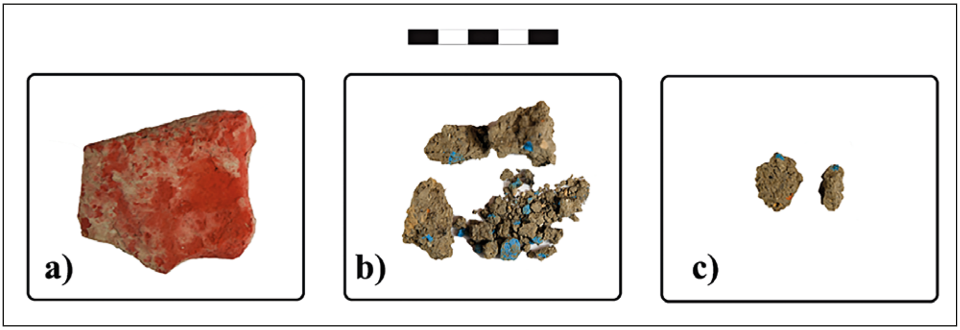

Fig. 2 – Some of the new pigments found out during the 2017 excavation: a) US 1230, inv. 2017/1019; b) US 1213, inv. 2017/2475; c) US 1213, inv. 2017/2498 (picture M. Natalucci).

Fig. 3 – Palm-shaped antefix of the *Uni*'s temple (US 1142 inv. 2015/3451): on the left, some pictures taken with a Celestron microscope where traces of red and black pictorial layers are visible; on the right, 3D reconstruction. Scale on the picture: 10 cm (pictures P. Baraldi; reconstruction M. Natalucci).

fig. 6a; Govi 2019, 545-548, fig. 10). In the antefix inv. 2015/3451, traces of black and red pigments were visible on the palmette leaves, the volutes, and the external border. As shown by numerous analogies of other antefixes found in Marzabotto during the excavations of the 19th and 20th centuries (Bertani 1993, vol. 2, 64-81), it is possible to suppose the presence of a red stripe that runs around the external border (Fig. 3). The VIL technique did not detect the presence of Egyptian blue either on the architectural decoration of the temple of *Tinia* (Sassatelli, Govi 2005, 35-36), or on the roof tiles of the well in the center of the *Plateia* D (Sassatelli 1985, 158-160), or on a well curb decorated with dolphins and waves (inv. 568; see Sassatelli 1985, 160-161; 1991, 182). A most sophisticated polychromy characterized some flat shingles, found out in the 19th century and nowadays exposed in the National Museum of Marzabotto. These shingles, together with semi-cylindrical cover-tiles, assembled a mixed Laconic-Corinthian roof that is

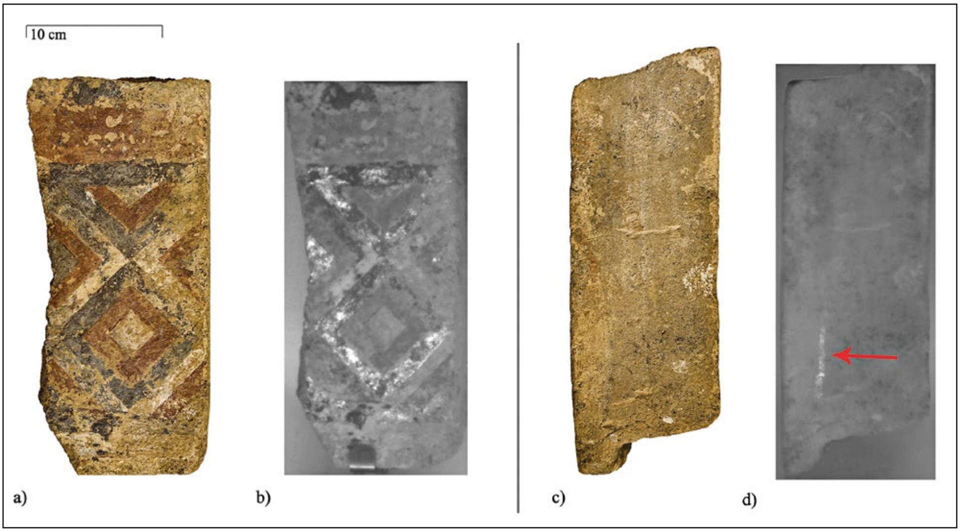

Fig. 4 – Tile fragment inv. 606. Lower surface and external surface of the raised border with a vertical line in Egyptian blue: a-c) reflected visible light; b-d) VIS-induced luminescence, under excitation from a Philips TLD lamp (pictures M. Natalucci and A. Rossi).

very common in the Marzabotto buildings (Gruška *et al.* 2017, 167). In particular, the tiles with a diagonal checkred pattern probably belonged to the pitched roof of the temple C on the acropolis (Vitali 2001, 50-51 and 60-62). In their painted decoration, the analysis attested the presence of red ochre, black, white and Egyptian blue. Thanks to the VIL technique, the use of the Egyptian blue in the Etruscan Po Valley has been proven for the first time, but the study allows us also to make further observations on the pattern and the technique of this decoration.

The position of the decoration and the fragment dimensions have allowed the reconstruction of the tile modules (Schifone 1967, 441, fig. 5; Bertani 1993, 165-167 and fig. 35). The eaves-tiles with nail-holes are decorated on the inferior surface along the shorter side, while the last tiles of the pitched roof present the painted pattern along the longer side and on one of the raised borders to create a sort of raked sima. The descriptions of G. Gozzadini (1865, 27, pl. 10) and E. Brizio (1889, col. 301, pl. IX) about painted tiles in a better state of conservation, found in the 19th century and nowadays lost, allow us to suppose a tile module of 84×44 cm. Indeed, it is possible to hypothesize the presence of four 11 cm-wide squares on the shorter side. Moreover, the nail-hole, that usually is placed at 2/3 of the tile length, is 28 cm far from the inferior edge. This hypothesis finds a confirmation in some flat shingles of *Tinia*'s temple that have similar dimensions of 84×47 cm (Sassatelli 2009, 332).

In the eaves-tiles, the decoration is a 28 cm-wide band, delimited by three horizontal lines (red, white, blue) along the border, and in the inner side by one blue line and a red stripe. The central area is adorned by a series of oblique squares. Each of them is composed of three inscribed squares with alternating colors. In the tile inv. 606 (Fig. 4), the squares continue on the external surface of the high raised border and they are delimited by a vertical line in Egyptian blue, not visible to the naked eye but detected by the VIL. This element highlights remarkable attention also to the non-visible details. The tiles, which were set on the facades, present the same diagonal checkered decoration along the longer side. According to the Gozzadini drawings (Gozzadini 1865, tab. 10.5), the decoration probably ended in the inner part with the same blue and red bands which, however, are not currently preserved in any fragments. D. Vitali has also recognized an example of angular tile with the decoration on both sides in a photograph of the previous Museum in Villa Aria (Vitali 2001, 62). Thanks to these elements, it is possible to suppose a decorated band that ran around the extremity of the roof along the four sides and that included the raked simas on the front and the rear of the temple (Schifone 1967, 441, fig. 5).

The presence of Egyptian blue has been detected in the fragments inv. 604, 606, 608, 609, 611, 612 and 614. The analysis has also permitted us to check the spatial distribution of the pigment on the surface (Figs. 4 and 6). The pigment is no longer visible in some areas, while in other parts its color is altered by a serious state of deterioration. The VIL shows that blue pigments were applied over a black layer, probably in order to obtain a darker blue. This technique has been detected also in other Etruscan architectural decorations that were found in Orvieto (Stopponi 1991, 1154-1155) and Vigna Parrocchiale in *Caere* (Bordignon *et al.* 2007, 33). The same procedure of superposing layers to obtain different hues is attested also in some Etruscan antefixes from *Caere* and Orvieto, currently preserved at the Ny Carlsberg Glyptotek of Copenhagen (Brøns, Hedegaard, Sargent 2016; Brøns, Sargent, Skovmøller 2016). The VIL also led to the hypothesis of different remakes and replacements of the roof decoration. Indeed, the Egyptian blue is not present in some tiles where there is just the black layer (inv. 605, 607, 610, 613, 615, 616). On the contrary, in the fragment inv. 614 blue and red are applied over a white layer and the black color is not used (Fig. 6). We can therefore suppose that the blue would have appeared lighter on this tile. Consequently, the same pattern was reproduced with different techniques, probably to substitute the old and damaged tiles in different periods.

With the high presence of calcite in the analyzed samples it can be supposed that the pigments were mixed with limewater and then they were applied by means of the fresco technique (Baraldi, Natalucci, Rossi 2017, 104; Winter 2009, 521-522). The result is a strong cohesion and a sizable thickness of the pictorial layer with a full saturation of colors.

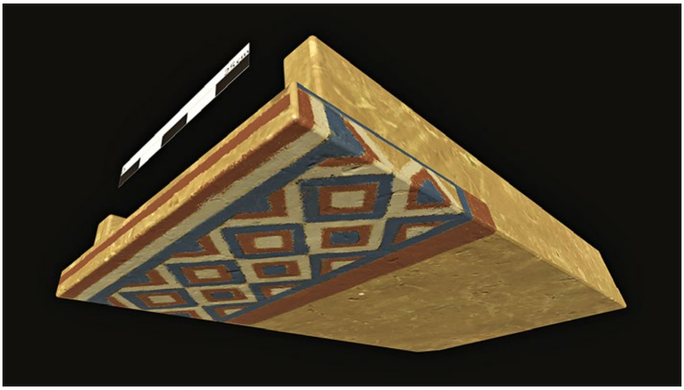

Fig. 5 – Reconstruction of the polychromy of the eaves-tile inv. 606. Scale on the picture: 25 cm (reconstruction M. Natalucci).

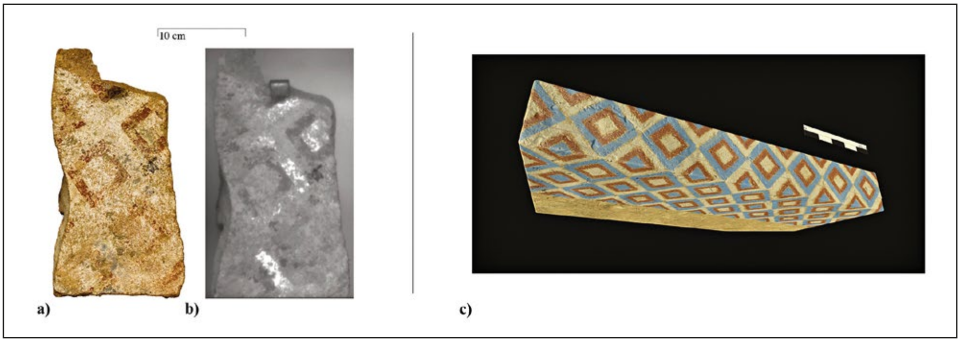

Fig. 6 – Final tile of the sloping roof inv. 614: a) reflected visible light; b) VIS-induced luminescence; c) reconstruction of the polychromy. Scale on the picture: 25 cm (pictures M. Natalucci and A. Rossi; reconstruction M. Natalucci).

At the end of the study, the program Blender 2.78c was used to shape a three-dimensional representation of the antefix of *Uni*'s temple (Fig. 3) and the painted tiles (Figs. 5 and 6). The main aims were the virtual restoration of the artefacts and the reconstruction of the ancient polychromy. The restitution of the original aspect of the architectural terracottas could be useful both for the research and for the dissemination. Indeed, 3D models can be combined to obtain a reliable proposal of the architectural decorations of the city buildings (Garagnani, Gaucci, Gruška 2016, 316). The simulation of the roof reconstruction in a digital environment leads to acquiring information about the complex system of coverage assembly and the congruence of the modules of the roof elements. In accordance with the complexity of the assembly, specialized artisans and a preliminary project could be supposed, as the finding of an engraved letter on a tile fragment demonstrates (Bertani 1993, 120, pl. XXII.12). Furthermore, the 3D models can help the visitors to appreciate the lost polychromy and to contextualize the terracotta fragments, exhibited in the Museum.

The reconstruction of the antefix was achieved with integrations of the gaps according to the symmetrical composition of the palmette. The painted tiles were shaped based on the real measurements and the reconstructive hypothesis of the module. The main difficulty has been the rendering of the original polychromy. Indeed, it is necessary to consider the method to measure colors, their alteration due to external agents, and the final restitution of the terracotta materiality. The black, white and red hue that was used in the reconstructions was obtained from pictures of the architectural decorations, calibrated by means of the ColorChecker technology. In this way, it was possible to establish that the red ochre used to paint the roof tiles and the palm-shaped antefix had the same hue as the raw pigments found during the excavation of *Uni*'s temple. Since the blue appears degraded in the tiles, its shade cannot be considered for a realistic reconstruction, so the hue of the raw Egyptian blue pigments found on the site was used. To create the texture of the painted decoration applied on Blender, Adobe Photoshop CC 2014 was used. Different layers were added on the terracotta texture and a digital brush, which leaves marks of the brush strokes as it can be seen in the tile fragments, was chosen. The realistic texturing on Blender allows us to paint the decoration pattern without covering up the terracotta texture characterized by a sizable roughness. Because of the material properties and the lime binder, the colors were rendered with a high percentage of opacity. The technique of superposing layers of different colors, detected by the archaeometric analysis, were digitally simulated. To reproduce the dark blue, a blue layer with a transparency, which was set to 50% opacity, was added on a black layer (Fig. 5). Instead, in the reconstruction of the tile inv. 614, blue and red were overlapped on a white preparatory ground, so the colors appear lighter (Fig. 6). The digital reproduction of these two different techniques proves that they determine distinct chromatic effects.

In conclusion, this research retraced all the steps of the production of an architectural decoration, from the raw pigments to the final 3D digital reconstruction. Thanks to the archaeometric analysis, the decoration technique has been detected. Moreover, the study demonstrates that in the 5th century BC, in spite of what was previously thought, the artisans of *Kainua* knew and applied the new colors and the innovative techniques coming from the Tyrrhenian Etruria. This contact is confirmed in other similarities with the sanctuaries of the southern and north-central Etruria, such as the planimetric characteristics of the temples, the decorative systems and the epigraphy of the votive texts, as E. Govi has recently highlighted (Govi 2019, 546-547). At the same time, it is clear that the polychromy in *Kainua* was not common and it was earmarked only for important buildings such as temples or sacred structures. That is because black, red and white pigments were easily produced or found in the area, while colors like Egyptian blue were probably rare and expressly imported. Finally, the reconstructions offer a better understanding of the decorative system of the city temples, which is usually found in a fragmentary state. They allow us to visualize the various chromatic results obtained with different decoration techniques, which can no longer be appreciated in the preserved fragments. Although many 3D models of Etruscan temples have been elaborated (Baglione *et al.* 2017, fig. 3), the philologically correct restitution of the architectural decorations still presents many difficulties: the fragmentary state of the finds, the lack of the complete decorative system and the different phases of redecoration could impede a complete reconstruction of a building (Taccola, Rosselli 2017, 246-247). Nowadays, numerous proposals of building reconstruction are based on 3D scans of roof elements, such as the house B and zone F of Acquarossa (Lulof, Sepers 2017). The BIM technology, recently applied for the reconstruction of the city of *Kainua* (Garagnani, Gaucci, Govi 2016; Garagnani, Gaucci, Gruška 2016), could represent a new approach to these problems. In the future, the study of the painted architectural terracottas may contribute to improve the restitution of the buildings in *Kainua*, which has already been realized in the project FIR 2013 KAINUA. *Reconstructing, Perceiving, Disseminating the Lost Reality. Transmedial Technologies for the Etruscan City of Marzabotto* (Garagnani 2017; Garagnani, Gaucci 2017).

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ABSTRACT

The city of *Kainua* (Marzabotto), inhabited between the end of the 6th century BC and the beginning of the 4th century BC, is one of the most important and best-preserved Etruscan centers. During the excavations performed by the University of Bologna in the area of the temple of *Uni*, masses of rare red ochre and Egyptian blue pigments have been found. After this discovery, a series of analyses has been carried out in order to study the polychromy of the architectural terracottas of the site. Thanks to spectroscopic analysis, it has been possible to examine the composition of the pigments that were employed. Moreover, the Visible-Induced Luminescence (VIL) technique not only confirmed the use of Egyptian blue, but also allowed to rediscover the decoration pattern of some painted tiles which belonged to one of the temples of the acropolis. This discovery is very important because the use of Egyptian blue had never been attested before in the Etruscan Po Valley. Lastly, the study has allowed to create a 3D reconstruction of some painted architectural elements, which are preserved nowadays in fragments.

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ANTEFIXES FROM MUSEO PROVINCIALE CAMPANO IN CAPUA. A PROPOSAL FOR A VIRTUAL RECONSTRUCTION

1. Introduction

This paper aims to illustrate the results of a three-dimensional reconstructive study carried out on a group of terracotta finds preserved in the Museo Provinciale Campano of Capua (Minervini 1880; Winter 1978, 27 *et seq*.; Kästner 1984, 66-74; Koch 1912; Johannowsky 1989; Winter 1993; Rescigno 1998). The materials, architectural antefixes dated between the second quarter of the 6th century and the beginning of the 5th BC, were found in a private fund located in Curti, in the province of Caserta, during archaeological excavations started in 1845 and definitively never concluded. The excavation campaign unearthed a sanctuary, today considered one of the most famous places of worship of Capua *vetus* (Rescigno 2009, 29-40).

The studies carried out since the 20th century return a reading and a classification of these materials based on the wide tradition, sedimented on the connection between an artefact and the workshop in which it was produced and whose study cannot ignore techniques and methods through which it has been produced. Specifically, these antefixes were placed on the top of the numerous buildings that populated the sanctuary and were mass-produced inside shops by *fictores,* craftsmen that were specialized in the manufacture of terracotta.

The craftsman shaped a considerable number of prototypes, primary terracotta models from which were made matrices, moulds that bore in negative the shape of the prototype and that allowed to replicate it positively for an indefinite number of times. Sometimes the handicraftsman could choose to make different matrices by combining together parts of existing prototypes, creating antefixes similar to the original model, but different for some details of the frame, of the lath or of the central field.

This modularity, that is reflected in the more or less evident formal variations of the models, constitutes the discriminating factor for the study and identification of types and series.

The classification of these materials has been developed through an alphanumeric coding system and refers to the one already organized and illustrated by Carlo Rescigno, the scientific coordinator of the present work, in his studies about the covering systems of archaic buildings (Rescigno 1998).

The system consists in assigning a code to each series of materials, composed of a first letter that identifies the formal parameters of the finding and therefore the group; then follows a four-digit numerical module in which the first digit identifies the *protome* depicted, the second digit spots the iconography and the last two pinpoint the numbering of series (Rescigno 1998).

A further element of macroscopic classification has been added to this code, following a study program conducted at the beginning of the 2000s by the Department of Humanities and Cultural Heritage (DiLBEC) of the University of Campania Luigi Vanvitelli[1], aimed at grouping together several series having one or more formal variations, but all deriving from the same prototype.

This element, identified in the 'type of series', is marked by a letter of the alphabet and circumscribes further fundamental information in order to catalog these materials: the chronological arc in which the series ascribed to that given type have been produced.

The matrix, as a consequence of a continuous use during production, was subject to a process of attrition that began to manifest through the creation of finds that presented formal details characterized by poor sharpness, until determining the actual breaking of the matrix itself. Accordingly, the need to model a new matrix arose for the craftsman; this was done by using the *surmoulage* technique: through a prototype obtained from a matrix (*patrice*), therefore not a primary model, a new mould identical in shape to the disused one was made, but with slightly reduced dimensions (Fig. 1).

Today, dimensional variations allow us to delineate a 'genealogical' sequence in the production process of the matrices, determining a further classification of finds ascribed to a given series through a grouping by generations, identified by Roman numerals (Cuomo di Caprio 2007, 223-230).

The group of antefixes that has been chosen to be examined here is that of female heads within the nimbus, consisting of about 260 items divided into 30 series, identified by the code C3000 and in turn grouped into 15 types, from letter A to Q. To each series, a minimum of 1 and a maximum of 24 occurrences have been ascribed and a maximum of two generations have been identified. The group also includes a considerable number of non-architectural destination slabs (about 40) characterized by the absence of the roof tile, for which a votive function is likely to assume. These finds have been equally ascribed a different type of series, considering the formal analogies with architectural slabs.

2. Virtual Reality and 3D reconstruction

Commonly, we tend to identify virtual representations as illusory and imaginary realities, but virtual reality has nothing to do with illusion; it is rather a form of reality that can be artificially represented by the use of a

[1] The reconnaissance and study project of the architectural materials preserved in the Museo Provinciale Campano of Capua was coordinated by Carlo Rescigno and has led to the drafting of some thesis works, such as: Esposito Palmieri L. a.a. 2002-2003, *Le antefisse arcaiche del Museo Campano di Capua. Le serie nimbate ed entro fiore di loto a testa femminile,* Seconda Università degli Studi di Napoli, Facoltà di Lettere e Filosofia, Tesi di Laurea quadriennale; Grassia A.M. a.a. 2002-2003, *Le antefisse arcaiche del Museo Campano di Capua. Le serie nimbate a maschera gorgonica,* Seconda Università degli Studi di Napoli, Facoltà di Lettere e Filosofia, Tesi di Laurea quadriennale.

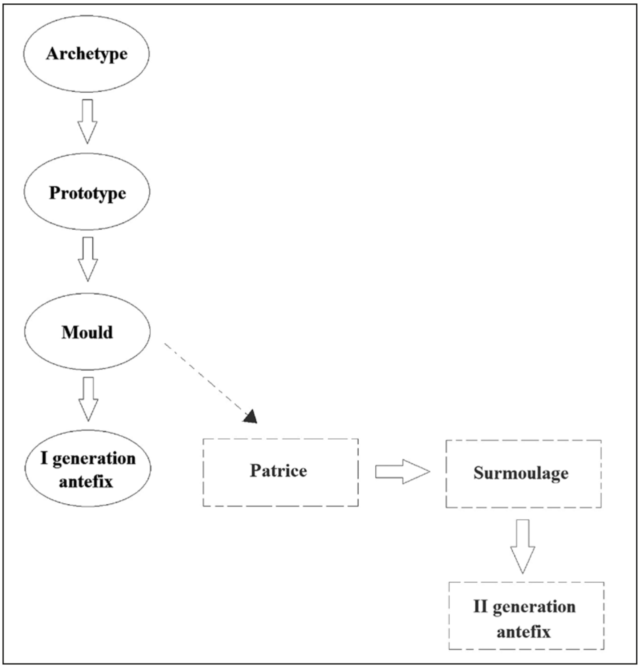

Fig. 1 – Diagram of the working process of an antefix.

computer and only through the trespassing of three physical dimensions. Far from being immaterial, it has its own consistency, made up of numerical and chromatic entities, geometric quantities and physical dimensions.

Virtual Reality in the cultural area is a method of representation complementary to Virtual Restoration, a discipline that was born in the mid-nineties with the main purpose of returning their original assets to movable or immovable property. Its aim is to optimize their accessibility and use as well as to restore values of the civilization's historical record and testimony. (Bennardi, Furferi 2007; Gabellone 2010; Limoncelli 2012).

Although every 3D restoration activity takes place in a virtual environment, it is good to remember that the methodological approach adopted by Virtual Restoring, exactly like the traditional discipline of Restoration, requires us to act on an asset in full compliance with the principles of reversibility, recognition, minimum intervention and compatibility, already codified in the Athens Charter for the Restoration of Historic Monuments, produced in 1931 (Strassoldo 2007).

When we talk about Virtual Restoration, we associate it with all those conservative interventions necessary to bring the property back to an optimal condition of readability, without necessarily intervening on gaps and *lacuna*s, except in those cases where the lack of integration unavoidably compromises the use of the property object of the restoration.

On the other hand, when, for reasons of readability and usability or even just for the purpose of facing a mere reconstructive study, it is necessary to integrate chromatic gaps or material lack to give back its formal integrity to the property. In this case, 3D reconstruction comes into play and can be framed as a micro-area of the Virtual Restoration. It is the working modality that proposes to return to the property its formal unity, through the correspondences of data deriving from graphic models acquired through digital surveys developed in Handmade Modeling modality, Procedural modality, Laser Scanning or Photomodelling (Migliari 2001).

In the case of sculptures, and more specifically of terracotta ones, that include antefixes, the 3D reconstruction allows you to make a reinstatement of missing parts that can be reconstructed through two approaches: where the find has been preserved into a fragmentary but complete state, it is possible to work by reassembling it and correcting the presence of any cracks; where instead the fragments are not sufficient to recompose the find in full, but they contain a sufficient amount of formal data, it is possible to work by reconstructing the sculpture through a series of interpolations, always considering the philological-reconstructive principles, essential to achieve a historical restoration (Vaccari 1996).

Finally, there are areas of intervention in a virtual environment that, although they do not lead to a 3D reconstruction and often not even to a properly so called intervention, they are fundamental because they are preparatory to any restorative approach: preliminary analysis of the asset and damage assessment; neither of the two operations involves the direct approach to the property.

To evaluate the entity of the work to do, it is important to execute a precise and detailed survey that can return one or more virtual models such as to guarantee an exact calculation of the real find's physical properties: mass, surface, height, width, depth and modular measurements where needed.

On the other hand, the damage assessment operation can be performed by means of a two-dimensional survey and is externalized in an analysis, expressed as a percentage, of the gaps relating to the pictorial and material surface of the artefact (Limoncelli 2011; Gabellone 2020, 107-121).

3. Antefixes with a female head within the nimbus

The case study examined here, that will be part of a larger PhD research project aimed at reconstructing the prototypes of all the groups of archaic antefixes preserved in the Museo Provinciale Campano of Capua, consists of a virtual reconstruction of the group of antefixes with a female head within the nimbus.

For taxonomic and methodological reasons, six elements articulated in three series also converge in this analysis. Two of these series belong to the group of antefixes with a female head without frame and one is associated with the group of antefixes with a female head and straight *palmette*. The first two series, F3201 and F3203, include four antefixes with a female head without a frame modeled almost all-round with a clear Dedalic type (Koch 1912; Mingazzini 1938; Johannowsky 1989, 185; Rescigno 1998, 130-132).

The other one, series C3101, has formal elements similar to the group of antefixes with a straight *palmette,* but a female head with Dedalic kind is inscribed on a leaf (Koch 1912; Rescigno 1998, 84-85).

To complete what has been said in the previous paragraphs, the modularity and seriality used by the artisans specialized in modeling these materials are the essential characteristics that contribute to the realization of 3D reconstruction, because they offer the possibility of ideally overlapping the slabs received in a fragmentary state, until a virtual formal unit composed of elements belonging to a plurality of real finds is reached.

The first phase of the work involved the beating of about 130 three-dimensional surveys, in order to obtain virtual models of the artefacts.

The main tools of the preliminary phase of survey are two: a database that organizes and makes all information relating to materials being studied easily accessible and a Laser Scanner. As already discussed in the previous paragraph, the main techniques for carrying out a three-dimensional survey of an object are Photomodelling and Laser Scanning. The second methodology of survey was used for this study (Bernardini, Rushmeier 2000, 41-62; Peloso 2005, 219-24; Bianchini 2009).

The Laser Scanning is a digital survey technique based on the principles of reverse engineering. The scanner receives the metric data of an object in the form of an input and returns a CAD model as output (Limoncelli 2012, 134-139).

Here, a laser scanner for small objects equipped with structured light has been used. Structured light is a 3D survey technique that consists in projecting horizontal and vertical beams of light on a scene to calculate its depth and other information about the surface.

The laser beam (Light Amplification by Stimulated Emission of Radiation) is fired on the object through the interpolation of a series of four white LEDs positioned around each of the three digital cameras, one of which is a color camera that allows the beam to be reflected in all directions, useful for detecting the entire surface.

The tool used here promises a margin of error between 0.01 and 0.05 mm, guarantees the simultaneous acquisition of the texture with a resolution between 50 and 200 DPI, thanks to the presence of a projector with white light pattern, that can detect objects up to 50 cm and offers the possibility to export the mesh instantly (Bartolucci 2009), without generating it from a point cloud. The significant number of scans realized was determined by the need to survey each element in two different moments: the front and back side.

This beating method proves to be decisive when, given the monochrome surface of the terracotta and the loss of pictorial film where chromatic variations existed, the tool cannot detect differences of volumes and therefore is unable to return an output. This method guarantees that each scan is quickly completed but requires more operation during data processing. In this case, it has been possible to reattach the two sides of each antefix through a non-automated function of Vxelements, the execution program of the Laser Scanner, but it is emphasized that it is possible to achieve the same results through any other 3D Modeling program.

The next step is to export the file in 3D format. Here, OBJ format has been used, the most compatible with Modeling software among all the existing formats. Once the meshes in OBJ format have been obtained, it is possible to proceed with the actual reconstruction of the prototypes.

3.1 *Reconstruction of fragmented antefixes*

Case study: prototype of the series C3220 (Type E, 525-500 BC) (Fig. 2).

The prototype was rebuilt on the basis of a very large amount of data, since 24 elements are attributed to the series in question, some of which have been preserved in their material surface in a percentage higher than 50%. Reconstruction was realized from finds models nos. 100/029, 100/015 and 100/190, which was fragmented into four mating parts and was reconstructed into a unitary model. Other examples of similar cases of elements recovered fragmented and reconstructed are nos. 100/030, 100/059, 100/199. The reattachment of the fragments was realized through a manual geometric processing technique, the Polygonal Modeling that acts through the manipulation of vertices and faces of the mesh in order to obtain complex surfaces that are then combined through Boolean unions.

All the reconstructions have been carried out exploiting the combined use of 3D Modeling programs: Maya, Rhinoceros, Meshlab and Autodesk Meshmixer (Rocchini *et al.* 2001; Limoncelli 2012, 131-139).

3.2 *Two variants of prototype reconstruction*

Case study: prototype of the series C3202 (Type C; 550-540 BC) (Fig. 3).

This case is the example of reconstruction of a series prototype that has at least two variants, that differ from each other for some details, a sign that the craftsman has used the same matrix to create the central field of all the slabs of the series, but he has modulated from time to time different matrices for laths, frames and a nimbus.

Fig. 2 – Series C3220 - Starting models and prototype reconstruction.

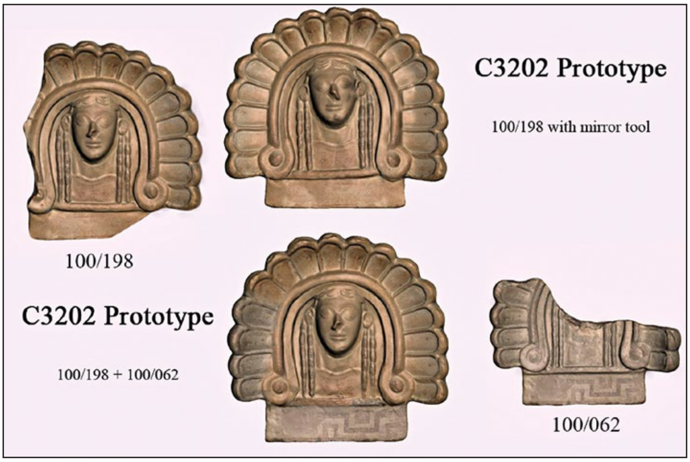

Fig. 3 – Series C3202 - Starting models and two variants of prototype reconstruction.

The first prototype reconstruction was realized starting from the union of the finds nos. 100/198 and 100/062 and has a 16-leaf nimbus and the lath obtained from the find no. 100/062, taller and wider (tot. ht. 32.5 cm; tot. w. 34 cm; ht. lath 5.6 cm; w. lath 22.7 cm); the second prototype reconstruction, on the other hand, was carried out through one of the most common

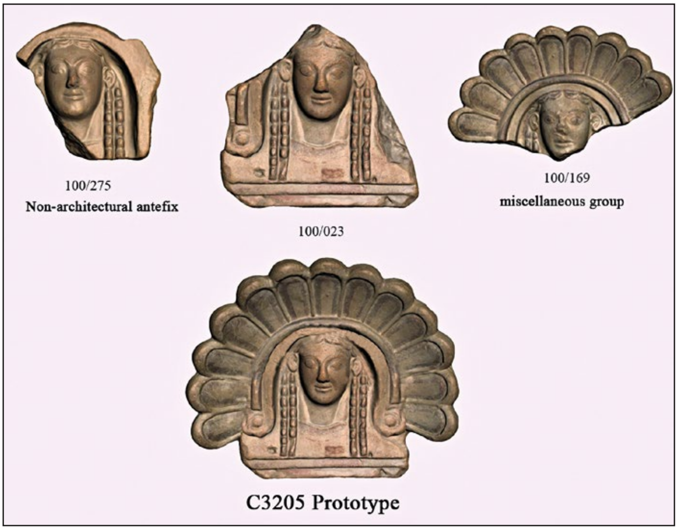

Fig. 4 – Series C3205 – Starting models and prototype reconstruction.

techniques of Polygonal Modeling, the mirroring of single find no. 100/198. Prototype has a 17-leaf nimbus and a lower and narrower lath, that determines a lower height of the entire slab (tot. ht. 31.9 cm; tot. w. 34 cm; ht. lath 5 cm; w. lath 21.7 cm).

3.3 *Reconstruction through non-architectural antefixes*

Case study: prototype of the series C3205 (Type C; 550-540 BC) (Fig. 4).

This reconstruction differs from the previous ones because it has been made through the modulation of three finds, two of which are not strictly attributable to the series C3205, but one of these is included in the group of non-architectural antefixes relating to the series C3205 and the other one is part of a miscellaneous collection of antefixes that present formal characteristics similar to the whole Type C, but, for reasons generally linked to the non-optimal state of conservation or to the small size of the fragment, it has not been possible to ascribe them exactly to a series.

3.4 *Reconstruction of II generation prototypes*

Case study: prototype of the series C3214 (Type H; 500-480 BC) (Fig. 5).

The case analyzed below, intends to illustrate the reconstruction of II generation series prototype, therefore undersized compared to the other elements ascribed to the same series that did not save sufficient formal data to reconstruct the I generation prototype.

Fig. 5 – Series C3214 – Starting model, prototype reconstruction and 3D modelling phases.

To reconstruct the *protome*, the frame and the nimbus of leaves, slab no. 100/235 was used, almost fully preserved, except for part of the lath; to rebuild it, slab no. 100/235 was modeled together with slab no. 100/064. It is emphasized that find no. 100/235 belongs to the group of non-architectural antefixes of the Type H. For this reason, the roof tile was reconstructed through the mirroring of the one saved on the back of the antefix no. 100/064.

The image (Fig. 6) illustrates an example of a generational gap that materializes in a reduction of dimensions between I and II generation slab: the ι module (distance between eyes) has a 0.6 cm size gap, while the η module (distance between the hairline and the chin) differs by 1 cm.

Another example of II generation prototype reconstruction is that of the one relating to the series C3219, reconstructed through the modeling of finds nos. 100/199 (preserved in a fragmented state and previously reconstructed) and 100/043.

Fig. 6 – I and II generation finds: comparison of models and modules.

3.5 *Partial prototype reconstruction*

Case study: prototype of series C3101 (Type B; 560-550 BC) (Fig. 7).

The case in the figure is an example of reconstruction prototypes of series that count only one occurrence, therefore there is not enough data to be able to obtain a complete formal reconstruction. On this prototype a reconstruction work was advanced just based on the data obtained from the find no. 100/038. Through the use of Polygonal Modeling tools, such as mirroring, duplication of the mesh and cutting planes, the rectangular section belt and a leaf of the nimbus were reconstructed.

Prototypes of series C3207 (Type E; 525-500 BC), series C3208 (Type E; 525-500 BC), C 3215 (Type I; end of V BC), series C3218 (Type C; 550-540 BC), series C3221 (Type E; 525-500 BC), series C 3223 (Type I; end of VI BC) (Fig. 8):

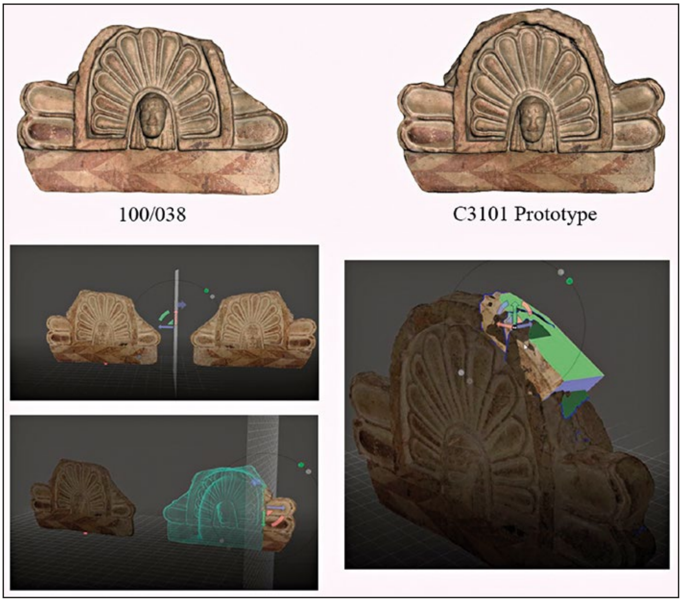

Fig. 7 – Partial prototype reconstruction and 3D modelling phases.

Fig. 8 – Prospect of examples of partially reconstructed prototypes.

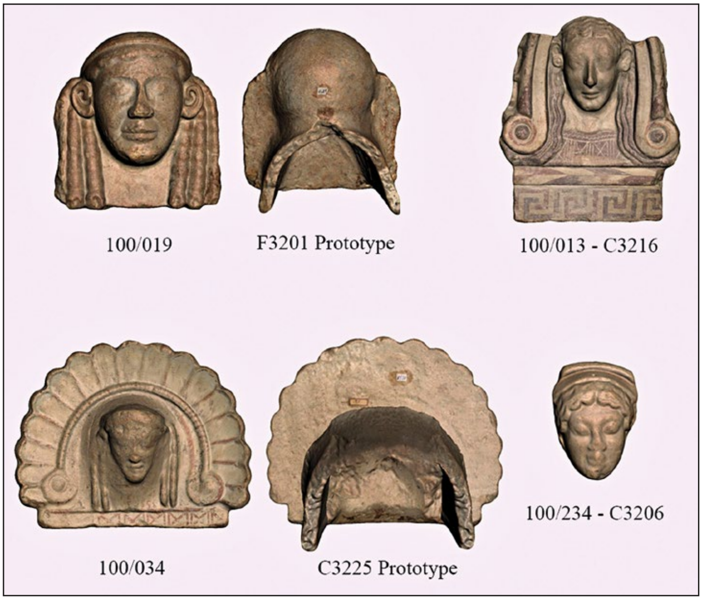

Fig. 9 – Examples of whole finds and non-reconstructable prototypes.

The image summarizes other cases of partial reconstruction of prototypes of series to whom is attributed a single find.

3.6 *Whole finds and non-reconstructable prototypes*

Case studies: prototype of series F3201 (Type A; 575-550 BC), C3225 (Type M; uncertain chronological arc), C3216 (Type I; end of VI BC), C3206 (Type D; 530 BC approx.) (Fig. 9).

The figure shows two cases of prototypes that cannot be reconstructed (no. 100/013 – series C3216 and no. 100/234 – series C3206) as they are related to series for each of which a single fragment of reduced size has been saved or, as in the case of slab no. 100/013, as they are in a conservative state that does not allow satisfactory reconstructive studies. Then, following cases of finds preserved in full, that do not require any formal reconstruction, but that can instead be used for a reconstructive work of the pictorial film, through cleaning of any accumulations of *patinas* or non-original grouting, optimization of the texture and integration of possible gaps (Limoncelli 2012, 51-89). Find no. 100/034 should also be noted, which has been saved intact except for the horseshoe-shaped roof tile, that was instead modeled based on the information obtained from roof tiles preserved intact within the same type.

4. Conclusions

The methodological approach used to develop series prototypes of these antefixes, based on analogical-comparative criteria, would seem to guarantee convincing results as it regards classes of mass-produced ceramic materials, although the work is still nearing completion and therefore remains subject to improvements and modifications.

However, it remains to be considered that this kind of production is not always characterized by criteria of absolute symmetry as it regards parts that make up the single find, which sometimes makes it necessary to create more than one reconstructive proposal for the same prototype, in order to bring with absolute certainty, among the possible hypotheses the intention of the craftsman too.

It is considerable above all other example cases, the one relating to nimbus leaves: they never appear identical in terms of width and thickness and sometimes even in odd quantities, which often makes it difficult to identify the exact number of leaves, subject to variations among the finds belonging to the same series.

Therefore, as we have already had the opportunity to analyze, even that analogical-comparative criterion existing between finds belonging to the same series, may sometimes not be present, leaving room for a variety of details that make slabs similar but not identical. In this case it is possible to resort to the realization of several reconstructive hypotheses too. The work on this group of 260 finds that are articulated into 30 series has allowed us to realize a total prototype 3D reconstruction for 10 series and to achieve a partial result for 11 prototypes[2]. About the remaining series, finds have been preserved in a far too fragmentary state of conservation (often only the female head has reached us) to be able to put forward any reconstructive hypothesis that has a scientific basis.

As already anticipated, the 3D survey of the slabs was developed by working in two different moments on the two faces of each find, which entailed the need to carry out 152 scans in order to obtain the 3D models of 76 antefixes. This mass of data, consisting of both models taken from originals and prototype 3D reconstructions, will give rise to a unitary virtual *corpus* of architectural materials preserved in the Museo Provinciale Campano of Capua.

This digital repertoire, cataloged on the basis of the methodological criteria that contribute to the study and classification of serial productions, will flow into a platform that allows the sharing of the data collected and those

[2] It is emphasized that this work will flow into a unitary study still in progress that analyzes further groups of antefixes preserved at the Museo Provinciale Campano of Capua, which makes it liable to implementations and adjustments.

obtained through 3D modeling, becoming a tool for scientific publication, knowledge, study, but also for monitoring, conservation and protection, in order to contribute to the implementation of the sector of experimentation with new forms of documentation and Cultural Heritage editions.

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ABSTRACT

The paper aims to illustrate an intervention of digital restoration carried out on different groups of antefixes coming from excavations started in 1845 in a private fund today located in Curti, near Caserta and pertaining to sacred building roofs of a sanctuary whose oldest phase is dated to the 6th century BC. Nowadays, finds are preserved in the Museo Provinciale Campano, located in Capua. Particularly, two hundred and fifty antefixes belonging to the group named 'female heads within the nimbus', have been studied, articulated into thirty different series, filed in a database created *ad hoc*, and the digital restoration of their prototypes has been completed. Issues relating to seriality and traceability of these finds to individual archetypes will be explored, features that make a faithful 3D reconstruction of a prototype possible, based on the combination of physical data of fragmented antefixes pertaining to each series. Furthermore, phases and techniques of detection and scanning of an archaeological find using a laser scanner for small objects will be particularly analyzed. It will show how to achieve a mesh from a scanning file and how to elaborate it. Lastly, processing steps necessary to the realization of a 3D restoration will be illustrated through modeling techniques and collation of different 3D scannings. These kinds of technological experimentations contribute to diversify our memory transmission modes. They offer the chance to create digital and implementable catalogs, useful for a dynamic documentation of the Archaeological Heritage, but also and above all, fundamental tools for the monitoring, conservation and fruition of analyzed *corpora*.

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CLASSICAL POTTERY IN COLLECTION: THE MEMO PROJECT AND THE RECREATION OF A 'CONTEXT'

1. Introduction: how to understand and disseminate the complexity

«At present, there is no existing science whose special interest is the combining of pieces of information […]. Every evolutionary step is an addition of information to an already existing system». This is what Gregory Bateson wrote in 1984 (Bateson 1984, 21). Today these words can be a useful tool to understand the complexity and the extent of the definition of 'virtual' and, specifically, of 'virtual archaeology', understood as experimental classification of new contexts with cognitive and connective interactions. The great communicative and experimental impact belonging to archaeology study is enhanced by the digital interfaces and their intelligibility beyond the limited space of the scientific community.

The virtual space, in an archaeological dimension, must be hierarchically contextualized in order to identify the information units onto the geometry of the models: theoretically, the models should be 'disassembled' and 'reassembled' to verify the geometry and the function.

The geometrical complexity of an object indicates something very articulate and this is the reason why, in the past, some mathematicians tried to relate the concepts of beauty, order and complexity. In particular, in 1933, the mathematician George Birkhoff (1884-1944) proposed the following formula:

$$M = \frac{C}{O}$$

where: M is the aesthetic measure, O the order and C the complexity (Birkhoff 1933; Guidi *et al*. 2010, 338).

About the same topic, in 1999 Jean-Louis Le Moigne, a specialist in theory systems and constructive epistemology, wrote (Le Moigne 1999, 196; Guidi, Russo, Beraldin 2010, 339): «The complexity of a system is not necessarily a property of such system (whether it be natural or artificial), it is rather a property of the representation currently available of such a system, described according to one or many codes (or languages), our representation of complexity transforms itself and, with it, the modalities of apprehension that we can give to ourselves. Complexity is in the code and not in the nature of things» (Le Moigne 1999, p. 196).

Complexity becomes intelligible if the observer has the tool to understand it. So, an archaeological find can be considered and studied as a complex system containing information not immediately perceptible to the observer.

The language that allows the identification of them is the result of a scientific and technological evolution that allows archaeologists to ideally break down the system for and overall and an individual morphological entities study.

The 18th and 19th centuries were characterized by the antiquarian accumulation; today, one of the archaeological challenges concerns the study of the informative communicability of the numerous objects, archaeological or presumed archaeological, which decorate the richest public or private collections from all over the world which, however, the data of their context of discovery and/or origin were lost or unknown.

The complexity is not only in the archaeological characterization but also in their study and understanding of their importance for the professional audience and the general public. This is one of the challenges of Project MemO, *The Memory of Objects. A multidisciplinary approach to the study, digitalization and value enhancement of Greek and Southern Italian pottery in Veneto* (leader partner Department of Cultural Heritage of the University of Padua, supported by the Fondazione Cassa di Risparmio di Padova e Rovigo), has decided to capture and to take on for an increase in the accessibility of the archaeological data.

E.F.

2. The MemO Project

The MemO Project is focused on the archaeological collections preserved in Veneto (Salvadori, Baggio 2017; Baggio 2019; Salvadori 2019). These collections include a rich heritage of Greek and Southern Italian pottery, of which social and cultural role is very important, with regards to ceramic studies and, simultaneously, in terms of defining our modern identity.

As a matter of fact, Venice and Veneto witnessed a very early form of Greek- and Southern Italian-vase collecting and, as these items were considered a symbol of cultural and social distinction, their presence in the collections of several Venetian notables was documented as early as the 16th century (De Paoli 2006): in Padua, in the collection of jurist Marco Mantova Benavides (*Museo di Antichità nella Padova del Cinquecento* 2013); in Venice, in the collections of the Grimani di Santa Maria Formosa family, of Apostolo Zeno, of Jacopo Contarini and Onorio Arrigoni (Favaretto 2004); in Verona, in the collection of Scipione Maffei; in Adria, in the Bocchi's collection (Wiel-Marin 2005) and in Rovigo, in the Silvestri's collection.

While the better part of these items now belongs to several European museums, another part has contributed to the formation of the Veneto Region Museums, which over the years have become 'recipients of private collections': the Museo Archeologico Nazionale di Adria has incorporated the Bocchi collection (*CVA* Italia 28, Adria Museo civico I; 65, Adria, Museo Archeologico

Nazionale II) and, in the 18th century, Andrea Vallisneri donated the Mantova Benavides collection to the Museo di Scienze Archeologiche e Arte in Palazzo Liviano, which was further enriched in the 2000s by the bequest of the Merlin and Marchetti collections, of recent formation (Menegazzi 2013; Salvadori, Baggio 2017).

Starting from this situation, the great patrimony of Greek and Southern Italian vases, belonging to various museum collections in Veneto, will be brought back to light through investigation and by enhancing their value, using a multidisciplinary approach that integrates traditional archaeological methods of investigation with new high-resolution and photorealistic 3D scanning, digital image processing techniques and archaeometric analyses.

The advance in archaeological studies of the last few decades requires a new examination of the materials, whose semantic and communicative potential can nowadays be analyzed in innovative ways. MemO's scientific structure innovatively aims to cross-check the data on collection items (with no origin context) with those on items coming from recent stratigraphic contexts, on the basis of scientific excavations carried out in Italy. It will then be possible to map the finding contexts and, consequently, to refine dating and to study material associations.

Moreover, recent discoveries have further enriched the patrimony of artifacts that, in themselves, are the basis for studies on the figures of vase painters and potters, on workshop structure and on the relation between artisanal production and buyers. Furthermore, they are key to the reconstruction of iconography dissemination dynamics and to understanding the link between iconographic theme and vase shape and function and, lastly, to the symbolic ideology behind figurative choices.

Going back to the issues raised by the study of a collection, another problem concerns forging Antiquities: only a multi-disciplinary approach will allow us to distinguish authentic items from forgeries, ranging from archaeometric techniques to traditional comparative archaeological analyses. Moreover, from a social and cultural point of view, the forged artifact is a valuable source of information regarding the knowledge, tastes, techniques, art market dynamics and epistemological and axiological values at the time of its creation.

Therefore, we believe it is possible to draw advantage of the 'unprovenanced' items as some interactive 'research and teaching tools' in a double perspective: in the eyes of scholars, students, and professionals, dealing with the preservation and promotion of archaeological heritage, they could provide the chance to develop and train effective, low-cost, and non-invasive means for the authentication of the artifacts to be studied. In the eyes of academics and professionals as well as of private collectors, dealers, and the wider audience, 'unprovenanced' private collection items could be the key to enhancing the cultural, social, and historical value that authentic antiquities (with origin context) do bear in telling ancient art history and the fortune of the Antique in the modern and contemporary period. In a broader perspective, looted antiquities and forgeries could lead to understand (and, maybe, fight) the current widespread phenomena of forgery and illicit trade in archaeological material, as well as to develop a 'community awareness' of the crimes against Cultural Heritage and the therewith-connected material and intellectual consequences for the integrity of the field of ancient art history, with the aim to contribute in the creation of a new public spirit, for the promotion of a law-abiding culture concerning Cultural Heritage.

What we propose is to re-evaluate the status of forgeries, not from a legal point of view (it is still an execrable phenomenon for the economic loss it causes both to private collectors and public institutions, for its ethical and psychological implications and for its hand in the falsification of history), but from an anthropological one: by un-veiling forgeries, we re-veal the truth, i.e. the instances of cultural, epistemological and aesthetic history that produced them. As a matter of fact, the reproduction was both a 'victim of' and a 'witness to' those instances and, due to its 'palimpsestic' nature, it bears their mark.

M.S.

3. The decontextualization of archaeological artifacts: limits and potentials

Alessandro Della Seta stated that archaeologists are all those who make the subject of particular, technical, scientific and historical investigations, the individual classes of objects and monuments excavated from the subsoil or remained on the top (Della Seta 1913), remarking, already at the beginning of the last century, how the activity of the discipline was oriented towards a differentiated plurality of artifacts.

However, they were not (and they are not even today) attributable only to research with scientific and/or stratigraphic purposes: lack of documentation (of the excavation, of the artifacts), fortuitous finds (remained far from the clamor of the news), clandestine excavations, disfigurement of ancient monuments and thefts (from the Modern Age to the present day) are all elements to be taken into account when thinking about the nature of an object, or when thinking about the different roads that have led to the knowledge of the same.

The history of studies (e.g., see Barbanera 2015) shows how, in the past, archaeological excavations were often not adequately documented, due to the nature of the discipline itself, which went from eighteenth-century antiques (oriented towards targeted interest in certain categories of artifacts) to scientific subject today (aimed at the global study of the products of mankind).

It often happens, in fact, that the archaeological material, or presumed as such, does not derive from investigated, safe and incontrovertible contexts but is due to fortuitous, sporadic findings, which occurred over time and due to the resumption of the taste of the ancient, with the contextual diffusion of the collecting phenomenon in the modern and contemporary age. It was precisely this activity that led to the creation, within the legal systems of the pre-unification states (Emiliani 2015), of legislation for the protection of the archaeological heritage which led to legislating on the exclusive property of the material found: this legislation then reaches nowadays, merging into the Code of cultural heritage and landscape.

Alongside these fortuitous finds and the lawful dissemination of these archaeological objects, there is also the spread of undue behavior, such as the practice of clandestine excavations and the illegal trafficking of objects and works of art, further elements emphasizing the loss and/or the destruction of the contexts of origin.

All these elements appear among the main causes of destruction of the contexts of discovery, isolating the artifact in an 'information limbo' that often involves the disinterest of the scholars themselves (Hilgert 2016). According to this line of thought, the artifacts lose their qualification as a historical source and their very informative potential due to this decontextualization. On the contrary, a different approach, although it recognizes the documentary damage suffered, equally identifies a strong information component intrinsic to the very nature of the artifacts such as products desired, conceived, created, used and deposited by mankind.

These considerations, valid for any type of artifact, can see a practical example in ceramics (Frank 2007), generally considered to be the most common class of objects in archaeological contexts and generating a by now centuries-old tradition of studies, now increasingly multidisciplinary and innovative (Gliozzo 2020).

Although, for an archaeologist, the loss of the context of provenance/discovery of an object is a real damage (with regard to ceramics, especially as regards its ability as a chronological source), even greater than the loss of the artifact itself, it, as an individual element, he can, in any case, provide different and qualified information (Zamparo 2019):

– on the production methods and techniques, i.e. on the knowledge and skills of the civilization that created the artifact, thanks to the combination of archaeological sciences with diagnostic disciplines;
– thanks to the technological-formal study, therefore, we arrive at the analysis of the social and economic condition of those who produced that artifact, through the serial and overall study of the production, or through the possible written, iconographic, epigraphic sources and through the tradition that has come down to the present day;
– at the same time, it is possible to reconstruct the social context in which this object was marketed and, obviously through technological considerations, to

establish its use, thus also hypothesizing the different phases of its material 'life' (use, breakage, repair/recomposition, reuse, eventual de-functionalization and relative re-functionalization, breakdown or definitive loss of the function and its deposition);
– the single artifact, moreover, can inform us about its movements, that is its place of realization (through chemical-physical and petrographic analysis) and about any movements made before its deposition, breakage or loss;
– at the same time, this single object can show us the alterations it has undergone, over time, in its context of deposition, that is, how natural agents and anthropic actions may have modified it during the years of its long and silent rest;
– contextually, finally, it is possible to reconstruct the events inherent to the 'second life' of the objects, from the moment of their discovery to the last owner (passing through acquisitions, donations, bequests, publications and exhibitions), that is, to reconstruct how society contemporary conceive and reflect itself in the ancient world.

It seems significant, at this point, to recall the words that Ranuccio Bianchi Bandinelli used to describe the work of art, referable to any type of product of mankind: «Each face of the polyhedron reflects a particular element – social, economic, political – which enters as a component of the whole and each face is both subordinate to the whole and to some extent determining for it. The whole would not be valid if one were missing [...]. Each of these guides led us to penetrate the formation of the polyhedron» (Bianchi Bandinelli 1974-1975, 181).

According to this logic, a systematic, scientific study of artifacts deprived of their own context of discovery or provenance that is systematic, scientific, mediated by the archaeological method and supported by diagnostic data can fill some information gaps still left without answers.

Thanks to the study of this material, on the basis of the knowledge developed also through the known and stratigraphically investigated contexts, we can increase our knowledge of the ancient world, its productions, the skills of its craftsmen and the society they addressed (Luby, Lightfoot, Bradshow 2013).

At the same time, however, this decontextualized material (Voss, Kane 2012), often synonymous with the 'second life' of objects, provides us with information on the modern and contemporary age itself, namely:

– on the revival of ancient taste in society, i.e. on its diffusion, on its consequences in artistic production and on the cultural, social and economic repercussions that the findings have entailed;
– on the birth of new productions imitating the ancient tradition, with the revival of themes, iconographies, forms, materials, knowledge and techniques, or on the ancient prototypes used in the new manufactories;

– on the contextual development of the modalities for the protection of archaeological artifacts, archaeological researches and findings, above all for the contrast of clandestine excavations, illicit trafficking and the phenomenon of forgery;
– on the history of private collecting, that is, how these artifacts entered a socio-economic system governed by the 'supply-demand' mechanism, or how they changed the art market;
– on the formation, especially in the 19th century, of archaeological museums through the direct acquisition of artifacts or deriving from bequests and donations, that is, on the ability of these artifacts to change the very perception of ancient culture through their display.

All this information, otherwise lost, provides a snapshot not only of ancient society but also of contemporary society.

L.Z.

4. The 3D models of Marchetti and Merlin collections

The transition from 'humanities computing' to 'digital humanities' was theorized as a positive evolution of humanistic computing. In a recent interview, released for the online periodical *Cultural Work*, Jeffrey Schnapp, founder and director of the Harvard University metaLAB, said that a definition of digital humanities reduced to a simple application of computer tools to the study of cultural heritage would be relatively trivial. Moreover, in the nineties «we stopped talking about Computational Humanities or Humanistic Computing, and we started to think about Digital Humanities». Furthermore, Schnapp highlights that: «the expression Digital Humanities marked the moment of transition in which the distinction between the world of digital technologies and culture in society does not exist anymore and there is a rethinking of what research in the human sciences could be» (interview by S. Capezzuto with J. Schnapp for *Il lavoro culturale*, http://www.lavoroculturale.org/intervista-a-jeffrey-schnapp/). So, humanities computing should give a new experimental model of the human sciences and a new social practice of designing culture. In the following years, the impressive technological development (personal computers, graphical interfaces, the implementation of WorldWideWeb) has deeply changed the research practices in the field of humanistic and computer science and it has significantly influenced the relationship between the representation and processing of the information.

3D survey methodologies are the protagonists of this shift towards new models of communication of knowledge with the goal of an extension of the cultural offer. It is a language that emphasizes the perceptual aspects with interactive images and 3D models in order to make easier the understanding of complex aspects not immediately readable. It is a collaborative and multidisciplinary type of communication based on the laboratory as a research unit: it is better to work in a team where sectoral skills (such as history of art, archaeology, 3D survey) converge into the creation of a new research model.

The traditional modeling process starts with a conceptual formulation of the object defined in its details with representation methods.

During the pre-processing phase, the first question that we must be asked concerns the purpose of the model, because the applications could be different: from multimedia presentation to 3D modeling for morphometric study. Moreover, during the planning phase of the survey, the material and geometric characteristics of the object must be considered.

Marchetti and Merlin collections are characterized by a strong variability in dimensions and shapes of the artifacts and for this reason it is necessary to use a scanner that is adaptable and facilitates view planning. Moreover, in addition to the geometry, the texture has been acquired in order to obtain very high resolution 3D and photorealist models.

For all these reasons a structured light scanner was chosen the Cronos Dual from Open Technologies[1]. It is a type of active sensor that projects on the surface a light pattern, sequence of black and white stripes. Their deformation is acquired with a digital camera to reconstruct the geometry of the surface. Cronos Dual works with a double field of view: far field and near field. Moreover, a turntable synchronized with the acquisition software was used to guarantee a first alignment during the acquisition phase, which is essential for continuous control of the quality of the survey.

The acquisition and data processing (Fig. 1) involve consequential but distinct phases, defined in the literature as a work pipeline:

– Data acquisition: the instrument acquires the data using the projection of patterns of light that change according to the morphology of the surface. The deformation is acquired through a camera and used for the calculation of three-dimensional coordinates (triplets of x, y and z coordinates where z represents the distance between the instrument and the acquired object) (Laga *et al*. 2018). Moreover, in addition to the spatial information, also the chromatic information (RGB) is recorded.
– Checking of the goodness of the acquired data: using the calibrated turntable and setting a fixed rotation angle of 32° it was possible to do a rough alignment during the acquisitions. This is essential to verify in real time the goodness of the survey and identify the possible presence of non-sampled areas.
– Points filtering: in order to remove all the points (defined as spurious) not belonging to the geometry of the artifacts.

[1] Cronos Dual from Open Technologies with an accuracy of 0,10 ÷ 0,40 μm; camera resolution 2×1.3 MPixels; acquisition and processing software: Optical RevEng 2.4 SR 8 Pro.

Fig. 1 – Padova, Marchetti collection, CM7, pseudo-centuripine vase with lid decorated with a female figure. On the left the very high-resolution 3D model; on the right the 3D photorealistic model. The vase and its lid were acquired individually in far field with 33 scans for the lid and 44 for the vase.

– Range map alignment, in order to put all the single range maps into a common coordinate system where all the scans lie aligned on their mutual overlapping region. The pairwise ICP alignment algorithm, followed by a global registration, was used.
– Range map merger (or fusion), to build a single, non-redundant triangulated mesh. After the registration, there are several overlapping partials meshes, one for each captured view. The next stage of the reconstruction pipeline must integrate them to build a single triangle mesh of the object.
– Mesh editing, to improve the quality of the reconstructed mesh. The acquisition process may have incomplete or uncorrected areas. This step requires the use of hole filling algorithms and the editing of the topological mistakes (non-manifold face, self-intersection, unstable face).
– Mesh simplification, to accurately reduce the huge number of triangles, producing 3D models with different high-quality Level of Details (LoD).
– Color mapping, to enrich the information by adding color information to the geometry representation, producing in output a high resolution 3D and photorealistic model (Zamparo, Faresin 2019; Salemi, Faresin in press).

E.F.

5. Conclusions: an approach for the recontextualization of classical ceramics

As seen in the previous paragraph, the affirmation of the internet as a privileged tool for accessing and sharing cultural heritage has introduced new opportunities for archaeology and cultural heritage: compared to traditional forms of academic research, digital approaches are more collaborative and multidisciplinary, while referring to traditional approaches.

The introduction of digital has led to profound transformations at a technical and cultural level. Digital Humanities, in fact, are not limited to 'digital culture', updating traditional knowledge (they do not represent only the 'what' and 'how'), but redefine many consolidated practices such as, in this context, the study of archaeological finds.

This digital system takes shape, in the MemO Project, with the creation of a website for the communication of research, training and dissemination activities implemented thanks to the support of the Fondazione Cassa di Risparmio di Padova e Rovigo.

Parallel to the website (www.progettomemo.it), a 3D survey campaign was created and a database for the conservation and promotion of the data obtained during the research phases was developed.

In fact, this ultra- and inter-disciplinary path has involved, in the MemO Project, the creation of very high resolution 3D models of the collectibles involved, including – in addition to the Marchetti and Merlin collections – also the fourteen collections preserved in the main archaeological museums of Veneto: these, as seen above, saw the use of structured light instrumentation with micrometric resolution, fundamental for the digital reconstruction of the characteristics and origins of the vessels, as well as for studying both macroscopic and micrometric details. Furthermore, by also acquiring the texture data, it was possible to create a digital archive, which aims to become a tool for the dissemination of knowledge and dissemination due to the ability of the 3D models to remain unchanged over time and the interactivity with which they can be interrogated by users for the extraction of information.

The results obtained through 3D surveying and modeling are therefore part of a sector that sees the intervention and management of cultural heritage from a formal, conservative and informative point of view as central elements, with repercussions on the museum sector, on training, on cultural tourism and on the communications industry that uses ICT (Information and Communications Technology): in fact, one of the objectives of the MemO Project consists precisely in the creation of a digital system (website and database) that can be used as a container for all information relating to the asset, a useful tool for the management of the artifacts both for cataloging (scientific research) and for virtual use in the museum environment (Stylianidis, Remondino 2016).

The website, in fact, represents the access interface for the MemO Project database. Born on the basis of the Paduan experience gained around the TESS (Ghedini *et al.* 2007), TECT (Salvadori, Scagliarini 2014), ADAM (Kirschner 2008) and KERAMOS (Dobreva, Baggio 2013) projects, the database large cataloging and digitization projects launched with the Post-Paralipomena Project (Giudice, Barresi 2003) and with the Beazley Archive (Kurtz 2009), realizing what was hypothesized in 1999 by Irene Favaretto (Favaretto, Bodon 1999).

The database, created thanks to the contribution of Marco Tognon, Paolo Kirschner and Luciano Giacomel, was designed to be usable online, to be usable by different categories of users (open-access) based on their characteristics (researchers, students, collectors, members of the public administration, museum professionals) and to provide the possibility of research on over 120 items ordered in 15 different sections (Faresin, Zamparo in press), elaborated on the basis of the needs expressed by individual museums, by the Superintendencies involved and by the most recent legislation issued by the Istituto Centrale per il Catalogo e la Documentazione.

The database of the MemO Project, the result of the combined and multidisciplinary research that involves new technologies and scientific diagnostics from the archaeological discipline, intends to be configured as a tool:

– for archaeological research, i.e. for the study of the Greek and Southern Italian material present in Veneto which from the condition of a series of objects often

decontextualized can finally provide quantitative and qualitative data for the understanding of trade (ancient and contemporary), for the transmission of images in an external context from the one in which they were generated and for the verification of the diffused material types (Wingfield 2017; Voss 2012);
– for the digitization, communication and value enhancement of cultural goods currently not on display, belonging to public or private entities, in order to increase knowledge about the presence of this material and allow the launch of new studies on still unpublished artifacts;
– for the creation of a regional network between the participating museums and cultural institutes, i.e. for the systematization of the presence of Greek and Southern Italian ceramics for the purposes of value enhancing and promoting culture, therefore, for the increase of accessibility to the national cultural heritage (Luigini, Panciroli 2018);
– for the investigation of collecting, a phenomenon present in Veneto since the 15th century and still highly active today that has allowed the establishment of the main collections now preserved in the region's public museums;
– for the sharing of appraisals carried out on non-authentic objects and for the dissemination of a culture of legality in the art-historical field, i.e. with the aim of studying, digitizing and cataloging even false objects in order to document their presence and allow their easier recognition in the future;
– to improve the understanding of objects that are often difficult to understand precisely because of those multiple levels of reading previously investigated.

In this way, once again, archaeology appears as a fascinating book full of information but to be read with the right pair of glasses.

L.Z.

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ABSTRACT

Heir to a centuries-old tradition, the phenomenon of collecting ancient pottery, especially Greek and Southern-Italian, is still particularly active, and denoting a still lively adherence to classical taste. The materials of these collections, however, often appear decontextualized, that is to say deprived of their fundamental informative component. Since 2018, through a multidisciplinary approach, the MemO Project, directed by the Department of Cultural Heritage of the University of Padova, has dealt with the study of these materials in order to reconstruct their history and origin, i.e. to systematically recount their memory. This contribution intends to analyze the complexity of the narration of the archaeological data for the decontextualized material and, above all, to detect its informative potential in order to recreate the original context. Through a multidisciplinary teamwork, we intend to present the results obtained in the context of the reconstruction of the history of inevitably inaccessible materials.

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ETRUSCAN HYPOGEA IN 3D: A PROPOSAL FOR AN IMMERSIVE AND INTERACTIVE VISUALIZATION OF VOLTERRA'S FUNERARY CONTEXTS

1. Introduction

Within the framework of a workshop focused on the potential of pottery, and material culture in general, for the reconstruction of archaeological contexts, however, it does not seem out of place to present a contribution in which the topic is approached in the opposite direction, that is, starting from the context.

First of all, what do we mean by 'context' in archaeology? By transposing the definition of this term as given by linguistics, we can define it as the physical, spatial, and temporal situation in which an anthropic or natural action takes place. In archaeology, the object removed from its context has little scientific value, though it is intrinsically precious; in turn, the context without the object loses much of its informative potential. An empty or incomplete context is likely to give a partial or incorrect idea of how it was originally conceived or how it took shape.

In the case study herein, the context is represented by a selection of Etruscan hypogea located in Volterra, which are empty containers now, although the architectural complexity of some tombs may provide important information itself. In antiquity, however, these underground rooms must have looked quite different, densely populated with urns and other grave goods, as documented by ancient and recent finds from intact contexts, that is, contexts that have never been affected by grave robberies.

This research is part of a long-lasting and fruitful collaboration between the University of Pisa and the Scuola Normale Superiore, and more specifically between the Drawing and Restoration Laboratory (LaDiRe) of the Department of Civilization and Forms of Knowledge (UniPi) and the Virtual Reality Center of the SMART Lab (SNS) (Albertini *et al.* 2014; Olivito, Taccola, Albertini 2015; Albertini *et al.* 2016; Olivito, Taccola, Albertini 2016a; Olivito, Taccola, Albertini 2016b; Albertini *et al.* 2017; Albertini, Baldini, Taccola 2017; Taccola *et al.* forthcoming). The scientific project, titled *Ipogei etruschi di Volterra in 3D*, was made official by an agreement signed between the two institutes and the Municipality of Volterra in 2017, and it ended in September 2019. A first preliminary experiment resulting from such collaboration was presented at the KAINUA 2017 International Conference in Honor of Professor Giuseppe Sassatelli's 70th Birthday (Bologna 2017) and published in the conference proceedings (Taccola, Rosselli 2017).

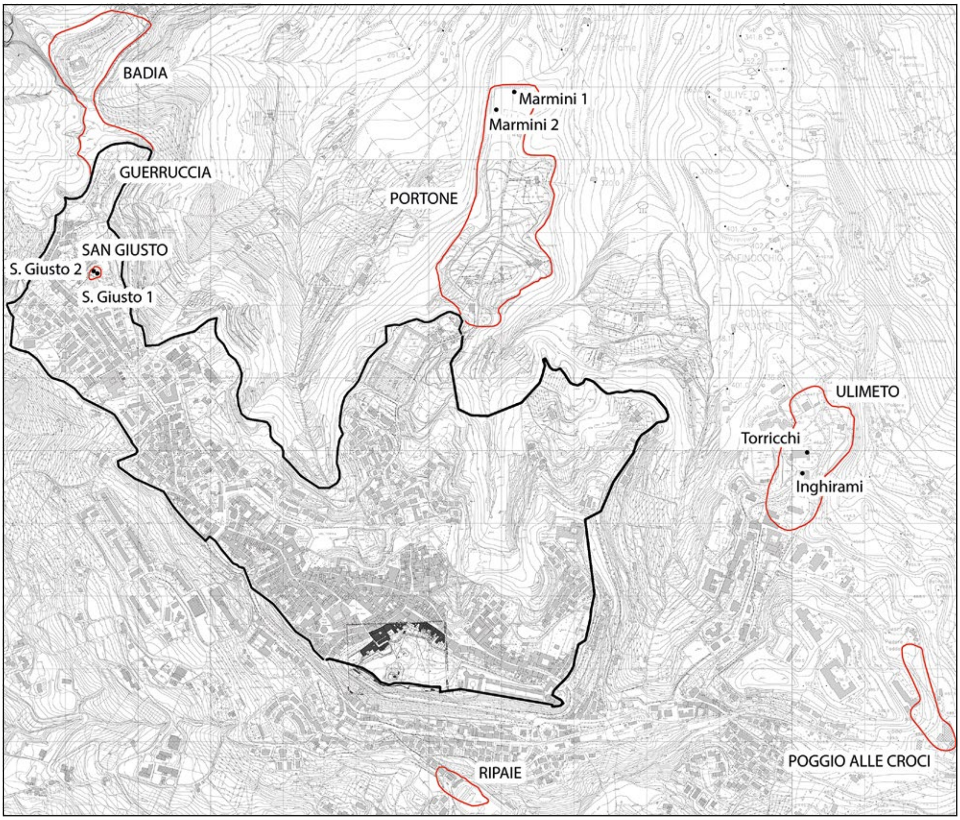

Fig. 1 – Map of Volterra. In black, the Hellenistic age walls; in red, the boundaries of the necropolises (capital letters). The black dots point to the location of the tombs selected for the VR application (lowercase).

As it will be better explained in the following pages, the main purpose of the research was to create an immersive and interactive visualization experience that could be easily learnt and enjoyed, using low-cost mobile devices, of six Etruscan hypogean tombs located in Volterra.

E.T.

2. The archaeological context

The 3D visualization of some well-preserved hypogea of Volterra is part of a wider ongoing research program carried out by the Archaeological Superintendence and the University of Pisa, which plans to accomplish a census of the Etruscan tombs of the ancient city, both those known from literary sources but no longer identifiable, and those that are still visible, with the aim of drawing up the archaeological map of the Municipality of Volterra and enhancing the still-visible funerary monuments.

As it is known, the Etruscan necropolises surrounded the plateau of Volterra by all sides (Fig. 1) and occupied the large limestone slopes on the northwest side, along the road to Pisa (necropolis of San Giusto-Guerruccia-Badia), the North side (necropolis of Portone), and the East side, beyond the valley of Pinzano (necropolis of Ulimeto-Poggio alle Croci). On the southern hillside, consisting of a steep slope of detrital material without calcareous surfacing, was located the necropolis of Ripaie (Rosselli 2018), which is no longer visible because it was covered when the municipal stadium was built. The necropolises of Volterra were generally used, some of them continuously, from the Iron Age to the Hellenistic period, and also utilized for Roman graves. Whereas there is no evidence of burials of the Villanovan and early-Orientalizing period, placed into simple pits or ditches, some chamber tombs carved into the limestone rock, called 'panchina', are still visible in the main necropolises. They were dug partly during the Archaic period and in large numbers in the Hellenistic age, when Volterra reached a considerable demographic development, as testified by hundreds of locally-manufactured urns and cinerary vases, dating from the late 4th to the 1st century BC.

Two hypogea situated in the neighborhood of San Giusto are currently the only remains of a large Etruscan necropolis risen in the Archaic and Classical age, originally extending on the northwest side of Volterra's plateau, not far from the deep landslide known as 'Le Balze'. Other hypogea of the same period have been discovered in the past decades both in the adjacent area of Santa Chiara and on the Guerruccia plain (Minto 1930), but nowadays most of those tombs are hidden under modern buildings and no longer visible. As all these graves were located within the Hellenistic town-walls, built between the end of the 4th and the beginning of the 3rd century BC, they were necessarily excavated before the fortification was built. Outside the walls, the large number of tombs discovered in the area of Badia and Montebradoni since the 18th century demonstrates the wide extension of the northwest Etruscan necropolis, used for a very long time up to the Roman Imperial age. Both hypogea are carved into the South side of the hill, where the church of San Giusto stands; the simpler one consists of a quadrangular room without benches around the walls, which probably have been completely removed at some indefinite time. When it was found, in 1985, it had already been looted, but a careful excavation unearthed some small ceramic fragments laying on the ground, dating to the late 4th century BC. The second hypogeum has a complex plan, consisting of a central rectangular atrium, with four small rooms with benches carved into the rock all around it. The tomb, totally empty, was discovered in the 19th century, and it was used as a shelter for the inhabitants of Volterra during the

Second World War, in 1944. Later, in the 1980s, the structure was restored and made accessible to visitors. The multi-chamber plan of such hypogeum recalls some similar specimens, dating between the 6th and 5th centuries BC, attested in Volterra on the nearby Guerruccia terrace and in the Valdelsa district.

The necropolis of the Portone is located outside the North portion of the Hellenistic walls and, as for the other necropolises of Volterra, it had been intensely explored since the 18th century by the owners of the local farmhouses. In fact, the first finding of a hypogeum full of cinerary urns dates back to 1731, when the discoverer transferred the artifacts to the Municipality of Volterra, thus starting the collection of the public museum. In that period, some Volaterran noblemen put together large collections of urns and grave goods extracted from the hypogea that had been discovered in their estates, most of which were acquired by the municipal museum and some sold to other museums, both in Tuscany and abroad. In the following century, the excavation of the necropolis was promoted by private collectors as well as by the Guarnacci Museum (Fiumi 1977); the latest explorations of the area, conducted by the Superintendency, date back to the 1970s (Cristofani 1973). The most common types of hypogea in the necropolis of the Portone have a circular plan with a central pillar or a quadrangular plan, but simple caves of a small size (called 'nicchiotti') have also been reported. All these structures, together with the cinerary urns and other grave goods, testify that the necropolis was mainly frequented in the Hellenistic period; however, the area was used as burial place even in earlier times, as proven by the discovery of some Iron Age pit tombs and grave goods related to the Archaic period.

Despite the large number of tombs known from literary sources, today only two remarkable hypogea are visible in the northern part of the area, the so-called 'Marmini', known since 1880 and currently open to visitors, in addition to a few small chambers along the modern road that crosses the necropolis, which have partly collapsed and are not accessible. One of the hypogea of Marmini has a complex plan, that consists of a central rectangular room with four small chambers in a radial arrangement; it is very similar to the late-Archaic and Classical hypogea of the necropolis of Guerruccia and San Giusto, but, because of the lack of any data about the burials in it, the period during which the tomb was actually used cannot be accurately known (Rosselli 2015). The second monument is located not far from the first one and consists of a circular chamber with two levels of benches running along the wall. In the middle of the room a rock pillar, bearing some noticeable traces of the grooves made by chisels, supports the ceiling. Despite the loss of all the original materials contained in the tomb, the circular plan with the pillar can reasonably suggest a timeline ranging between the 3rd and 1st centuries BC.

The necropolis of Ulimeto is placed on a long ridge in the eastern part of Volterra, joining the nearby low hill of Poggio alle Croci. Over time, a high number of Etruscan tombs have been unearthed from such areas, but, because of the considerable transformation of the landscape, due to the construction of the city hospital buildings, the original extension of the funeral area cannot be easily identified. However, the necropolis of Ulimeto also seems to have been mainly used in the Hellenistic period, with some evidence up to the Roman Imperial age. On the other hand, there are few burials relating to previous periods of Etruscan history. Also in this case, the most significant discoveries occurred in the 18th century and were made by the owners of the surrounding villas, in particular the noble Inghirami family, but also by the Municipality and the Guarnacci Museum. In recent times, the most remarkable findings occurred during the construction of the hospital buildings.

There are only two well-preserved and accessible tombs in the necropolis of Ulimeto. The first one is the well-known Inghirami tomb, discovered in 1861 near a country house belonging to the homonymous Volaterran family. The hypogeum was found intact, with over fifty cinerary urns inside related to several generations of the Etruscan *gens Ati* and laid over a long period, between the 2nd and 1st centuries BC. The urns remained inside the chamber until 1899, when they were acquired for the Archaeological Museum of Florence by Luigi Adriano Milani, who built a copy of the hypogeum in the garden of the Museum and filled it with the original artifacts. A steep dromos with steps carved into the limestone leads to a circular room with a large bench. At the center of the chamber stands a pillar, with a low platform in front of it, probably a stand for the urns. A short distance away from the Inghirami tomb is the hypogeum of Torricchi, located under a modern building and recently investigated by the University of Pisa (Rosselli 2020). The complex plan of the hypogeum, consisting of a large trapezoidal atrium which leads to three small grave chambers carved in the back wall, can be compared to other funerary monuments of the late-Archaic period of Volterra, although the ceramic sherds collected inside do not date earlier than the second half of the 4th century BC. The tomb hosted the ashes and burials of several generations of an aristocratic Etruscan family, as shown by the high quality of the remains of the grave goods placed next to the deceased.

L.R.

3. 3D data acquisition

The preliminary step to the accomplishment of the project was the choice of the tombs to be modeled in 3D and the survey itself.

Regarding the first point, we selected the most architecturally representative and safely accessible hypogea. Indeed, many of the underground tombs of Volterra, such as those of the necropolis of Badia and Guerruccia, Northwest of the city, were dug in a geologically very unstable ground, exposed to frequent

Fig. 2 – Examples of architectural structures of Etruscan hypogean tombs in Volterra. From left to right: Marmini 1 tomb, hypogeum of Torricchi and San Giusto 2 tomb (3D model top view).

landslides and currently inaccessible. Therefore, the choice fell on the two Marmini tombs (necropolis of the Portone), the Inghirami tomb and the hypogeum of Torricchi (necropolis of Ulimeto), and the two San Giusto tombs (Figs. 1-2).

Concerning the second point, the surveying procedure used for the 3D documentation was photogrammetry, the technique «which allows the derivation of accurate, metric and semantic information from photographs» (Remondino 2014). Although the subject has already been mentioned (Taccola, Rosselli 2017), it is appropriate to briefly review the workflow and the issues that emerged during the data acquisition process.

Agisoft Metashape is the software used to create the point cloud (Structure from Motion + Dense Image Matching algorithms) and the polygonal model of the tombs. The main issue is related to the lighting of the scene. Despite the use of calibrated lamps, positioned, whenever possible, at the same distance and angle from the SLR camera and the surface to be surveyed, the lighting was not always homogeneous. Such radiometric irregularity, as well as requiring the acquisition of a greater number of images, produced artifacts and noise in the point cloud to be cleaned manually with a further work step. Furthermore, dark zones and modern artifacts, such as cables, work tools, etc. had to be masked, i.e. virtually removed. Agisoft Metashape creates images with an alpha channel. It means that, when aligning images and creating the dense cloud, the software excludes portions of the photo masked with the black color of the alpha channel from the calculations, and therefore it does not display them in the point cloud.

For each tomb, Ground Control Points (GCPs), materialized as temporary and/or removable targets distributed on the floor, walls, and ceilings of the underground chambers, were measured with a total station. The GCPs were

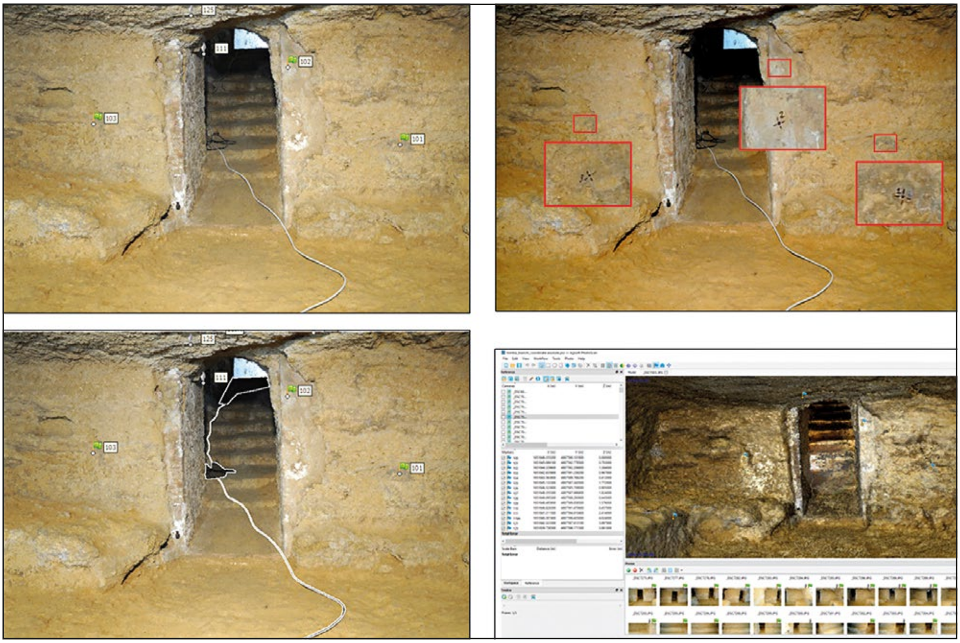

Fig. 3 – From top left, clockwise: detail of the removable GCPs; the original image; the image overlaid with the alpha channel mask; the corresponding point cloud: modern artifacts have been left out of the calculation.

uploaded in the software to scale and orient the point cloud: this procedure can also be used to estimate the accuracy/error of the point cloud itself. On average, the error generated in the survey of the six tombs is widely compatible with the aims of the project (Fig. 3).

As will be briefly discussed in paragraph 6.1, the acquisition and processing of the 3D data were followed by the post-processing and optimization of the 3D models, in order to make models that could be perfectly adaptable to the expected application and devices.

E.T.

4. Immersive and interactive VR in archaeology: a brief introduction

Archaeology derives undisputed advantages from the use of virtual reality, and particularly from 3D reconstruction, above all to present the researcher with an overall and understandable vision of the data represented.

The first examples of research that united these apparently so distant worlds date back to when technology was not yet ripe to deal with the technical complexities that this discipline requires both for the representation of data and for the interaction with them. The representation of three-dimensional space through two-dimensional techniques, tools and technologies, intrinsically encompasses problems and limitations that can only be overcome through new approaches that exploit our way of perceiving the real world (Reilly 1991).

Modern virtual technologies (virtual reality headset, augmented reality glasses, immersive projections, etc.) have opened new opportunities in the field of research, enhancing the visual approach of archaeological data (Bruno *et al*. 2010).

It is easy to understand how it is increasingly important not to consider digital technologies as simple tools to create highly impressive and photorealistic reconstructions. In reverse, they are an extremely effective tool for those who aim to set up, visualize and interrogate a complex set of scientific data in visual form. At the same time, they are configured as extraordinary information vehicles that allow faster and more open dissemination of knowledge.

In this sense, the development of new techniques for the natural interaction of gestures in virtual environments is a topic of particular interest, allowing to reproduce and simulate, not only mentally but also physically, the operations and activities to which we are accustomed during our daily life and consequently during 'standard' research activities (Barceló 2001).

In addition, the increasingly high quantitative and qualitative level of data available to scholars represents a heterogeneous database, which can be more appropriately and effectively examined through the visual, virtual, and immersive representations of the data itself.

In this regard, digital technologies allow us to pursue a collection, visualization, and management of data in a much more accurate, detailed, rapid, and economic way than a few years ago.

If the use for scientific and research purposes can be certainly counted among the main ones, the possible impact that such a tool may have on the public of non-experts is not to be overlooked.

On the one hand, therefore, the main purpose of the discipline is to allow our scientific knowledge of the past to be more accurate, dynamic, not limited to static and definitive reconstructions, but rather open to continuous investigations on a set of multifaceted data. On the other hand, the need to share knowledge in a broader, easier, faster, and more accessible way for both experts and non-experts is no less stringent.

The variety of data that we can acquire and collect today undoubtedly requires innovative approaches to managing them, which can be more appropriately used and studied through visual representations of the data. In this sense, immersive and interactive virtual environments, together with the entire set of digital tools available, are the best way to analyze such data and try to answer in a more articulated way the many questions still open, formulating new questions to be investigated in the near future.

N.A.

5. Concept and evolution of the application

As previously mentioned, the research focused on the implementation of an interactive and immersive virtual reality application, which can be easily used on ordinary, low-maintenance and low-cost devices.

A beta version of the application, dedicated to the Hypogeum of Torricchi, was released in 2017 (Taccola, Rosselli 2017). The interaction mode (gaze-based only), the user interface and the type of VR headset (cardboard VR headset) are very basic and rudimentary.

This version was submitted to users of different ages, levels of education and IT skills, on the occasion of the FAI Heritage Days (March 2017). This step was functional to designing a new version that would take account of any feedback received. First of all, it was found that gaze-based interaction was not immediately intuitive and was not always correctly performed. In

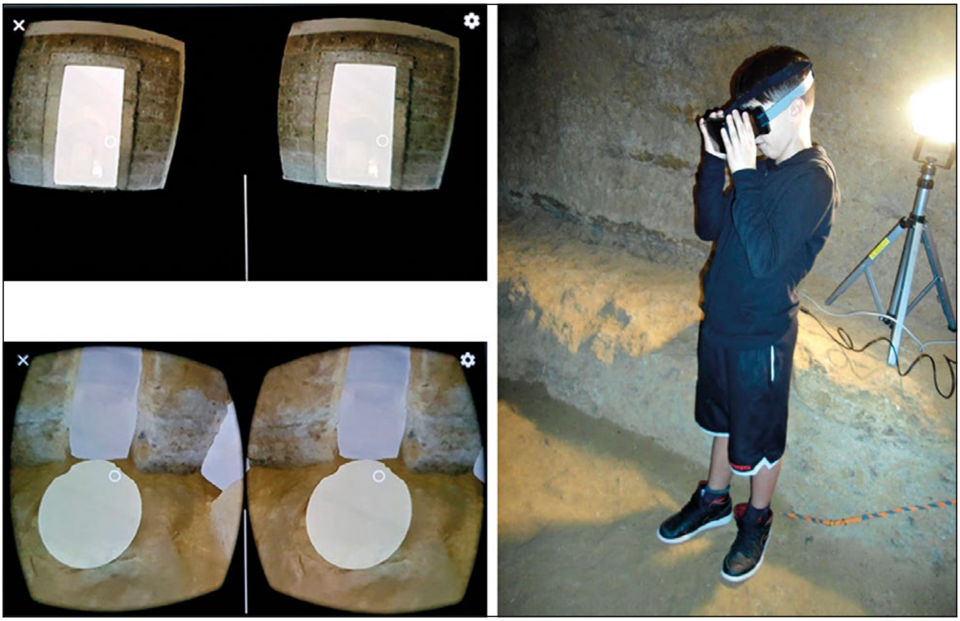

Fig. 4 – Details from the VR headset of the beta version of the application: the excessive size of the UI elements is clearly noticeable. On the right, the presentation of the application in the hypogeum of Torricchi.

Fig. 5 – The home page of the VR and the touch screen applications, with the logo and credits.

addition, the teleporting from the dromos to the underground chamber was too fast and, in some cases, it caused dizziness. The lack of textual information and the excessive size of the UI (User Interface) icons to interact with were issues that needed to be solved as well (Fig. 4).

Following the first release of the application, which was theoretically very user-friendly, even for non-expert users (apart from the aforesaid issues), the need arose to redesign the virtual experience in the underground tombs of Volterra in the light of the new hardware available.

The research went in two directions: creating a touch version of the application, downloadable for free from all mobile devices, such as smartphones and tablets; and a VR version available at the Guarnacci Museum in Volterra.

At an early stage, the use of a more complex VR headset was envisaged, equipped with motion sensors to perform, together with the controllers, free movement within the 3D model, the possibility of obtaining metric data, displaying annotations and metadata at various levels of complexity and detail: in other words, to interact naturally with the objects around the place, by reproducing complex gestures. Such a kind of approach can be defined as Active VR, with a medium to high level of interaction.

However, considering the users' target (museum visitors), we chose a less complex approach, which could be defined as Passive VR, that is, with a lower level of interaction. In short, a VR application that closely resembles the above-mentioned beta version. This involved using a lower-performing device and a simple, easy-to-learn interaction mode. Therefore, an easy-to-manage tool for both users and Museum staff, who would have otherwise had to be trained in the use of the application and the maintenance of the device. Not to mention the cost, which would have been much more substantial in the case of a wired VR headset like Oculus Rift or HTC Vive used with a high-performance laptop computer.

We worked on the UI, to make the interactive icons more appealing and diversified according to the metadata they stand for (for example, textual information, stratigraphic units, archaeological finds). The textual contents were written in a simple language, which combined the completeness of the information with the brevity of the text, so that it could be read without straining one's eyes, both on a mobile device and on the VR viewer. Because of this, the texts had to be divided and distributed across different points of the application: in the general introduction to the necropolises, at the entrance and inside the tombs. In the latter case, the panel with the text is also accompanied by multimedia contents (specifically, images and archival drawings). As part of the coordinated image of the project, we developed a logo that reproduced the idealized plan of a tomb (Fig. 5).

The more technical aspects, related to the structure of the application, the type of device used, the methods of interaction and the UI solutions, are illustrated in the following paragraphs.

E.T.

6. Implementation of VR and touch screen applications

Both VR and touch screen applications were developed with Unity, a game engine widely used in the creation of real-time 3D experiences. Unity can be used to create multiplatform solutions with minimal effort, such as VR experiences that can be easily adapted to the different headsets supported by the game engine.

We chose the Samsung Gear VR wireless headset – developed by Samsung and maintained by Oculus – as our target device to be used during the tour of the museum. The device is compatible with many Samsung smartphone models, and it ensures a fully immersive and interactive experience in the virtual scenario. Also, Oculus offers a Unity integration package, which includes several ready-to-use scripts and samples. This kind of experience provides the unprecedented opportunity to enjoy a virtual visit of all the archaeological sites at once. The headset is provided with a small controller, through which the user can interact with the virtual environment. Moreover, the Samsung Gear VR is lighter than a wired headset, and the wireless technology offers easy portability. All these features can contribute to reducing the users' discomfort.

The touch screen application is usable with all the devices running at least Android 7.0 Nougat, and it will be released on the Play Store soon. The touch input is handled natively by Unity; however, the Touchscript plugin has been integrated into this project, as it offers high-level support for gesture recognition.

6.1 *Setup of the virtual scenario and considerations about performance*

Since the performance of a wireless smartphone-based device is lower than that of a PC-based headset, some precautionary measures have to be taken to provide a proper frame rate (which is about 60 frames per second (FPS) for the real-time experience. The acquisition process with Agisoft Metashape generated 3D meshes, composed on average of almost 1.2 million triangles and 4.7 million vertices. Such geometries are excessively big for a smartphone to render – twice as much, for VR applications – in real-time. For this reason, the 3D models had to be optimized, retopologized and decimated. Such operations were performed within the Geomagic Studio software. The purpose of the procedure is to reduce mesh complexity, while keeping the geometry as unchanged as possible. Such optimization processes produced meshes of ca. 200k vertices and less than 100k triangles. After this process, polygonal models were once again imported into Agisoft Metashape to generate photorealistic textures.

After that, the 3D hypogea were imported into Unity, where virtual lights were positioned in every room for good visibility in the virtual environments. Due to the lack of natural sources of lights, virtual lights were set up for even lighting. Considering that the environment is static and that real-time lights weigh on performance, Unity can be used to create lightmaps, which are textures containing information about how the light behaves on 3D static surfaces. In this way, the rendering engine does not need to compute the light at runtime, thus relieving the workload and increasing the number of FPS.

6.2 *Structure of the application*

The application is organized in different virtual scenarios. Each scenario contains the results of the photogrammetry and the relevant metadata.

After the experience is started, a 3D virtual map of Volterra is shown in front of the user. The areas of interest (necropolises) are highlighted with a blue fade-in-fade-out effect, which is triggered as soon as the user's gaze crosses the perimeters. Once the area is selected with the controller, the user's view is brought closer to it, and an informative panel with a short but exhaustive historical description of the tombs is shown. From this panel, the user can pick a specific hypogeum to be virtually visited among the available ones.

A soft fade screen leads to a change of scenery, and the user's view is placed in front of the 3D virtual model of the tomb. Additional informative panels are visible at the entrance and inside the environment, to give historical information, pictures and curiosities. The environment is enriched with virtual indicators in the shape of rounded pointers planted in the ground. The purpose of such markers is to point at metadata and/or at objects found within the context of the tomb. Each indicator has a different icon, representing the type

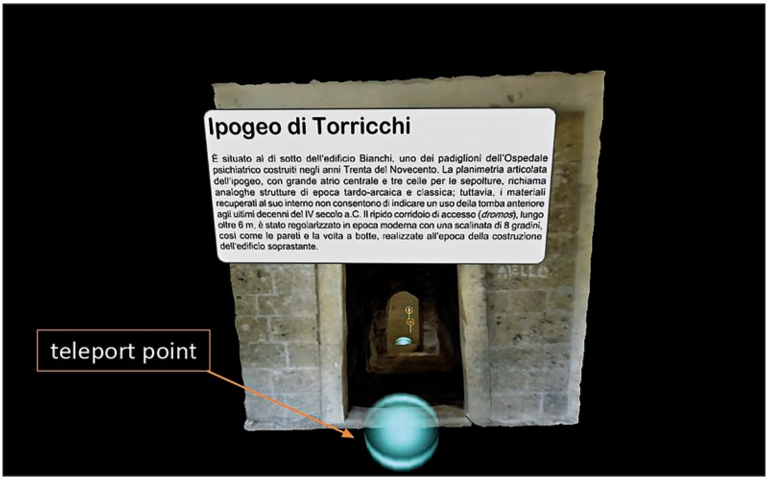

Fig. 6 – The entrance to the hypogeum of Torricchi, with the relevant introductory textual metadata. The teleport point is a virtual button to be pushed to get into the virtual environment.

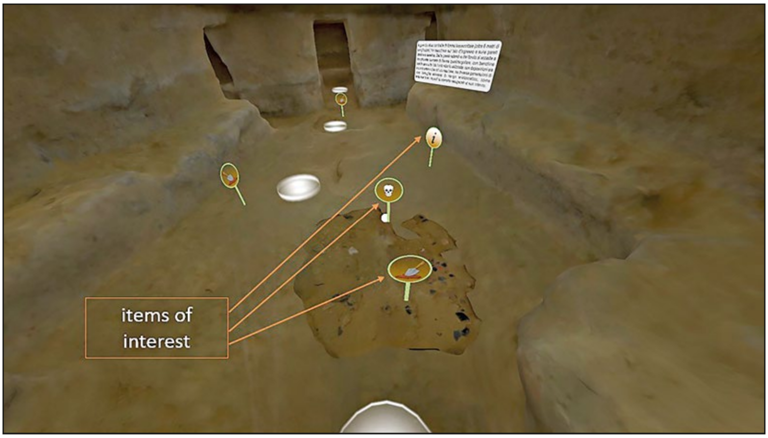

Fig. 7 – The central atrium of the hypogeum of Torricchi, enriched by the icons indicating the items of interest.

of metadata it is associated with. Furthermore, in order to avoid obstructing any part of the tomb walls, metadata information is hidden by default and can be retrieved by selecting the corresponding indicator.

The chosen VR headset does not offer positional tracking. Hence, in order to let the user move in the virtual environment, we developed a solution based on teleport points. Teleport points were implemented in the shape of flat, glowing cylinders (Fig. 6). A teleport point is a specific location where the user can move by selecting it with the controller. This provides a complete overview of the location, and the user can also thoroughly focus on the details.

The virtual hypogeum of Torricchi is worth mentioning, as its scenario has been enriched with some items of interest. In particular, several archaeological layers and, within one of them, a partially intact human jaw, were identified during the excavation process. In these cases, the presence of the items is announced by specific icons (Fig. 7). By selecting the jaw indicator, the virtual object gets close to the user and starts rotating. The archaeological layers can be shown or hidden at will.

6.3 *Interaction*

VR. As anticipated in the previous section, gaze-based interaction with the support of a controller was implemented for the VR application. A white circular pointer at the center of the screen indicates what the user is looking at. When the pointer crosses an area or an object of interest, it grows larger, showing that the area is selectable. The selection occurs by clicking on the round button of the controller. Moreover, the 'Back' button on the controller can be used to go back to the main scenario.

Touch screen. Regarding the touch screen application, the interaction is obviously based on touch. The features that in VR are available by pressing buttons on the controller, such as Select or Go Back, have been integrated through gestures or specific UI buttons.

The *Drag gesture* shifts the view of the camera, so that the user can look around the virtual environment.

The *Tap gesture* is used to select teleport points, excavations indicators, and UI buttons.

In the current version, the Pinch-Zoom gesture is not provided, for the sake of consistency with the VR version, where the possibility 'to get close' is denied because of the lack of a positional tracking feature.

M.M.

7. Conclusions: results and outlook

Creating immersive VR experiences of archaeological contexts, in the sense of a structure/container, within which one can move and interact comparatively easily, is now mainstream.

Research centers and museum institutions take such a type of approach as a tool for knowledge, for the users it is addressed to. Often, however, the design of a VR application is more focused on the technical aspects and the

Fig. 8 – Hypogeum of Torricchi. Virtual repositioning of the grave goods reconstructed from the sherds found during the excavation (3D models of the urn on the left and red-figured *kelebe* downloaded from Sketchfab.com).

exploitation of the hardware/software potential rather than on the user target and the information it conveys.

On our part, the choice of a simple and intuitive method of interaction, through commonly used or low-cost devices, and the use of easy-to-read (texts) and easily understandable metadata (archival images), have been deliberately adapted to the end-user, that is, to the standard museum visitor. Even making the application downloadable for mobile devices is part of the intention to share scientific information, albeit simplified.

Not to mention the social, as well as educational, role that this tool can play towards individuals with motor disabilities: an immersive VR experience of inaccessible places would be a viable approach to virtually break down otherwise impassable architectural barriers.

The project presented herein is not only the culmination of a research work based on interdisciplinary collaboration, but it is also a springboard for new developments and implementations, involving better-performing hardware and a more complex range of gestures, as originally planned. For example, the virtual experience can be further enriched, especially for those tombs, such as the hypogeum of Torricchi or the Inghirami tomb, of whose composition and grave goods we have reliable information (Fig. 8).

Hence, in cases like these, a 'complete' context, recomposed from the movable and immovable elements characterizing it at a given moment in its history, can be faithfully recreated. Even the integration of ambient sounds and dynamic lights (simulating torches or oil lamps), or a collaborative approach by several users at the same time, could be a further element enhancing the feeling of embodiment and engagement (Forte 2014) within the virtual environment.

E.T.

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https://sketchfab.com/leletaccola/collections/necropoli-di-volterra
SMART official site:
https://smart.sns.it/
SMART Virtual Reality Center Youtube channel:
https://www.youtube.com/channel/UCH9LDHlZU6_cXvygb1yWUbA
Touch screen application download (mobile devices)
http://smart.sns.it/volterra/VolterraTouch.apk

ABSTRACT

This article describes an interdisciplinary study carried out by a team of archaeologists, 3D surveyors and experts of new technologies applied to cultural heritage. The research was aimed at developing a virtual reality experience dedicated to Etruscan hypogean tombs in the city of Volterra. The application, intended for non-expert users, has been implemented in a touch screen version (mobile devices) as well as in VR mode (Samsung Gear Headset). In both versions, the user can easily interact with the immersive virtual context, browsing through the necropolises and/or underground tombs, and acquire textual and multimedia information.

ARCHAEOLOGICAL COMPUTING: SELECTED PAPERS FROM THE 2020 IMEKO TC-4 METROARCHAEO INTERNATIONAL CONFERENCE

edited by

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ARCHAEOLOGICAL COMPUTING AND THE METROARCHAEO INTERNATIONAL CONFERENCE AWARD: AN INTRODUCTION

The annual 2020 IMEKO TC-4 International Conference on Metrology for Archaeology, MetroArchaeo, organized by the Trento University, was held as a virtual event due to the Covid emergency. As the previous editions, regularly convened each year since 2015, also the 2020 event provided an important opportunity to bring together various contributions devoted to the expanding interest of archaeological sciences in new technologies and analytical techniques, with the aim of discussing production and interpretation of measurements and data.

While in 2020 «Archeologia e Calcolatori» published the special section on *Logic and Computing* presented during the 2019 Florence Conference, for this issue of the journal the ten best papers on archaeological computing were selected (https://www.metroarcheo.com/ma2020/awards). Awarded by an international Scientific Committee, the papers concern some case studies relating to archaeological sites, monuments and artifacts, in which digital technologies have enhanced innovative research and communication solutions, testifying to the potential strength of the dialogue between human and exact sciences. A common thread that seems to link almost all the selected papers is the use of 3D solutions for documentation, preservation and sharing of archaeological monuments and artifacts.

The first articles illustrate three relevant contexts: the Grado I Roman shipwreck (Costa, Beltrame), an interesting wreck found in 1986 by the coast of Grado (Gorizia), the late-Republican *insula* 4-6 in Paestum (Bosco *et al.*), and the NE slopes of the Palatine hill and the Colosseum valley area (Brienza, Fornaciari). In the last years digital technologies have largely supported documentation and studies of submerged heritage. In the Grado Roman shipwreck, the Ca' Foscari University research team processed the collected data in order to obtain a complete virtual 3D model of the shipwreck in its different phases, from the hull and the cargo *in situ* to the reconstruction of the original ship before the sinking, with the aim to make it accessible to a wider public and disseminate the importance of the underwater archaeological remains.

In the *insula* 4-6 in Paestum, thanks to BIM models the digital representation of the structures allowed a more precise identification of the buildings, their relationships and their transformation over the time. Also in the excavations conducted at the NE slopes of the Palatine hill the use of digital tools allowed to better understand the history of architectural and urban aspects of this central zone of Rome. For the analysis of the ancient walls, image-based-modelling helped to create a very detailed 3D documentation linked to a DBMS dedicated to the ancient structural features. Reconstructive hypotheses have been formulated and chronological architectural sequences verified in order to analyze the relationships between the different buildings.

As for the use of 3D in the study of ancient artifacts, Tavella *et al.* estimate the volumetric capacity of some vessels from the Neolithic site of Lugo di Grezzana (Verona, Italy) thanks to an open source 3D computer graphics software. Guček Puhar *et al.* examine a Palaeolithic hunting weapon from Ljubljanica River, emphasizing the importance of a 3D reconstruction obtained from microcomputer tomographic 2D images in order to select the right procedure for conservation and restoration. Finally, Aquino *et al.* illustrate the use of photogrammetry in 3D objects modelling, with a view to making otherwise inaccessible objects visible to the public.

Archaeological artifacts as object to be documented, analyzed and monitored for conservation over time through digital technologies are central in the papers by P. Triolo *et al.*, S. Mazzocato *et al.* and D. Giuffrida *et al.* In particular, in this last case study, which is focused on some findings preserved in the Archaeological Museum of Lipari, the virtual reconstruction is combined with the chemical analysis conducted within a 'mobile laboratory' that allows working without moving the objects from their place of preservation.

The interaction between archaeology and archaeometry continues to yield interesting results in order to solve questions on dating, provenance and originality of archaeological artifacts. In their paper, Antonelli *et al.* present the results of an archaeometric research conducted on architectural and sculptural white and polychrome marbles used in central Adriatic area during the Late Republic and Early Empire, with the aim of determining their geographical origin through macroscopic examination and laboratory investigations.

Finally, the Scientific Committee selected two additional papers (Piro *et al.* and Leucci *et al.*) presented during the 2020 Conference, in order to include the Special Session 1 'Multiscale and multitemporal high resolution remote sensing and non-destructive testing for archaeology and monumental heritage'. The session focused on new approaches to geo-archaeological data for the study of ancient sites in order to enhance the knowledge of investigated areas in relation to historical reconstruction, creation of useful tools for preventive archaeology and preservation of archaeological and monumental heritage.

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3D MODELLING FROM ARCHIVE AND LEGACY DATA: PRELIMINARY DATA PROCESSING ON THE ROMAN SHIPWRECK GRADO I

1. Introduction and state of the art

Digital technologies are widely employed to support documentation and studies of researchers, in order to make cultural heritage and maritime archaeology available. The potential of these tools allows us to obtain 3D models from data archives and legacy data that can be studied and visualized with innovative solutions and technologies (Mollema, McKinnon 2016; Atkinson *et al.* 2019; Green 2019). The creation of a virtual 3D model from disused and unattractive archive documents allows the general public to access innovative archaeological research concerning archaeological sites that are not visible or not exhibited in museums (Mertes 2014).

Usually, a large amount of data is produced during the excavation of a shipwreck; some of these, called legacy data, become essentially useless, or usable only through difficult and time-consuming processes. The recovery of legacy data represents an essential requirement to avoid the loss of relevant data (Secci *et al.* 2019; Woods *et al.* 2020). Through the processing and elaboration of different kinds of documentation and legacy data, it is possible to obtain a complete virtual 3D model in order to allow the general public to access innovative archaeological research concerning underwater cultural heritage.

The team of Maritime Archaeology of the Ca' Foscari University is working on different archaeological topics to enhance knowledge about shipwrecks through these technologies. The first project to use legacy data concerns the Napoleonic brig *Mercurio*; on this shipwreck, excavated from 2001 to 2011 (Beltrame 2019), the researchers used legacy data and scanned the negatives of the analogical images from the reports of past excavations, proposing a particular and original way to generate a virtual model of ancient shipwrecks from archival and heterogeneous data of a non-conventional photogrammetric survey (Secci *et al.* 2019). Furthermore, the brig was modelled on the construction drawings of the twin sister brig Cygne to obtain a complete virtual model and create a digital museum installation at the Museo Nazionale di Archeologia del Mare in Caorle, Italy (Beltrame, Barbiani in press).

Another project was undertaken on the Byzantine shipwreck of Cape Stoba. A cargo of wine amphoras was virtually reconstructed and arranged in the original position by processing and analysing different types of documentation realized during the excavations, from 2009 to 2015, to obtain a complete model of the cargo that can be navigated following the stratigraphic excavation and where the disposal of the nine types of amphoras can be analysed using a digital 3D database (Costa 2019).

In pursuit of these goals, the team decided to work on a more complex archaeological site, analysing and processing the documentation realized from 1990 to 2000 with different techniques, some of which, such as underwater analogic photogrammetry, are obsolete. For the Roman shipwreck of Grado, we used the perspective drawings of the shipwreck and the amphoras, various measurements taken during the excavations, the analogical images (which we have digitalized), and the cardboard study model made in 2000 in order to obtain a complete virtual 3D model in its different phases, from the hull and the cargo *in situ* to the reconstruction of the original ship before the sinking. This activity is part of the Interreg Italy-Croatia UnderwaterMuse - Immersive Underwater Museum Experience for a Wider Inclusion Project, which promotes a new kind of accessibility to a wider public through a digital approach to the underwater archaeological sites of the Adriatic Sea, both on new sites and on old excavations. The main aim of our action is the development of a methodological and technological protocol for the documentation and the communication of an archaeological site as a complex and multi-stratified context. The objective is therefore to transform the site into an underwater archaeological park (or eco-museum) through digital, innovative, and experimental methodologies and techniques in order to disseminate the importance of underwater cultural heritages.

2. The Roman shipwreck Grado I

The wreck, which lays at a depth of 15 m, 6 miles off the coast of Grado (Gorizia), was discovered in 1986 and underwent numerous excavation campaigns, from 1987 to 1999, coordinated by Paola Lopreato of the local Archaeological Superintendence, which have seen the complete recovery of the cargo and, by dismantling of each single piece, of the hull. This kind of recovery of the wooden elements was a consequence of a failed project of one-solution recovery, which compromised the entire bow of the ship that had been destroyed, underwater, by a storm. The hull, preserved for a length of 13.1 m and a width of 6.1 m before the destruction of the bow, on the starboard side reaches the level of the deck of which very little evidence is conserved (Fig. 1a) (Auriemma 1999; Beltrame, Auriemma 2013). A reconstructive study, by mean of a 1:10 scale cardboard model, built at the Centre for Maritime Archaeology of Roskilde, allowed the estimation of the original size of the ship as 16.5 m length, 5.9 m width, in the main section, and 2 m height. The model, thanks to the use of the frames and the conservation of the first planks attached to the keel (garboards), allowed the reconstruction of

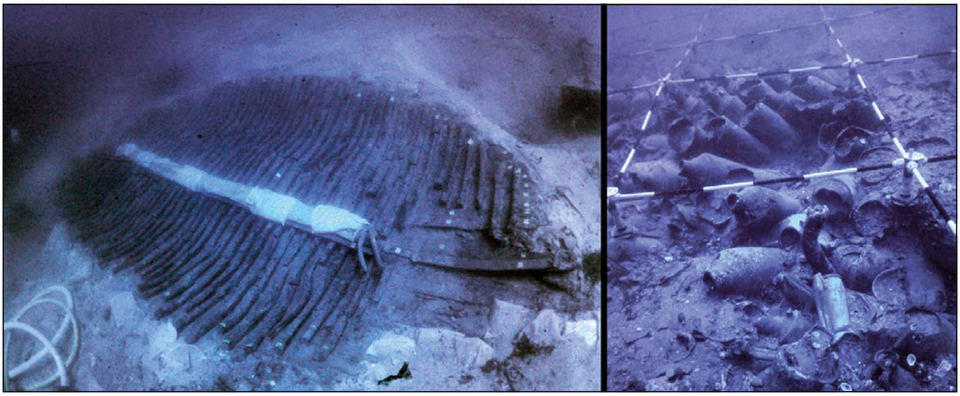

Fig. 1 – a) the hull during the excavation, after the recovery of the amphoras; b) a detail of the amphoras and the suction pump (photo Polo Museale Friuli Venezia Giulia).

the bow, despite the destruction of the planking and the loss of the junction of the keel with the stem (Beltrame, Gaddi 2000). The cargo was composed by a fragmented barrel filled with fragments of glass bottles and by different types of about 600 amphoras storing fish sauces that had been processed in various ways (Fig. 1b).

The main types of amphorae were the Tripolitana, the Knossos A/53 and a type of small northern Italian amphora, thus allowing the preliminary estimation of a total weight of the cargo of 23-25 tons and a dating of the sinking to the middle of the 2nd century AD (Auriemma 2000). The presence of a hole on the planking, close to the keel and where a lead tube was inserted, led to the hypothesis that this tube was part of a suction pump that kept fish alive during the journey (Fig. 1b). This means that the ship, perhaps before a restoration, possibly carried, on the deck, wooden water tanks for this special transportation (Beltrame *et al.* 2011).

The hull was assembled, probably in a shipyard of the Upper Adriatic littoral, using the mortise-and-tenon joints technique to connect the external planking, the deck, and the repairs of the planking. The cardboard model was made following the shell-first method, used by the Roman shipwright of this period, which implies the hull was built before inserting the frames, which only had the role of reinforcing the planking and to simply correct the shape determined by the junction of the planks.

Regarding the shipwreck, meticulous studies of the hull (Beltrame, Auriemma 2013) and the cargo (Auriemma 2000) have been realized. The surveys and studies have produced various kinds of results and data which provide an opportunity to experiment the use of this documentation to three-dimensionally reconstruct the entire shipwreck for an additional and more in-depth study of the shape of the hull; furthermore, these provide the possibility to share and disseminate to the whole public a complete and innovative visualization of an already investigated site that is no longer accessible. The original data available for the shipwreck consist of 1:1 scale perspective drawings (plans and sections) of the hull, of each single wooden element, and of the cargo of amphoras, a series of colour and black and white analogic slides and negatives to create photomosaics, a cardboard 1:10 scale model with its 2D reconstruction of the hull lines and its 3D digital model. A critical aspect of the project was represented by legacy and heterogeneous data collected during the excavation campaigns in the 1990s when the survey was obviously still not suitable to create a complex digital result. The work consists in different phases of data processing and the procedure can be schematically described as follows:

– 3D modelling of the *in situ* hull (§ 3.1);
– 3D modelling of the *in situ* cargo of amphoras (§ 3.2);
– combination of the two processing phases for the complete *in situ* shipwreck (§ 3.2);
– 3D reconstruction of the original lines of the hull (§ 4);
– 3D reconstruction of the stowing position of the amphoras (future step of the project);
– combination of the two processing phases for the complete original cargo boat (future step of the project).

3. Data processing: *in situ* shipwreck

3.1 *The hull*

The 3D reconstruction of the *in situ* hull was obtained by processing the documentation of the excavation campaigns and the 1:1 scale documentation of every wooden element made by C. Beltrame and D. Gaddi in the laboratory after the dismantling and recovery of the hull. We used the software Rhinoceros for the elaboration of the 2D and 3D models. First, we modelled the frames and longitudinal elements, tracing the 2D lines on the 1:1 perspective drawings made in the laboratory that had been extruded, cut on different planes and joined to obtain a 3D model of every structural wooden element of the hull. Second, we moved them to the correct position, based on the *in situ* plan. Indeed, the original excavation drawings concern two maps, the first with the entire hull (external and internal planks, frames and longitudinal structural elements), the second with the highlighted structure and disposition of the frames. These elements were rotated consistently with the correct sections of the hull, obtained from the recovery project, which included a structure to lift the entire hull, designed at regular graphic sections every 50 cm

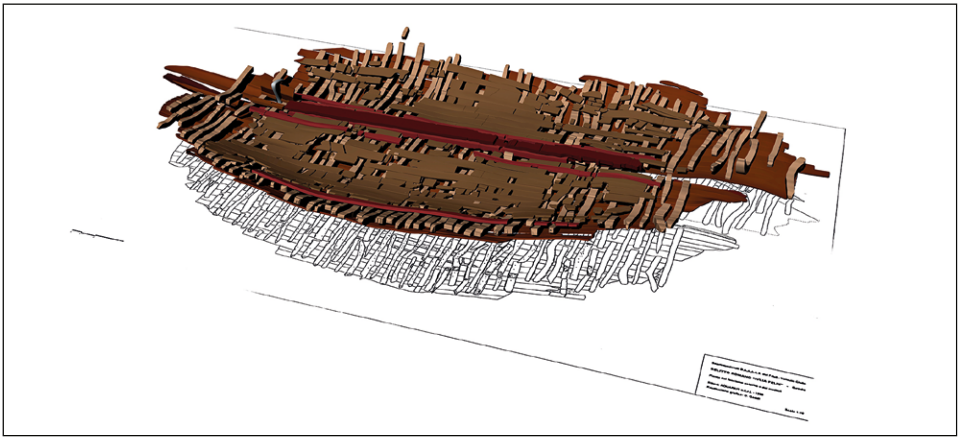

Fig. 2 – 3D model of the *in situ* hull (elaboration E. Costa).

on the hull; each of them was extrapolated and transversally placed in the correct section position extracted from the drawings of the structure. The external planking was created as a unique surface projected from the bottom onto the frames to maintain the perfect corresponding shape, it was extruded on the measurement of the thickness of the planks and was subdivided into twelve planks of the port side and nineteen planks of the starboard side, consistent with the correct shape from the drawings. The complete model of the *in situ* hull was subsequently compared and adjusted with the millimetric measurements of the archaeological sections, manually realized during the excavation. Every fragment of the inner planking was created on the *in situ* plan of the site and was leaned on the frames (Fig. 2).

3.2 *The cargo of amphoras*

The model of the cargo of the amphoras was created using two different procedures, which were subsequently compared and integrated. The excavation phases of the cargo of amphoras were documented daily in 1990 with a series of black and white analogic images designed to create a simple photomosaic. Consulting this kind of legacy data, stored in the archive of Polo Museale Friuli Venezia Giulia, was time-consuming due to the large amount of pre-processing operations. To obtain a digital workspace, the images had to be scanned and every group of images, due to their different light exposure, had to be separately enhanced and corrected in order to obtain better alignment of the images. Furthermore, the scanned images do not have Exif data and they do not maintain the parameters of digital images (position of principal point, focal length and distortion of the lens) that had to be employed by

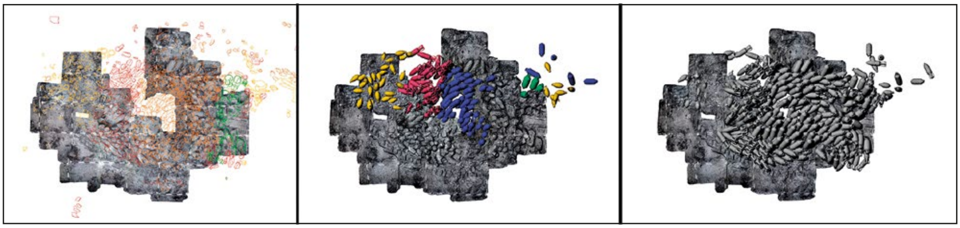

Fig. 3 – a) 1990 photogrammetric survey and vectorization of the 1995 plan; b) photogrammetric survey with the missing amphoras; c) photogrammetric survey with all the amphoras of one layer (elaboration E. Costa).

Fig. 4 – 3D model of the *in situ* hull and cargo (elaboration E. Costa).

photogrammetric software to create the inner orientation. A sufficient overlap and the automatic camera calibration of the software Agisoft Photoscan allowed the alignment of the images, the creation of a dense point cloud and the elaboration of a 3D model.

We had to retrieve the metric data from the plastic grid on the site that was regularly built every 1.50 m; the insertion of the obtained coordinates optimized the system convergence during the alignment phase of the images and improved the metric accuracy of the photogrammetric model. This alignment of the images is therefore metrically correct and the check with the coordinates on the sites could be defined as the correctness of the entire photogrammetric model, even without the digital parameters. We obtained four different projects of the excavation phase, which will be useful for future works regarding the dissemination of the procedures concerning excavation of an underwater archaeological site with amphoras and a hull. For this study

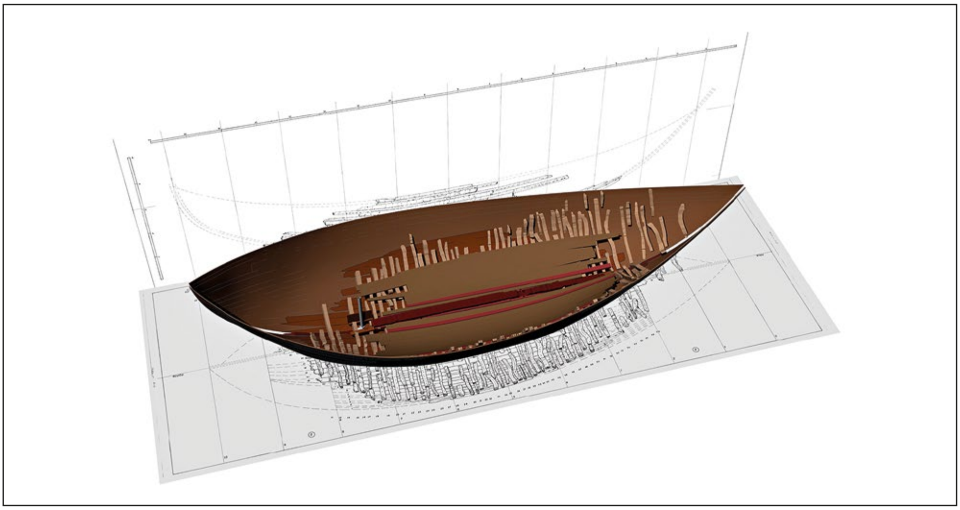

Fig. 5 – 3D model of the original lines of the hull (elaboration E. Costa).

we decided to document the last phase of the excavation process with this technique, which represents more than half of the cargo of amphoras.

In 1994 the cargo was completely excavated and, before the recovery of all the amphoras, an archaeological plan of the cargo was realized (Auriemma 1999). The plan was employed to integrate the 1990 photogrammetric survey with its missing parts. The software Rhinoceros was used to virtually model the amphoras and to overlay and integrate the two surveys (Fig. 3a). The two surveys perfectly correspond, and first we integrated the missing amphoras from the 1990 photogrammetric model and those in the 1994 plan (Fig. 3b), then we modelled all the amphoras of one layer (Fig. 3c).

To reconstruct the entire cargo, despite the photogrammetric model, we reproduced the same analytical process of the Byzantine shipwreck undertaken in 2016-2019 (Costa 2019), processing the 3D prototypes model of the seven typologies with a 360° revolution of the archaeological drawings together with the integrations of the handles. We matched each model with the photogrammetric model and with the existing plan, positioning xy coordinates on the drawings and z coordinates according to the overlapping of the amphoras and the measured vector from the feet and necks. The typologies of amphoras were differently coloured and modelled in seven different layers, allowing the analysis of their disposition on the site and facilitating the reconstruction of the original stowing position. The two processing phases were combined and the 3D model of the hull was integrated with the cargo of amphoras to obtain the complete *in situ* shipwreck (Fig. 4).

4. Data processing: reconstructed hull

After the excavations and the recovery of the shipwreck after dismantling (given that the single recovery solution failed), the hull lines were studied through the building of a 1:10 scale model in cardboard and plexiglass realized at the Centre of Maritime Archaeology in Roskilde by C. Beltrame and D. Gaddi (Beltrame, Auriemma 2013). This was subsequently surveyed, by the same researchers, using a measuring Cam2 Faro Arm to obtain a schematic geometric model of the constructive lines in correspondence with the frames and the planks. The cardboard model was also manually surveyed by G. Penzo (2000) to create the plan and the prospect of the starboard side. These data were integrated and compared to obtain the digital model of the preserved part and of the hypothetical lines of the hull.

First, we reconstructed two different surfaces, one on the transversal sections of the hull lines, manually surveyed, and one on the vector lines of the Faro Arm survey, but, since none of them naturally shaped, we decided to use the potential of digital tools to adjust some sections reaching a correct surface at a medium solution between the measures of both surveys. To check the correctness of the created surface of the hull, the scale cardboard model was surveyed with photogrammetry obtaining a point cloud used as a comparison. After that, we projected the original shapes of the existing planks on the surface, based on the 1:10 drawings of archaeological remains of the hull and we cut it into the twelve and nineteen existing portions of the hull. Then, the frames were duplicated from the *in situ* model and were rotated to perfectly match the surface, confirming the accuracy of the reconstructed shape of the hull lines. The inner planking was created on an inner surface in contact with the frames, reconstructing the original lines from the fragments (Fig. 5).

5. Conclusion

The next step of the activity on the Grado I Roman shipwreck will be the reconstruction of all the missing elements of the ship, showing, with different colours, the archaeological remains, the elements reconstructed on the basis of existing sources, and the elements completely reconstructed on hypotheses or comparisons with other shipwrecks. The work regarding the cargo, in contrast, will continue with the reconstruction of all the amphoras in the stowing position, before the sinking, starting from the disposition of them on the *in situ* model of the cargo. Then, the amphoras will be rotated from the tilted position of the sinking to the vertical position of the original cargo and will be moved in the stowing place, in correspondence of the frame and inner planking of the reconstructed hull.

Concluding, the recovery of archive and legacy data represents an essential requirement to avoid the loss of relevant information, but, at the same time, this kind of survey and documentation presents some critical aspects that could be resolved with a solid know-how in digital techniques. This work, as an action of the Interreg Italy-Croatia UnderwaterMuse - Immersive Underwater Museum Experience for a Wider Inclusion Project, wants to promote a digital accessibility for a wider public, following the main aim of the projects to disseminate the importance of the underwater cultural heritage. Digital technologies and innovative solutions allow the new visualization of sites that had not been available to the public before, such as the Grado I shipwreck.

At the same time, our work aims to focus on the relevance of the reuse of legacy data as an important tool in studying and analysing old documentation on shipwrecks; recreating an archaeological site through virtual technologies opens up the possibility of continuing the study of a site even after the archaeological investigation has ended, improving the scientific process of archaeological research.

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ABSTRACT

Ca' Foscari University is addressing different archaeological issues to enhance knowledge about shipwrecks through digital technologies. In the last few years, the team has applied virtual modelling and digital techniques on archive and legacy data, starting with an innovative museum installation regarding the wreck of the Napoleonic brig Mercurio and cargos of amphoras of the Byzantine shipwreck of Cape Stoba. The potential of digital technologies has allowed us to analyse and elaborate different kinds of documentation, including archives, to obtain 3D models that could be studied and visualized with innovative technological solutions. The paper presents an original proposal to create a 3D virtual model of an ancient shipwreck based on archival and heterogeneous data. Regarding the Grado I Roman shipwreck, we processed perspective drawings of the hull and the amphoras, measurements during the excavations, digitalization of analogical images and of a survey of the cardboard scale model to obtain a complete virtual 3D model of the shipwreck. Legacy data represent a precious source for bringing to life obsolete representations of cultural heritage.

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DEVELOPING AN ABIM SYSTEM: A NEW PROSPECTIVE FOR ARCHAEOLOGICAL DATA MANAGEMENT

1. Introduction

The widespread use of 3D topographical data in the research and conservation of archaeological assets has made it essential the set-up of new workflows, which could allow its best application and a successful interface with traditional documentation. High-resolution surveys obtained from laser scanning and photogrammetry are very often employed for the extraction of two-dimensional information (plans, sections, orthophotos, etc.) while most 3D data remain still underused. A large part of the studies in the field of managing heterogeneous data from cultural heritage research has shifted the focus from 3D GIS implementation to the creation of BIM (Building Information Modelling) applications for cultural heritage (Conor, Murphy 2012).

The BIM combines the ability to manage and visualise 3D data with the typical functions of a digital information system standing out because of its scientific accuracy. In the archaeological domain, this approach allows the creation of a complete and accessible data 'container', in which every single aspect of the asset can be immediately available for different purposes (preservation, fruition, maintenance and valorisation); furthermore, a BIM system let the information for future researches available.

BIM was conceived as an integrated system for the design and management of modern civil infrastructures (Eastman *et al.* 2008), but already in the first decade of the 2000s, its potential was tested in the field of the analysis of historical architectural heritage. From multidisciplinary studies the terms HBIM (Historical or Heritage BIM) and then ABIM (Archaeological BIM) were coined. HBIM was designed with the intention of suggesting an advanced methodology to control the processes of management, maintenance and enhancement of historic buildings (Murphy *et al.* 2013). More recently, from the wider HBIM approach a more specific application area was experimented in archaeology; this innovative methodology, named ABIM (Garagnani *et al.* 2016), is focused on the combination of digital survey of the existing archaeological remains with parametric reconstruction of structures, and, above all, on the strong presence of peculiar and often unique elements, distant from the 'traditional' modern structural types. If in the HBIM approach, the building technique and the design can be identified analysing the architectonic elements, in ABIM quite often the architectural components can be supposed only on the basis of the surviving archaeological remains. ABIM supports a more reflexive reconstruction which merges a typical 3D modelling workflow with the checking of different or alternative hypothesis. ABIM project combines 3D graphical data with a description of the archaeological interpretation.

BIM, with its innovative ability to connect aspects of civil engineering with data from analyses of antiquity disciplines, allows a greater transparency of reconstructive hypotheses that are fundamental basis for the research. As far as the use of BIM for historic buildings is concerned, many scholars focused on the way to adapt this approach to the architectural heritage, taking into account that parametric modelling of existing monuments leads to greater complexity (geometric and semantic) in relations to a new design (Potestà 2020).

Since it is indisputable that in the HBIM approach the 3D survey represents an objective starting point for the interpretation of the monument (Centofanti *et al.* 2016), it must be also considered that important information comes from the analysis of the buildings, often in a good state of preservation. Furthermore, fundamental data arise from the knowledge handed down through ancient texts, from the construction techniques, and as well as from the comparison with contemporary buildings.

The HBIM approach cannot be applied in the archaeological field, where often only few centimetres of the structures are preserved, or even only at foundation level. In this context, virtual reconstruction is widely used to hypothesise the likely shape and dimensions of buildings. As the BIM software are based on standard libraries for contemporary building objects, the use of BIM in archaeology requires the creation of specific libraries for the management of ancient architectural elements. This step is not automated and is often quite complex, as it involves the identification of the semantics behind the buildings and its construction techniques (Kreider 2013).

In addition to the geometrical data, ABIM can also contain countless detailed heterogeneous information (photos, drawings, descriptions, annotations) regarding the monument or single parts of it (Bosco *et al.* 2019); from this point of view ABIM is a large archive allowing to link any kind of data, particularly useful for the management of complex architectures or buildings. In this way, an effectively enriched ABIM can be the reference basis for philological, transparent and verifiable reconstructions of any archaeological evidence, as well as a virtual place on which the different professionals, working on the maintenance and valorisation of cultural heritage, can operate. The complexity of the archaeological evidence within a 3D representation must be classified by identifying each individual element that composes it; this process allows the recognition of the structure, function and level of detail to be achieved in the parametric modelling phase. The BIM objects are thus identified and their parameters and the level of information and detail with which they will be coded are established. Categories and types are defined

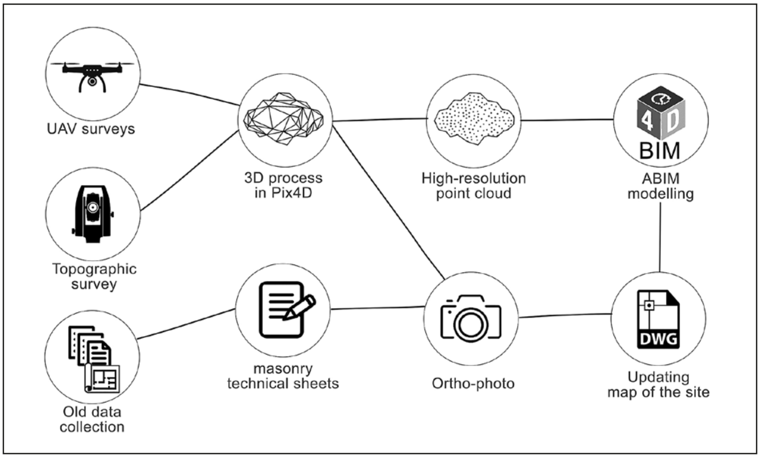

Fig. 1 – Workflow for the reconstructive analysis of *insula* 4-6 of Paestum.

and the chronological phases are assigned. Only at the end of the semantic definition the modelling phase starts. It is therefore essential to correctly define a methodological approach and a precise workflow according to the software chosen for the implementation.

This contribution shows the approach adopted for the reconstruction of the *insula* 4-6 of Paestum. The ABIM contains a digital survey of the existing structures carried out by aerial photogrammetry and an accurate modelling of the still visible walls; the information system has been enriched with the aim to analyse and manage multiple elements of the archaeological buildings (Fig. 1).

2. Paestum: the *insula* 4-6 project

In 2018, a collaboration between the Archaeological Park of Paestum and the University of Naples "L'Orientale" started to re-examine *insula* 4-6 of Paestum. This area has been investigated in the past several times, but despite the numerous on-field investigations, the documentation (photos, drawings, stratigraphic reports) is extremely scarce; the stratigraphical analysis misses completely and the only method to set a date for the archaeological evidences is to study the masonry and the constructive techniques.

The *insula* 4-6 dates back to the Late Republican period with several remakes at the end of Republican age and the beginning of Imperial age. The area has a N/S orientation and it is about 273 m long and 35 m width, corresponding to 120 Roman *actus*. In the northern part there is the large *domus* with a double *atrium* and peristyle and, after a slight variation in altitude, there are the rooms of the *thermae* built on the edge of a large open space, identifiable as the *palestra*. Toward South, there is another house, with the *atrium* and the peristyle clearly visible, while the limits of another possible *domus*, located in the southern strip of the block, appear less precise. This area has never been studied in deep and published, except for minor restoration and maintenance operations (Bosco *et al.* 2019).

The building structures, which characterise the *insula*, are preserved to a minimum height. As these rooms have been frequented for a long time and, therefore, have undergone great changes over time, it is not always clear what was their function in a different phase of life. Therefore, in order to better investigate the chronology, the extension and the organisation of the public and private buildings inside the *insula*, a new approach, based on the creation of a BIM for the archaeological needs, was chosen. Since the modelling process anchors its effectiveness on the true geometric transposition of reality, the survey is of fundamental importance. The so-called 'scans to BIM' process of reverse engineering marks the foundation that supports the entire subsequent parameterisation process.

The characteristics of *insula* 4-6 of Paestum have oriented the choice of surveying the existing structures, by means a photogrammetric acquisition by drone, supported by topographic anchorage to the georeferenced network of the Park. Archaeological research is increasingly using remote sensing methodologies and devices such as UAVs (Unmanned Aerial Vehicles), thanks to the evolution that, in recent years, has made these tools extremely versatile and precise (Remondino 2014). *Insula* 4-6 has an extension of approximately 12,000 m^2 and is located in an area of the Park that is relatively marginal to the visitor route. The almost total absence of obstacles that could hinder the path of the drone allowed a more accurate data acquisition from a low altitude with a consequent increase in the acquired details.

A DJI Phantom 4 was used for the shooting, while the alignments and dataset overlays were done with Pix4Dmapper software. Thanks to the targets arranged in the acquisition area and captured with the aid of the total station, it was possible to rotate the project on the coordinates of the network used by the Park (Bosco *et al.* 2020). The entire process generated a coloured point cloud of 3,897,284 million points. Several layers of information were extracted from the 3D survey, including a high-resolution orthophoto that allowed to quickly update the CAD plan provided by the Park.

3. The ABIM development

The coloured point cloud generated by the aerial photogrammetric survey and the 2D planimetry provided by the Park represent the geometric bases on which the ABIM model was created. After the necessary conversion

Fig. 2 – A partial 3D view of the point cloud in BIM.

of extensions for its correct reading, the point cloud was loaded into the BIM software[1] providing a 3D reference for the modelling of the parametric objects (Fig. 2).

The same cloud was the basis for the creation of the topographical reference surface, indispensable for the correct positioning of the model. To this purpose, the cloud was simplified[2], saved in .txt format and then loaded into the BIM project. Thanks to the geometric and environmental information provided by this data, it was possible to set up the 'reference levels'; the level has guided the construction of the ABIM allowing the design of specific plan and section views. To define semantic relations, the 'wall' object was chosen as a basic unit on which to build the hierarchy of the different architectural elements; the wall defines the semantics of the built environment as well as the LOD (Level of Detail) of the archaeological analysis.

Same families elements were modelled, based on the point cloud, by modifying the system families in the software on the basis of ancient technical construction knowledge (e.g. definition of the stratification of the specific construction technique and materials associated with it) (Fig. 3); for other

[1] Autodesk's BIM software Revit Architecture.

[2] In the open source software Cloud Compare.

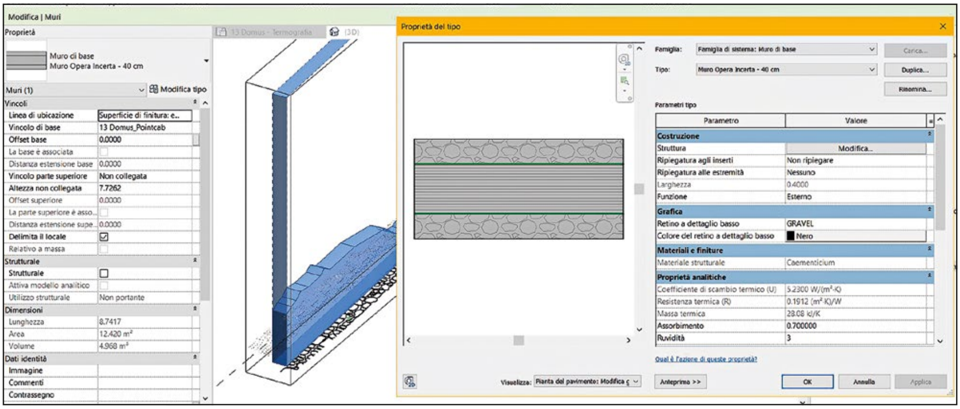

Fig. 3 – An example of a modified system family based on ancient construction techniques.

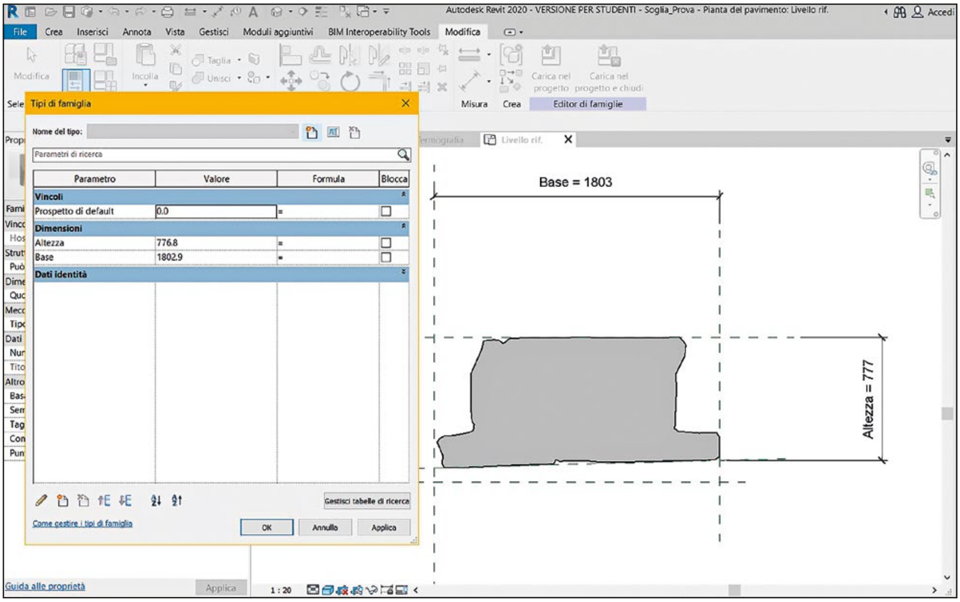

Fig. 4 – Creation in the 'local family' environment of the parametric object 'threshold'.

objects a new family was identified starting from a category of pertinence (e.g. structural, hydraulic, decorative, etc.) and the objects were parameterised, as local models, by defining their dimensions and their variation on the basis of specific measurements obtained from the study of local techniques (Fig. 4).

The specific characteristics of the objects, such as restoration interventions (ancient or modern), phases, state of preservation, etc. were added thanks to the associated information structure. For example, the chronology is annotated in a field dedicated to temporal references; this value can easily express the chronological period of the construction of the entity and its defunctionalisation. The single stratigraphic units, the analysis of degradation or the reconstruction of decorative systems are, instead, defined and noted in special 'views' linked to the specific object and, therefore, easily recalled for inspections and updates. The Properties tab of each object in the model can also be enriched with information through external links. In this way, it is possible to attach photos, archival material such as drawings, texts, and databases of different nature, including detailed 3D surveys, to the single entity.

4. Results

In the framework of the *insula* 4-6 Project in Paestum, a methodological workflow for the creation of an ABIM for data management aimed at the study, use and maintenance of the site, has been developed. Starting from the acquisition of 3D data by drone, the parametric modelling workflow was defined through several phases:

– pre-modelling, which has involved the definition and cataloguing of archaeological objects, construction techniques and specific materials;

– modelling, which has included the creation of archaeological parametric families, whose geometric accuracy was constantly verified through the point cloud provided by the 3D surveys;

– the informative enrichment of the model, which defines numerous aspects comprising the state of conservation and the type of construction; these documents were attached as external reports (e.g., photogrammetry, wall stratigraphy and degradation sheets).

An important aspect focused during the elaboration phases was the identification of the LODs (Levels of Development or Levels of Detail, based on American or Italian legislation), which establish the degrees of accuracy in the virtual rendering of the object in BIM. On the basis of the studies carried out, the concept of LODs has to be completely redesigned for the archaeological needs. In the archaeological field the level of detail of an ancient object is linked to its chronological phase and to its state of preservation, unlikely classifiable as real levels of detail in modelling. The evaluation of the Reliability Level, which takes into account both the geometric conformity and the ontological accuracy of the model with reference to the described reality, has been considered as a valid solution (Maiezza 2019). There is a need for an evaluation system of archaeological objects and models in the BIM environment, LOD for archaeology, which takes into account the specificity of objects whose specific function is closely linked to the chronological context of reference.

For the ABIM of *insula* 4-6, it was decided to enhance the information aspect of the BIM system and to identify increasing degrees of detail in the rendering of BIM objects based on the information related to them. In the 'architecture' section of the software, new 'families' were set up, associated with system types. The creation of libraries of archaeological objects allows to deepen the knowledge of the individual parts of the structure, to organise and plan the documentation to be produced and to attach it directly to the individual parametric element. In addition, ABIM, by bringing together all the geometric and information levels in a single virtual environment, has made it possible for the various specialists involved in the management and valorisation of the asset to access the data, simplifying interrogation and avoiding the loss of data.

5. Conclusions

The archaeological excavations carried out over the years in *insula* 4-6 of Paestum have left a scarce and inaccurate documentation. This has caused the loss of stratigraphic information and structural relationships. Only a detailed analysis of the masonry makes it possible to identify the relationships between the buildings, so as to provide a reconstruction of the life of the *insula* and its changes over time. By means of BIM, the research aims at unifying in a single system the possibility of operating reconstructive hypotheses on the real masonry, guaranteeing its structural reliability and allowing the management of heterogeneous data typical of archaeological research.

The paper, through the case study of Paestum, highlighted how it is possible to apply a BIM approach to an archaeological context, starting from the creation of specific families related to the well-known building typologies of the Roman and Late Antique periods. The creation of standard libraries based on the existing architectural and masonry elements makes the modelling phases particularly complex as the geometrical characteristics are linked to verifiable and reliable measurements and parameters. Furthermore, these libraries can be easily exported in interoperable format and reused for other archaeological sites.

The great versatility of the software's database interfaces makes it possible to customise the records by allowing the inclusion of standard entries for archaeological documentation. This parametric system thus becomes an interactive and interoperable container of archaeological objects, 3D geometric and environmental information, more powerful than a 3D GIS application. The choice was made to optimise the modelling of structures at an intermediate LOD, leaving the more detailed documentation to the annotative functions of the single instance and allowing the linking of multiple data extensions.

Future research perspectives will include the creation of guidelines for BIM application in archaeology; the challenge will be the implementation of open standard libraries covering different sectors of the archaeological domain. This approach will encourage the reuse of data in a multidisciplinary framework and will facilitate the overcoming of the limitation of GIS in 3D management.

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ABSTRACT

In the framework of a collaboration between the Archaeological Park of Paestum and the University of Naples “L’Orientale”, in 2018 the study of the *insula* 4-6 of Paestum has been resumed. The paper shows the so-called ABIM (Archaeological Building Information Modelling) methodological approach that involves combining digital survey with parametric reconstruction of the structures. The study aims to provide a complete information system useful for different purposes, from documentation to interpretation and management of archaeological data, with a special focus on standards and interoperability. For this purpose, CISA (Centro Interdipartimentale di Servizi di Archeologia de “L’Orientale”) carried out an aerial digital survey to provide a detailed and updated map of all the structures still visible, while the point cloud was used to develop the archaeological BIM.

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ROME: NE SLOPES OF THE PALATINE HILL. ARCHAEOLOGY OF ARCHITECTURE AND ANCIENT MASONRIES DEEP ANALYSIS

1. Introduction and archaeological framework

Since 1986 the area of the North East slopes of the Palatine hill facing the Colosseum valley has been the subject of a long archaeological research, carried out by the Dipartimento di Scienze dell'Antichità of the Sapienza, University of Rome[1]. During more than 30 years of excavations, the material remains of big buildings and monumental interventions have been discovered, testifying an environmental and topographical *continuum* where the development of different urban systems has involved a complex physical overlap of structures and architectural complexes, distributed over time (Fig. 1). Starting from the remains of Iron Age huts, found along the slope, we move on to an early urban planning attested by the presence of two sanctuaries dating to the Roman Monarchy (8th-7th century BCE) located along both sides of the ancient road leading to the Roman Forum: one of them can be identified with the *Curiae Veteres* and has been frequented until the affirmation of Christianity.

The installation of a residential district, along the road, is documented already during the archaic period: subsequently this area has been periodically rebuilt in the following centuries, until Augustus age. In this period, at the meeting point of five of the new 14 city zones planned by the emperor, the first *Meta Sudans* fountain was built, in front of the *Curiae Veteres* that were also reconstructed in monumental shape during the years of the emperor Claudius.

A real break-up here happened in conjunction with the great Nero's fire: after this disaster, Nero decided to carry out in this area a deep urban transformation ending with the realization of his majestic palace, the *Domus Aurea*. In the years between 64 and 68 CE a total reorganization of the road system was made, with a regular and orthogonal shape, according to the guidelines dictated by the palace project. In the valley the new architectural complex was characterized by columned porticoes around an artificial pond over which the Flavian dynasty will build the amphitheater; the Palatine hill slopes were regularized in terraces on arcades, while the new street climbing to the Roman Forum was flanked by arched porticoes.

The Flavian urban planning, focused on restoring a public dimension to the urban spaces occupied by the *Domus Aurea*, can be summarized in the

[1] We want to thank Prof. Clementina Panella for giving us the opportunity to participate, for long time, to her research; we also want to thank the staff of the Parco Archeologico del Colosseo (MIBACT) for the permission and support to our work, in particular Dr. Giulia Giovanetti.

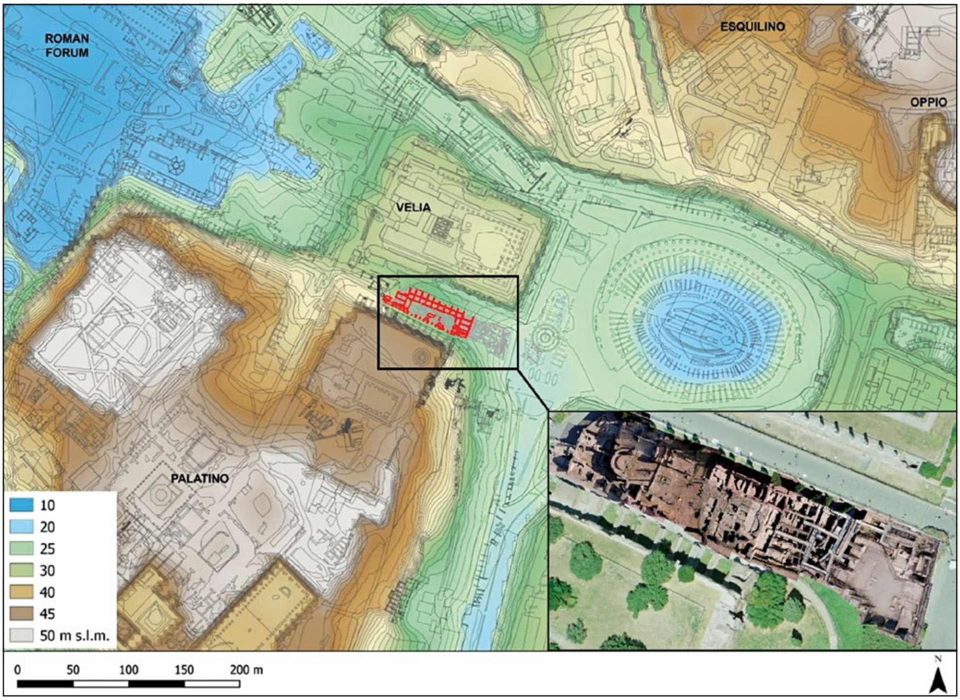

Fig. 1 – The investigated area in the centre of Rome.

reconstruction of the *Curiae* and the *Meta Sudans* fountain, both burnt in the fire, and, of course, in the construction of the Colosseum and its square. The area will be modified again by Hadrian with the construction of the Venus and Rome Temple and, on the opposite side, of a long building flanking the porticoed street going up to the Forum. After another catastrophic fire, at the end of the 2nd century CE the area was rebuilt again by the Severian dynasty: in close connection with the new sanctuary built on the *plateau* of Vigna Barberini, the whole front of North East Palatine's substructures was totally transformed while the previous constructions at its feet, destroyed by the fire, were replaced by a new building with a courtyard commonly called 'Bagni di Elagabalo'. Inside this monument, in the 4th century CE, a large banquet hall was obtained, with gardens and fountains and a small bath in the backyard.

Finally, with the construction of the Constantine's Arch and the restorations at the Venus and Rome Temple, the ancient urban history of the area was completed (for further information on the urban development of this area see Saguì, Cante 2015; Brienza 2016; Panella 2019; Panella *et al.* 2019).

The huge amount of documentation produced to record this stratigraphic sequence required the development of a data storage and management system

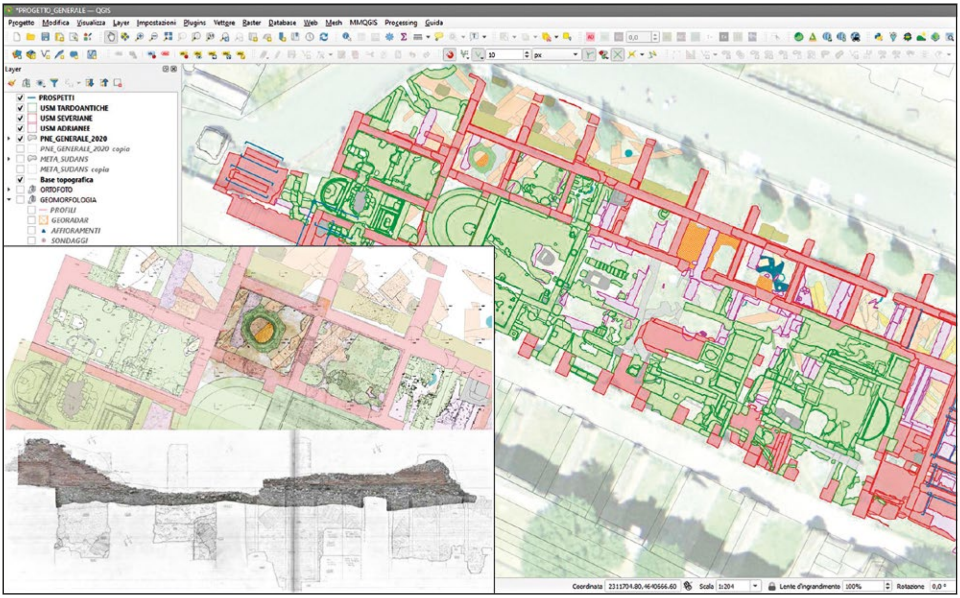

Fig. 2 – Intra-site GIS of the excavations.

dedicated to contextualize information and to propose new elements of research. The full archive is managed by an intra-site GIS for data-retrieving, spatial analysis and for the elaboration of archaeological themes and reconstructive models: this has been implemented using Microsoft Access and ESRI software, like ArcView and later ArcGIS. Over the years, this system has been updated in software, for the advent of new IT products, and in data contents: inside our spatial database, today, digital and analogical documentation (in particular handmade archaeological drawings and on-paper archaeological forms) are managed together, in order to maintain the integrity of the archive and the history of the research itself (Fig. 2) (Brienza 2006; Panella, Brienza 2009; Panella, Fano, Brienza 2015).

In order to achieve the best results in this operation, a memorandum of agreement has been approved by the Sapienza, University of Rome, the Kore University of Enna and the ISPC-CNR (Institute of Heritage Science, former Istituto per le Tecnologie Applicate ai Beni Culturali, ITABC), institution that since 2007 has collaborated with our research in particular in 3D survey and integrated geophysical prospecting (Piro 2006; Panella, Gabrielli, Giorgi 2011; Caratelli 2013; Giorgi 2013). During these years a big amount of raw data has been preserved in two different repositories, while only final elaborations were shared by the research staff: now we are working in order to unify the separate archives in a single spatial database, for investigation purposes but also for deontological instances, in order to leave a complete and single testimony of all our activities carried out in this important archaeological site during these decades.

Our intention is focused on giving access to the scientific community, but also to interested people, not only to the data (both synthetic and in-depth format) but also to the analysis system itself: paying great attention to the issues of open-data, ArcheoFOSS[2] and public archaeology (Volpe 2020) we have tested the migration of the entire dataset and its interrogation criteria and tools to an open-source webGIS platform, using web-oriented DBMS like PostgreSQL + PostGIS and GIS software like QGIS Server + LizMap.

In this new digital environment, starting from the general site map, it is possible to decompose the single architectures into their structural contexts and features, and verify the cognitive process for each one of them: passing from photos to 3D models, then to elevations, wall-samples up to the general synthesis of file-cards and records of ancient structures (Brienza *et al.* c.s.).

E.B.

2. Methods and tools

The study of ancient architectures today can adopt survey tools able to quickly detect objects in 3D with a certain precision: through these tools we have produced ortho-photo-plans that, gradually, have joined the traditional bidimensional documentation. We have also proposed three-dimensional sequences of excavated stratigraphic sequences as well as the reproduction of some ancient artifacts, suggesting their virtual-digital restoration.

Using image-based-modelling photogrammetry techniques based on Structure from Motion (having accuracy and photographic texturing) we made a new and very detailed 3D documentation of the ancient walls (about these techniques see Remondino, Campana 2014; Zachar, Horňák, Novaković 2017; Bianconi, Filippucci 2019).

For digital photogrammetry we have used the Agisof Metashape software, supported by total station to take precise measures (at least 5 targets for each façade) directly linked to our topographical network, in order to obtain an integrated and georeferenced survey. A 24.2 megapixel Canon EOS D200 reflex camera, with image stabilizer and a focal length of 18 mm, was used for the photos; in addition, a tripod and a telescopic rod were used to ensure better quality and to reach masonry sectors at high altitude; an

[2] About ArcheoFOSS, free and open-source software for archaeology, and the numerous international workshops organized from 2006 until today see http://archivio.archeofoss.org/.

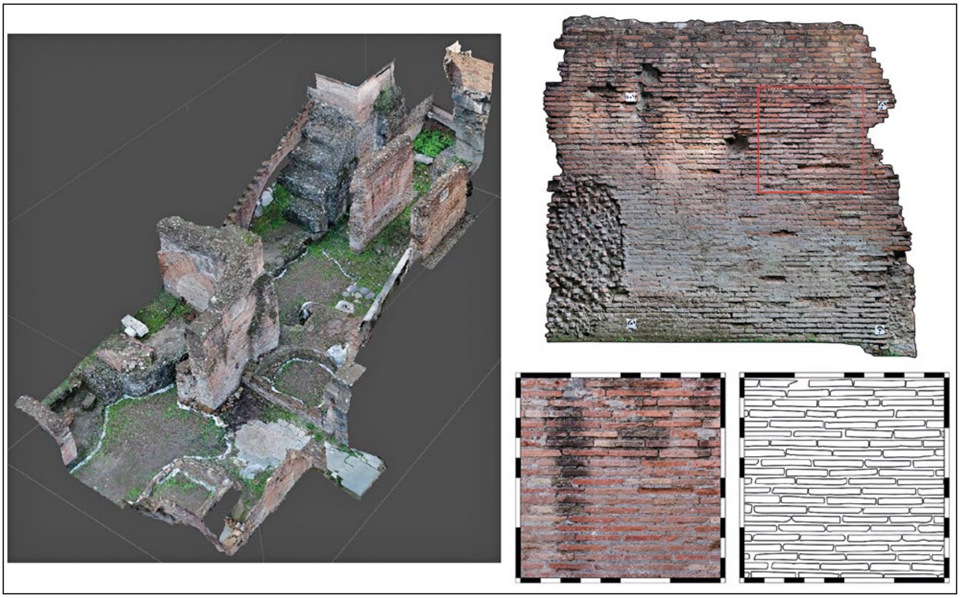

Fig. 3 – 3D survey of the ancient walls.

average of 30-40 shoots were taken for each acquisition, trying in this way not to burden the processing times.

Each wall was taken up completely, maintaining a constant distance: particular attention was paid to have a maximum accuracy survey of 1 sqm area samples, taken from facades, maintaining a maximum distance of 1 m, in order to obtain images with a high level of detail; in this way it was possible to use very-high quality orthophotos, having an average detail level between 0.2-0.4 mm pixel, for the stratigraphic reading and for samples quantifications (Fig. 3).

The new documentation included also a new Database Management System, following usual formats form ancient walls recording, but updating contents in consideration of the recent guidelines coming from the *Archaeology of Construction* and from the *Archaeology of Achitecture* (Camporeale, Dessales, Pizzo 2008, 2010, 2012; Brogiolo, Cagnana 2012; Bonetto, Camporeale, Pizzo 2014; Camporeale, De Laine, Pizzo 2016). We have planned a new file-card format to register information about the logistic of the ancient construction yards and the related dynamics on material production and ancient building organization, in addition to data relating to their measures, composition and nature.

In this way the chrono-typological analysis, which traditionally focuses on the recognition of the construction features by material aspect, has been

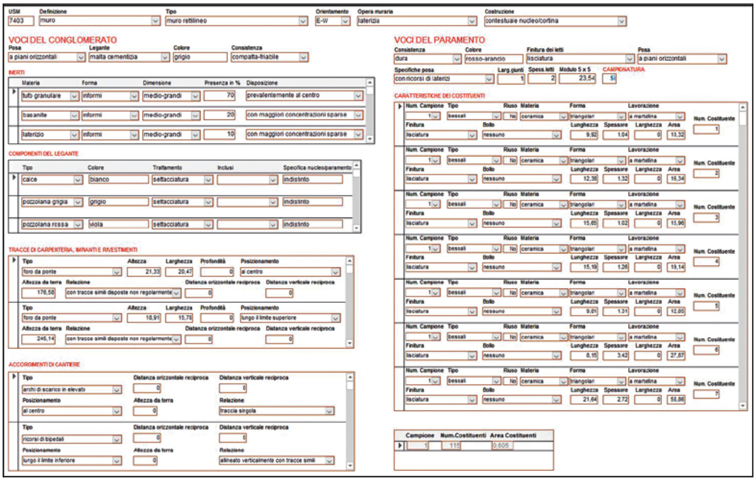

Fig. 4 – DBMS for ancient structures recording.

expanded with the collection of information related to building methods such as, for example, structural expedients for static stability, specific materials selection in relation to particular needs or quantification of the work in terms of time and number of the workers. Defining trends, measures and treatments of specific building materials can help us to identify diachronically the processes and resources of the ancient construction yards, while the stratigraphic analysis of the walls, with its identification of constructive temporal sequences, is crucial to understand the formative dynamics of the ancient architectures and must be done through observation of details on the basis of a precise and clearly legible survey. Obviously, in order to normalize the data entry and editing, we have encoded standard glossaries while the detailed morphometric information, derived from autoptic analysis of samples taken from wall facades (normally their size is 1 sqm), is managed by sub-cards where each ‘constituent’ (i.e. brick, block, etc.) is organized by type, use/reuse, material, manufacture, finishing, and measures (Fig. 4).

Elaborations from photogrammetry have been vectorized in GIS environment; for this purpose, next to the module dedicated to the analytical database of the ancient walls, a new apparatus has been created for the collection of all the data relevant to the documentary base. Here, photographs, 3D models acquired from scratch, sections and elevations, drawings and all the graphic documentation produced during the excavations, have found their place. In this way, through a simple query, it is possible to trace the whole corollary of raw and elaborated data that constitute the starting point for the analysis of each context.

For the quantifications of information coming from wall-facades-samples we have performed two GIS analysis procedures, comparing the DBMS data taken directly on the field, counting bricks and measures on wall facades, with those obtained automatically on spatial vector drawings made on very detailed orthophotos; in other words, the analyses were carried out on the same samples but using different ways: despite this, the results were indeed very similar, giving us a good indicator of a correct method.

Through the use of a series of expressions specifically dedicated it is also possible to calculate automatically and expeditiously the variable of the constituent/conglomerate ratio, but also the dimensions of the components of the facades with their degree of homogeneity and variability (about this type of investigation see Medri *et al.* 2016; Medri 2017; Serlorenzi, Camporeale 2017).

L.F.

3. Conclusions

Through the methodologies and tools described above, it is now possible to evaluate specific aspects of the ancient construction yards for each period, such as the extent of resources supply, the reuse index and building materials selection level and consequently refine the chronological sequence of the construction phases of the individual buildings. Furthermore, being able to have such a complex sequence of building interventions and referring them to public and private architectures, it is possible to plan a comparative analysis of the construction techniques adopted in relation to both chrono-typological aspects and to particular contingencies. Finally, we have a bigger chance to clarify the structural and contextual relationships of each construction yards with the surrounding buildings, in order to formulate wide-ranging and multi-temporal reconstructive hypotheses.

Some first outcomes of our work can be briefly exposed here. First of all, our 'very-close-range' photogrammetry approach to structural archaeological evidences, using very high definition shoots of samples and supported by total station, with automatic measurement of vectorial features, has given very encouraging results if compared to measures of samples directly taken, with a tape and one by one, on the ancient walls: the dimensions of bricks and other building components of the archaeological structure are always almost the same in both cases and mismatches are very few and very little.

In addiction, the colours and the type of materials can be clearly distinguished. This means that a mensio-chronological approach using this method can be correct; obviously a total analysis of building materials and their treatments (specially for mortars, concretes and conglomerates) still needs a direct autopsy, physical and material, of archaeological evidence.

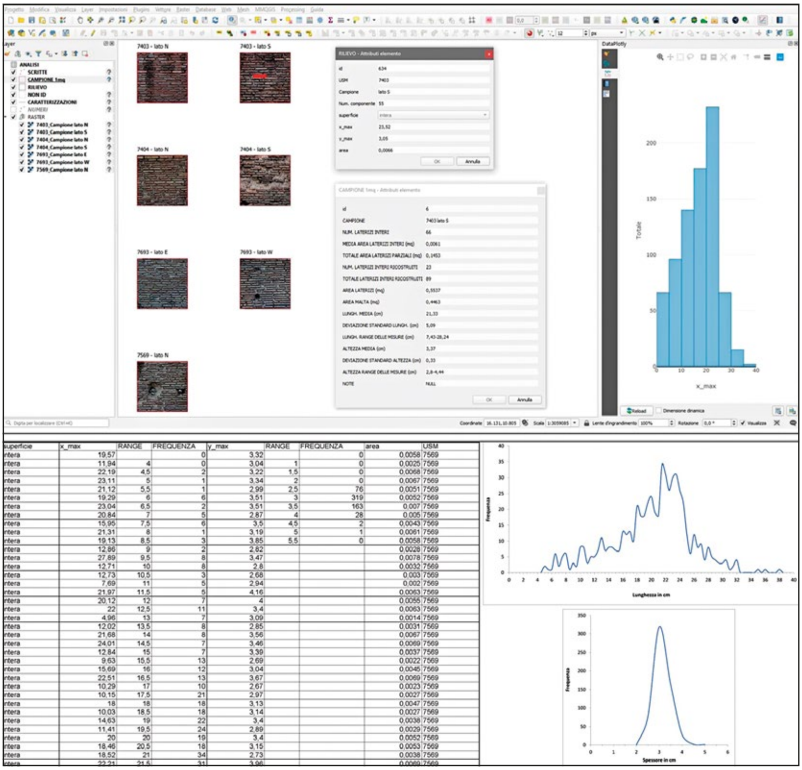

Fig. 5 – Sample analysis and statistics.

In particular cases, anyway, for emergency or during seasonal researches in foreign countries, this expeditive approach can be adopted on the field, obtaining reliable results in the subsequent study phase in the laboratory.

Another result of archaeological and architectural nature, which will be better studied during future research, concerns the accentuate reuse of building materials during the Severian age, which, compared to the topographical context (we are next emperor's palace in Rome) and the chronology (generally this building practice in the Capital is peculiar of Late Antiquity), seems to be an unusual phenomenon. However, as already detected here by a previous study of brick stamps found *in situ*, which shows the use of Hadrian's bricks in Severian masonry (Botticelli 2017), our overall analysis of the walls belonging to this period seems to confirm a very frequent use of fragmented and heterogeneous bricks that do not seem to be of new manufacture but recovered from older structures (Fig. 5). This recovery was probably facilitated by the state of the rubble after the fire of 192 CE and by the fact that the Severian brick facades were projected to be covered by decorative layers and surfaces. Despite actual pandemic situation, we hope to be soon able to clarify and to publish next developments of our research, together with our ISPC partners.

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ABSTRACT

The NE slopes of the Palatine hill and the Colosseum valley area have a long archaeological research history. Here the continuous urban development has produced the overlap of architectural complexes distributed over time. The huge amount of archaeological documents produced by the research is managed within a GIS environment. For the analysis of ancient walls we introduced the use of image-based-modelling photogrammetry in order to create a very detailed 3D documentation linked to a DBMS dedicated to ancient structural features. Through this methodology we can evaluate specific aspects of ancient construction yards for each period. We can also refine the chronological sequences of the architectural structures and verify the contextual relationships of the surrounding buildings in order to formulate wide-ranging reconstructive hypotheses.

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PRELIMINARY STUDIES ON THE VOLUMETRIC CAPACITY OF CERAMIC FROM THE NEOLITHIC SITE OF LUGO DI GREZZANA (VR) THROUGH 3D GRAPHICS SOFTWARE

1. Introduction

1.1 *The ceramic record*

The study takes into account ceramic finds from the Neolithic site of Lugo di Grezzana, which is located in the Lessini Mountains[1]. The site, dated between 5400 and 4900-4800/4700 BC cal., has been the object of decades of research directed by the Archaeological Heritage of Veneto Region (since 1991) in collaboration with the University of Trento (B. Bagolini Laboratory, since 1996) up until 2005 (Pedrotti, Salzani 2010). The site represents one of the main pieces of evidence for the understanding of occupation strategies and raw materials exploitation between the end of the 6th and the beginning of the 5th millennium BC (Pedrotti *et al.* 2015). It gave back a considerable amount of artefacts (Fig. 1) that allowed the attribution mainly to the Fiorano culture. This culture is present in Northern Italy during the early Neolithic and shows a typical homogeneity in vessels typology. Jugs are possibly one of the most distinctive shapes of the Fiorano culture and are often imported into contemporary cultures (Pessina, Tiné 2008).

Regarding the study of ceramic record, it is important to refer to the digitalization in 3D of some pottery mentioned in this paper through photogrammetry. This work was carried out at TeFALab (Laboratorio di Tecniche Fotografiche Avanzate, unit of LaBAAF, University of Trento) under the technical direction of Paolo Chistè. At the present time, a systematic analysis that evaluates the metric criteria of the ceramics of the Fiorano culture has not yet been carried out (Becker 2018). However, for the Neolithic of Northern Italy there is a typological classification of the vessels that distinguishes their morphology in relation to the profile, the diameter/height ratio and the size of the mouth (Banchieri *et al.* 1999). Nevertheless, this classification does not include the volumetric capacity parameter.

[1] The research project concerning the preliminary studies on the volumetric capacity of ceramic from the Neolithic site of Lugo di Grezzana (VR) is conducted by the research laboratory LaBAAF (Laboratorio Bagolini Archeologia Archeometria Fotografia) that belongs to CeASUm (Centro di Alti Studi Umanistici) of the University of Trento. The project has Prof.ssa Annaluisa Pedrotti as scientific manager and Paolo Chistè as technical director of TeFaLab (Laboratorio di Tecniche Fotografiche Avanzate, unit of LaBAAF). Chapters 2 and 5 is due to M. Ciela, chapters 3 and 4 is due to A. Tavella.

Fig. 1 – Vessel from the Neolithic site of Lugo di Grezzana (photo P. Chistè - LaBAAF; Pedrotti, Salzani 2010).

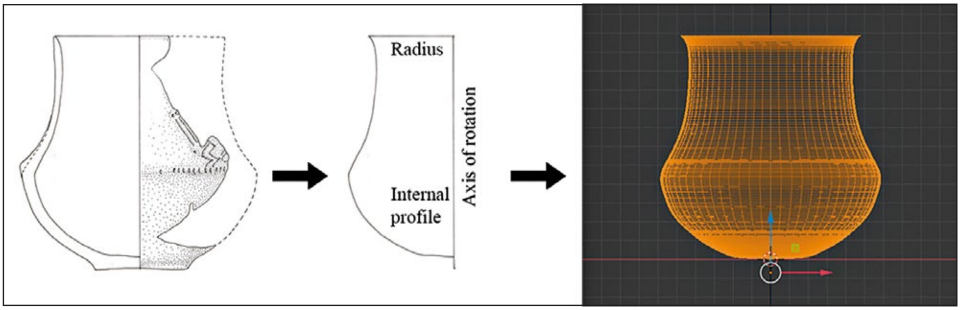

Fig. 2 – Summary scheme of the operating methodology performed with Blender.

1.2 *The calculation of volumetric capacity: the application of computer-assisted calculation through 3D graphics software*

The volumetric estimate of a pottery container can be calculated with direct or indirect methods. Direct measurements involve filling the vessel with liquid or solid materials, the latter adaptable to the internal shape. However, this method cannot be applied to the entire ceramic record, both because usually a limited percentage of the potteries are complete or reconstructed, and also for conservation issues (Engels *et al.* 2009; Rodriguez, Hastorf 2013; Velasco Felipe, Celdrán Beltrán 2019). Indirect measurements, on the other hand, are two-dimensional geometric methods and more recently computer-assisted calculations based on a 3D model. The latter, unlike direct measurements, does not require the availability of the artefact *in situ*, as the

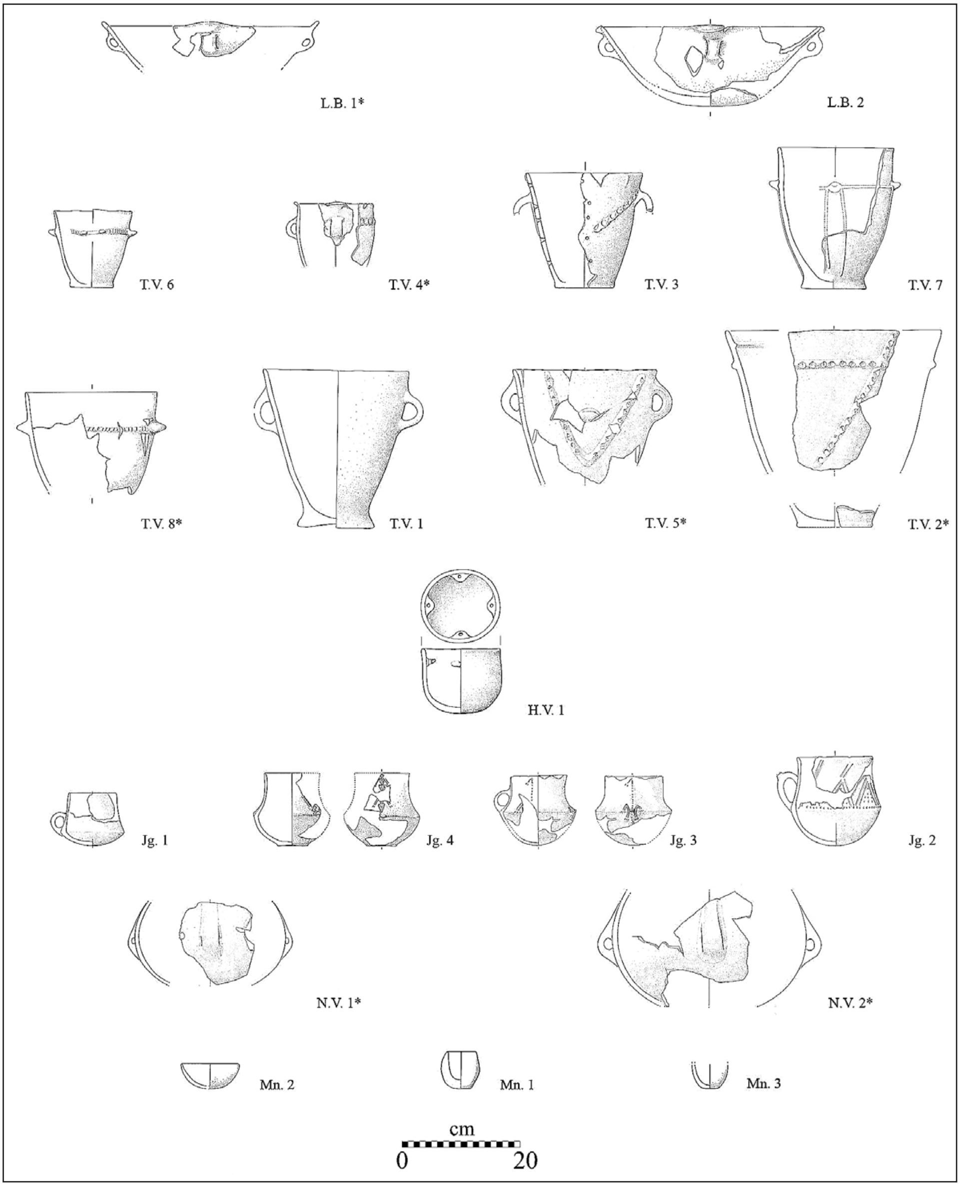

Fig. 3 – Typological table of the samples analysed during the study. Legend: H.V. = Internal Handles Vessel; Jg. = Jug; L.B. = Large Bowl; Mn. = Miniaturistic; N.V. = Necked Vessel; T.V. = Truncate cone-shaped Vessels; * = Partially preserved. Scale drawing 1:10 (Pedrotti, Salzani 2010; Pedrotti *et al.* 2015; Ciela 2019; Tavella 2019).

measurements are carried out using archaeological drawings, which have a continuous profile from the rim to the bottom, exploiting the principle of symmetry (Velasco Felipe, Celdrán Beltrán 2019). Pre-protohistoric artefacts often have an asymmetrical and irregular profile and are therefore an exception. The main software that can be used to apply the previously described indirect method are: AutoCAD, Rhinoceros and Blender (Sánchez Climent, Cerdeño Serrano 2014). In addition, other suitable programs as Kotyle (https://kotyle.readthedocs.io/en/latest/index.html#) and web applications like Capacity (https://capacity.ulb.be/index.php/en/research-center-in-archeology-and-heritage/; Karasik, Smilansky 2006). In this study, the 3D graphics program of choice was Blender since it is free and open source, which allows the users to generate extensions in order to improve it. The estimate of the volumetric calculation was relied on the 3D-Print Toolbox extension, although different add-ons are known to be effective as well (cfr. *supra*).

2. Materials

The methodological protocol was applied to a selection of 20 archaeological drawings (Fig. 3). The sample analysed was chosen taking into consideration typological and technological data. Twelve drawings illustrate whole artefacts, with a continuous profile (from the rim to the bottom of the vessel), while the others are only partially preserved. Hence, in order to reconstruct the original morphology, the drawings of the fragmented samples were integrated through the study of whole ceramic vessels belonging to the same typological class. For this group of samples is essential to keep in mind that the capacity estimate will have a greater degree of inaccuracy. The development of the operational methodology allowed the identification of the minimum requirements that the ceramics and the drawings must have. First of all, through the graphic representation it must be possible to obtain the diameter and the internal profile. Furthermore, it is necessary to know the scale of representation because the calculation of the volume must be obtained on a 1:1 scale. Lastly, it was observed that using a high-resolution drawing (d.p.i.) allowed a more accurate 3D model of the interior wall of the vase.

3. Methods

The calculation of the volumetric capacity was initially carried out by importing each drawing into Blender. The image was imported providing the exact graphic resolution of the file (d.p.i.). This step is necessary in order to avoid any changes in the original dimensions of the imported drawing which would therefore entail an incorrect estimate of the volume. Once this phase is finished, is possible to start with the generation and subsequently modelling the curve, dividing it into several segments in order to trace the underlying drawing. After obtaining a 2D profile of the inside of the vessel, it is necessary to generate a path, which will correspond with the rotation axis of the curve itself and with the midline of the archaeological drawing. Once the rotation axis is fixed, the curve can be rotated 360 degrees. As soon as the command is selected, it is necessary to define some options, namely: the Cartesian axis to which the curve is oriented, the object around which the rotation takes place and lastly the number of 'segments' the revolution is divided into, as a greater number of these entail a better graphic resolution and consequently a more accurate estimate of the volume. The rotation surface is converted into a solid by obtaining a mesh, and afterwards the solid is closed at the rim and at the base.

Once the solid is closed, the calculation of the volumetric capacity is performed automatically using the add-on 3D-Print and volume value expressed in cm^3 will be available in the *Result* box (Fig. 2). The validity of the procedure was previously established during the formulation of the method, through the graphic reproduction and the volumetric calculation of a cylinder of known dimensions (r = 5 cm; h = 20 cm). This procedure allowed to calculate the absolute and relative error in the method developed, taking into account the tolerance. The latter is characterized by different causes such as: the inherent uncertainty regarding the measured object, the conservation status, the operator, the procedure and the measuring instrument used. Taking these issues into account, it was calculated a tolerance of about ± 1 mm.

$$\text{Absolute Error (EA)} = (Vol_{max} - Vol_{min}) / 2 = 70.6889\ cm^3$$
$$\text{Relative Error (RE)} = EA / Vol_{avg} = 0.0449$$
$$\text{Percentage Error (PE)} = RE \times 100 = 4.49\ \%$$

The methodological approach was subsequently extended, considering two hypothetical types of contents, a liquid and a solid one. As to what concerns the estimate of the capacity, it has been treated converting the measure from cm^3 to ml (1 cm^3 = 1 ml). Instead, in the case of solids contents has been calculated the weight (grams) of three types of cereals such as: whole barley, emmer and naked wheats, selected accordingly to the data collected from archaeobotanical analysis carried out for the site of Lugo di Grezzana (Rottoli *et al.* 2015). The weights were estimated in relation to the bulk density of each kind of cereal (whole barley 0.61÷0.69 g/ml, emmer 0.47 g/ml e naked wheats 0.54 g/ml) (http://www.fao.org/infoods/infoods/tables-and-databases/faoinfoods-databases/en/; Güran 2009) and the volumes of the containers, according to the following formula:

$$\text{Weight} = \text{Bulk density} \times \text{Volume}$$

Lastly, metrical analysis were carried out through the correlation of the maximum volumetric capacity (cm^3), while the depth of the vessel was obtained from the ratio between diameter and height (Ø/h), and the typology (Banchieri *et al.* 1999).

4. Results

The calculation of the volumetric capacity allowed providing an estimate of the capacity (ml) and the weight of the different contents (g). At the same time, it was possible to correlate the values determined by the computer-assisted calculations with the ratio Ø/h (Tab. 1). Subsequently, the elaboration of the data took place through the compilation of a scatter plot, reporting the volumetric capacity in the X axis and the Ø/h ratio in the Y axis (Fig. 4).

Samples	Estimate Liquid Content (ml)	Estimate Solid Content (g)			Ø/H Ratio	Size Group
		Whole barley	Emmer	Naked wheats		
L.B. 1*	5276	3218÷3640	2480	2849	3,23	G3b
L.B. 2	6959	4245÷4802	3271	3758	2,74	G3b
T.V. 1	5646	3444÷3896	2654	3049	0,92	G3a
T.V. 2*	17307	10557÷11942	8134	9346	1,08	G4
T.V. 3	2967	1810÷2047	1394	1602	0,97	G3a
T.V. 4*	1329	811÷917	625	718	0,77	G2
T.V. 5*	5941	3624÷4099	2792	3208	0,82	G3a
T.V. 6	944	576÷651	444	510	1	G2
T.V. 7	3961	2416÷2733	1862	2139	0,8	G3a
T.V. 8*	5235	3193÷3612	2460	2827	0,87	G3a
H.V. 1	925	564÷638	435	500	1,16	G2
Jg. 1	125	76÷86	59	68	0,86	G1
Jg. 2	1825	1113÷1259	858	986	0,83	G2
Jg. 3	772	471÷533	363	417	0,83	G2
Jg. 4	839	512÷579	394	453	0,74	G2
N.V. 1*	6054	3693÷4177	2845	3269	0,47	G3a
N.V. 2*	13378	8161÷9231	6288	7224	0,26	G4
Mn. 1	53	32÷37	25	29	0,76	G1
Mn. 2	158	96÷109	74	85	2,24	G1
Mn. 3*	59	36÷41	28	32	1,14	G1

Tab. 1 – Summary of results (* = partially preserved).

Through the interpretation of the scatter plot, it was possible to group the ceramic samples into four size groups:

– Group 1: represented by four samples. The ceramic samples are characterized by a volume lower than approximately 200 cm^3, containing between 25 and 109 g of solid content and a Ø/h ratio is between 0.76 and 2.23. The wide range of the latter parameter is due to the fact that within the group there are different degrees of depth. Miniaturistic forms are in this group for a reduced volumetric capacity. In this group is also present a jug that differs from other equal typological samples for its lower volumetric capacity.
– Group 2: represented by six samples, whose ceramic forms are characterized by a volume between 750 and 1800 cm^3, containing between 363 and 1259 g of solid content and a Ø/h ratio between 0.74 and 1.16. Within the

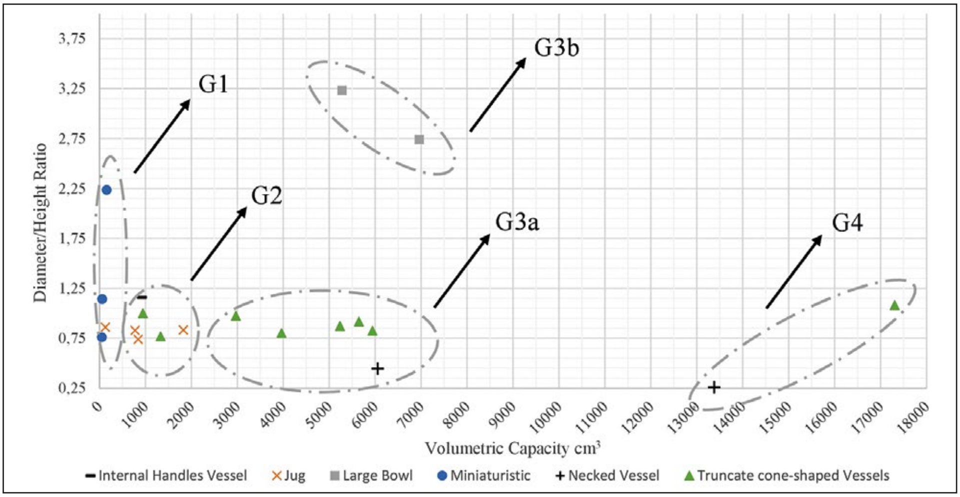

Fig. 4 – Scatter plot between volumetric capacity (X axis) and diameter/height ratio (Y axis).

group are included forms that are mainly represented by jugs, two truncate cone-shaped vessels and the internal handles vessel.

– Group 3: represented by eight samples. The ceramic forms are characterized by a volume between 2900 and 7000 cm^3, containing between 1394 and 4802 g of solid content. At the same time, the group is divided into two subgroups, which differ from each other for their depth (3a and 3b). The first subgroup (six samples) is represented by a Ø/h ratio between 0.44 and 0.97, mainly consisting of truncate cone-shaped vessels with the only exception of a neck vessel. The second subgroup (two samples) differs by a ratio of Ø/h between 2.74 and 3.23, consisting of the two large bowls.

– Group 4: represented by two samples, of which one necked vessel and one truncate cone-shaped vessel. They have a volumetric class, an estimate of solid content and a Ø/h ratio that differs from all the previous groups. They have a volume between 13000 and 17500 cm^3, a capacity of solid content between 6288 and 11942 g and a Ø/h ratio between 0.26 and 1.08.

As emerged from the results, some ceramic forms that have similar Ø/h ratios and the same typological classification can have different volumetric capacities. This statement is noticeable, for example, in the class of truncate cone-shaped vessels. This type of pottery has a Ø/h ratio with a very limited (between 0.77 and 1.08), conversely the volumetric capacity has a much wider degree of variation (between 944 to 17306 cm^3).

Although most of the truncate cone-shaped vessels appear to have a capacity that varies between 2900 and 7000 cm^3 (Group 3a), three samples have respectively a lower (T.V. 4* and T.V. 6 in Group 2) and a greater volumetric capacity, although the latter reconstructed (T.V. 2* in Group 4). At the same time, this oscillation is observable, although in minor way, in the jug's class. Most of the samples belong to Group 2 with a volumetric capacity between 750 and 1800 cm^3, with only one case within Group 1 (Jg. 1), which can be considered as a miniaturistic jug.

5. Discussion

This methodological protocol has led to obtain an analysis of the volumetric capacity of the vessels and to propose a division into size groups, which could be a reflection of different functional and/or cultural choices, as indicated by the change in volume found within some typological classes, such as truncate cone-shaped vessels and jugs. The observations reported are, however, preliminary as for some typological classes it was not possible to consider a group of samples adequately large; in addition, some typological categories are absent, such as bowls and jars, whose base is rarely preserved. The latter characteristic obviously makes it difficult to reconstruct the original height and consequently the calculation of their capacity. Another important factor is that the evaluation of the volumetric data is usually, in literature, correlated with other criteria. In addition to the dimensions and typological aspects taken into account in this paper, it would also be appropriate to consider the technological aspects such as the petrographic analysis (fabric), the surface treatment processes (smoothing, polishing, slip) (Cuomo di Caprio 2007), the use-wear and organic residues (Vieugué 2012; Orton *et al.* 2013; Vieugué *et al.* 2016). Only through a complete analysis of these parameters is generally possible to distinguish the ceramic samples into five functional categories such as storage, cooking (food preparation with heat), food preparation without heat, serving and transport (Rice 2015). Therefore, only with the systematic application of the method discussed in this paper and the evaluation of further investigation parameters, it will be possible to explain the functionality of the ceramic samples from Lugo di Grezzana site.

6. Conclusion

This study aimed to propose a methodology for the volumetric calculation of ceramic samples from the Neolithic site of Lugo di Grezzana, with the aid of a 3D graphics software, concluding that:

– The use of the Blender allowed to work directly on the published bibliography available, with no need for direct interaction with the object of study and to obtain a computerized calculation of the volume in just a short amount of time and just a few steps.

– At the same time, the application of the method to ceramic artefacts must consider the tolerance. The latter is determined, not only by parameters associated with the vessel itself (asymmetries, conservation status), but also by the graphic reproduction. For this reason, the results obtained must be considered as estimates of the volumetric capacity, in any case proving sufficiently valid to be applied to an archaeological study.
– The results emerged must be considered partial since only through the application of the method to a sufficiently large group of samples, not only from the Lugo di Grezzana site but also from contemporary archaeological contexts, could clearly define the vessel capacity for each typological class.
– The interpretation of scatter plot, made by the correlation between the volumetric capacity and the diameter and height ratio, led to the creation of different size group that contain different ceramic shapes. In fact, within some typological classes, can be observed a different degree of variability. Such variation could be a consequence of different functional uses and/or different cultural models.
– In general terms, the study of vessel capacity is one of the parameters necessary for the functional understanding of the artefacts. However, the volumetric data alone is not enough and must be correlated with the multidisciplinary study of the ceramic record and the archaeological context.

The results obtained highlight the informative potential of the method applied starting from the use of the 3D graphics software Blender. Future studies aimed at investigating this aspect in a systematic way will allow the gain of more information about the functionality of ceramic vessels.

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ABSTRACT

The aim of this study is to obtain an estimate of the volumetric capacity of a selection of ceramic vessels from the Neolithic site of Lugo di Grezzana (Verona, Italy). The method applied involved the use of Blender, a free and open source 3D computer graphics software. This program can calculate the volume from the graphic elaboration of the archaeological drawing of the artifacts. Through the calculation of volume it has been possible to obtain an estimate of the total capacity of the vessels, proposing two types of content. Volumetric estimates were then compared between the diameter and height of each ceramic vessels, to define size classes. The research shows that the internal variability of some ceramic shapes could be the consequence of different functional and/or cultural choices. The methodology tested in this paper could be applied in future research projects.

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ANATOMICAL-MORPHOLOGICAL ANALYSIS OF A VOLUMETRIC 3D MODEL OF AN ARCHAEOLOGICAL OBJECT

1. Introduction

Traditional radiology and, after 1975, computed tomography have been used in archaeology since their inception as non-invasive imaging techniques (Huges 2011) for dealing with delicate and valuable artefacts (e.g. mummies, Palaeolithic and ancient remains, papyrus scrolls, wood, metal tools, coins, jewellery, weapons, ceramics, wall paintings, etc.). It was not until the 21st century that microcomputed tomography (μCT) was gradually established as the desired non-invasive technique and method in archaeology. Its use and development are focused on the technological adaptation of industrial μCT recorders to archaeological (e.g. University of Bologna; 37th International Symposium on Archaeometry) and archaeometric treatment (Berdondini *et al.* 2011), as well as non-invasive archaeological analysis of small objects, which could be partially or permanently destroyed or damaged (Morigi *et al.* 2010; Albertin *et al.* 2019). To date, research attention has not been focused on the development of specific algorithms adapted to field or laboratory archaeological work.

In the field of 3D modelling, μCT is still limited to the reconstruction of surface 3D models or the examination of the anatomical structure of an archaeological object (Du Plessis *et al.* 2015; Re *et al.* 2016). There are only rare examples of reconstructing volumetric 3D models from 2D μCT images. This approach could greatly complement archaeological documentation, volumetric treatment and provide high-quality information when planning the use of optimal conservation methods and techniques. There is still a restrained attitude towards the use of μCT in archaeology, although archaeologists acknowledge that the results of microtomographic research are remarkable. This is partly due to the equipment which is still expensive and inaccessible to archaeologists. Therefore, easier, and more affordable 3D modelling technologies are used in virtual archaeology. This was also confirmed by the First CAA-GR Conference in Crete (Reilly, Beale 2015), which was aimed for researchers to exchange experiences on the use of new technological imaging methods in the preservation of cultural heritage based on the guidelines of The London Charter (Denard 2016) and The Seville Principles (Lopez-Menchero, Bendicho 2013). The conference marked the culmination of twenty years of development in the field of virtual archaeology. Currently, archaeologists should standardize the use of new information technologies in the field of cultural heritage (LiDAR, photogrammetry, computer modelling, additive manufacturing, visualization, hypertext, etc.). Archaeological reports in the last five years, despite the official restraint of the profession, confirm the growing interest in the use of micro- and nano computer tomography in archaeological and conservation work.

As sayd by Jeremy J. O'Brien, professor of physics and electrical engineering (Applbaum, Applbaum 2005), it is true that the use of computed tomography in archaeology and in the preservation of archaeological cultural heritage after 1979 was more due to the curiosity and individual interests of the archaeological and Egyptological elite than planned and systematic research work. It is therefore not surprising that a clearly defined interest in rendering surface and volume 3D models from two-dimensional tomographic or microtomographic images has not been expressed in archaeology yet. Somewhat wider interest in the use of computed tomography in archaeology began after 2015.

After 2016, computer scientists and archaeologists began using µCT to investigate the geometric and anatomical features of artefacts. CT and µCT have also become important analytical and diagnostic tools for planning and selecting more appropriate and efficient procedures for the conservation and restoration of archaeological objects. Some French (Introspect Project), British (RTISAD project), American (EDUCE Project, etc.), Canadian, Israeli, Austrian and German university research centres, specialized laboratories of state museums and private companies already use computed tomography as an indispensable part of the regular procedures of conserving and restoring archaeological exhibits.

Only in recent years (Albertin *et al.* 2019) has it become clear that industrial microcomputed tomography, as an advanced non-destructive imaging technique for researching the anatomical structures of various materials, can answer many unexplored questions, enrich archaeological documentation, and contribute to an optimal selection of quality conservation and restoration techniques. Outstanding projects exist, for example, in the X-ray tomography laboratory at the University of Bologna. The research is focused on the development of industrial CT and µCT systems for the needs of archaeological laboratories and museums. Solutions that are adapted to archaeological fields and laboratory work are the beginnings of a qualitative change in the treatment of archaeological objects.

In archaeology, we find isolated examples of reconstructed 3D models from 2D CT or µCT images. To date, no specific need has been expressed for the reconstruction of volumetric 3D models or for the addition of complete replicas of archaeological artefacts from 2D CT / µCT images. Reconstruction of 3D models of archaeological artefacts has so far been limited in archaeology primarily to surface 3D modelling, using photogrammetry, laser recorders, and structured light recorders. Various computer vision algorithms have been used (e.g.: SIFT, ICP, SfM, SfS, SfL, algorithm segmentation, self-learning algorithms, fuzzy clustering algorithm, etc.). In the last few years, deep learning is gaining importance. This is also the reason why the use of information technology in archaeology has focused on virtual archaeology, additive production of copies of artefacts from surface 3D models, and the digitization of basic archaeological documentation.

Due to the indicated peculiarities of the production (photogrammetry and other technologies) of 3D models in archaeology, no special algorithms have been developed for the reconstruction of surface and volumetric 3D models from CT or µCT images of archaeological objects. In the case of computed tomography, commercial algorithms are used for reconstruction and imaging, but they are mostly adapted to the needs of medical diagnostics or quality control of materials in industry. In the reconstruction of tomographic images in medicine, additive manufacturing, material analysis, and industrial control, the filtered feedback projection (FBP) algorithm has been standardized for some time. In recent years, some forgotten iterative reconstruction algorithms have reappeared in industrial tomography.

Their use has become more widespread with the increasing processing power of computers. Comparisons and research have shown some advantages of iterative reconstruction algorithms over the FBP algorithm (AIDR, ASIR and ASIRV, IRIS, SAFIRE, ADMIRE, MBIR, xSPECT, nMERA, etc.). Iterative reconstruction significantly improves image quality and 3D modelling with cyclic processing. New iterative algorithms are already embedded in the latest generations of CT readers (e.g. Siemens, Toshiba, GE Healthcare, Philips, Canon, etc.) and in most cases represent a trade secret.

2. Case study: the Palaeolithic wooden point from the Ljubljanica River

2.1 *The object of the tomographic reconstruction*

The object of tomographic reconstruction presented in in this article is a 40.000-year-old Palaeolithic hunting weapon (Gaspari *et al.* 2011; Kavur 2012). The Palaeolithic wooden point (Fig. 1) was found in 2008 in the Ljubljanica Riverbed near Vrhnika in Slovenia. It is made of yew wood. This wooden point is so far one of only eight known wooden Palaeolithic artefacts found in Europe.

2.2 *Problem*

After the conservation procedure and the last volumetric measurements, the current dimensions of the point are as follows: length 15.01 cm (was 16 cm when found, using traditional measurement method), width 4.9 cm (5.1

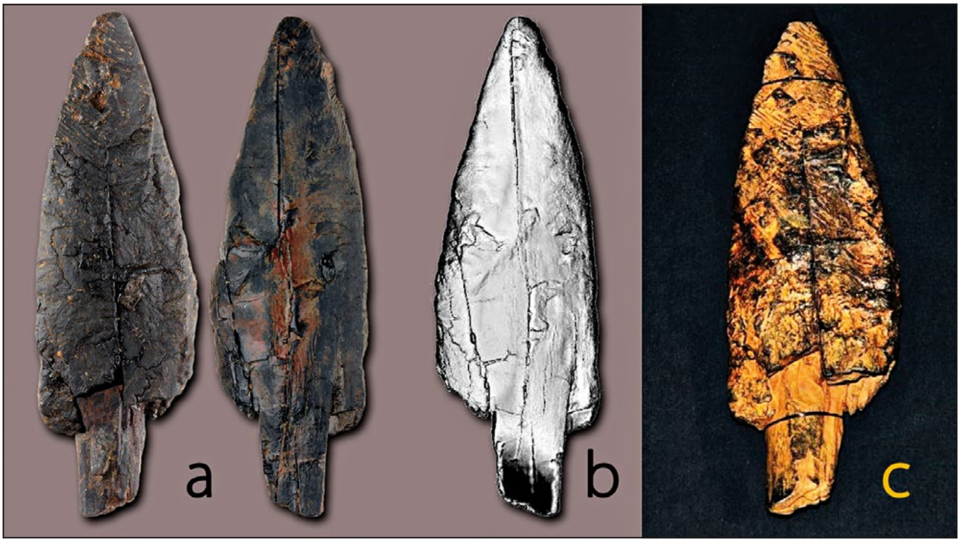

Fig. 1 – The Palaeolithic wooden point from the Ljubljanica River: a) photography of the point from 2008 when it was discovered (Slobodan Olić, Arhos d.o.o); b) 3D model; c) a photography of the exposed point in the City Museum of Ljubljana 2020 (model and photography E. Guček Puhar).

cm), thickness 2.3 cm (2.5 cm). The shape of the point has also changed (there is a strong bend of the lower part and a less pronounced one at the top of the point). Several surface cracks are also visible.

A volumetric comparison of surface 3D models created with the open-source graphical software tool CloudCompare before and after conservation, highlighted unexpected changes. The point changed after conservation its volumetric dimension (Fig. 2). Its volume decreased by almost 18.9 %, length by 5.7 %, width by 3.7 % and thickness by 18.3 %. There was also a visible change in its shape. The lower planting part was strongly and visibly bent. Volumetric comparisons, however, also exposed the bending of the tip point. External changes were identified by volumetric comparison of surface 3D models. These models, which have become widely accepted in archaeology today and the general standard of the signatories of the London Charter and Seville Principles, did not answer the question of what and where the actual (real) causes of external deformations are and in what condition the internal structure of the point is.

2.3 *Hypothesis*

Since microtomographic images of the Palaeolithic wooden point were available after conservation and since previous surface 3D models (Erič *et al.*

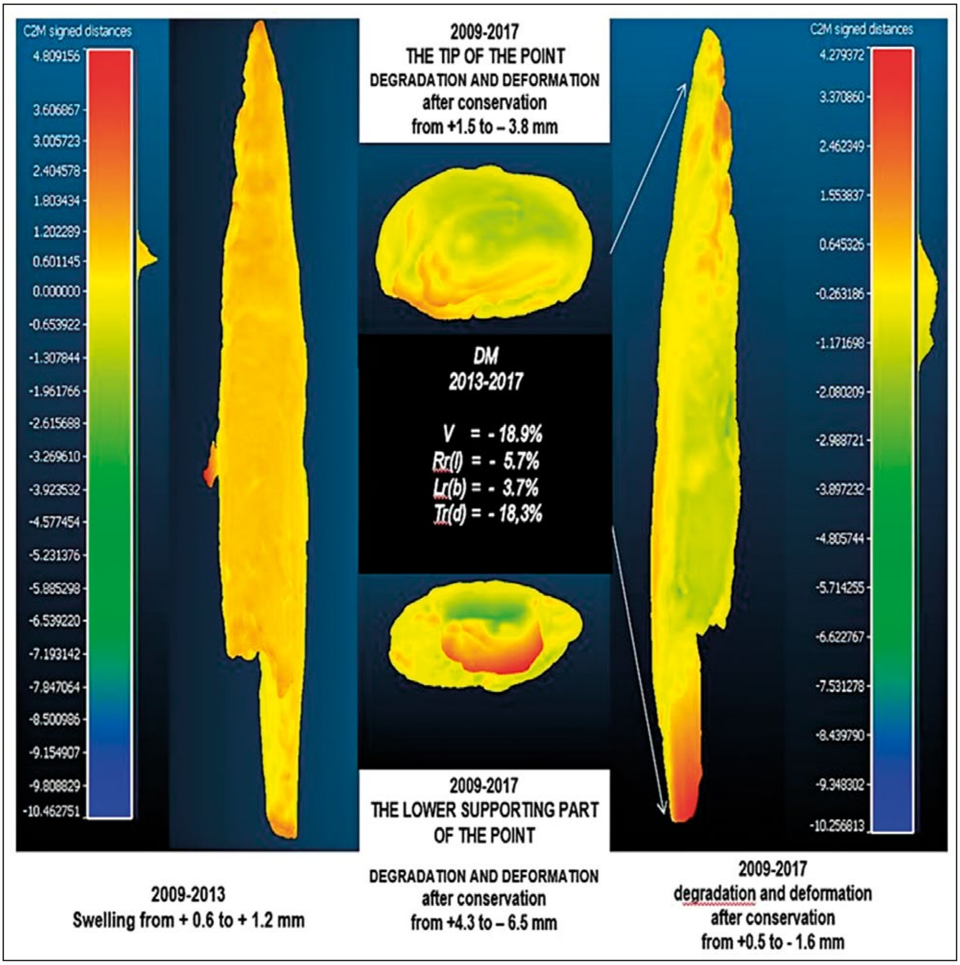

Fig. 2 – Volumetric changes of the surface 3D model of the point after the conservation process (2013-2017).

2018; Gučeк Puhar *et al.* 2018) did not provide a satisfactory answer to the question regarding the actual state of the artefact, we decided to reconstruct the volume 3D model. This should mainly highlight those anatomical features (cracks, fractures, etc.) of the point that directly or indirectly influenced its morphological, volume and surface changes during the melamine resin preservation phase (intensive soaking and drying).

By hypothesis, we estimated that the surface and volume 3D model of the point could provide archaeologists and conservators with more comprehensive

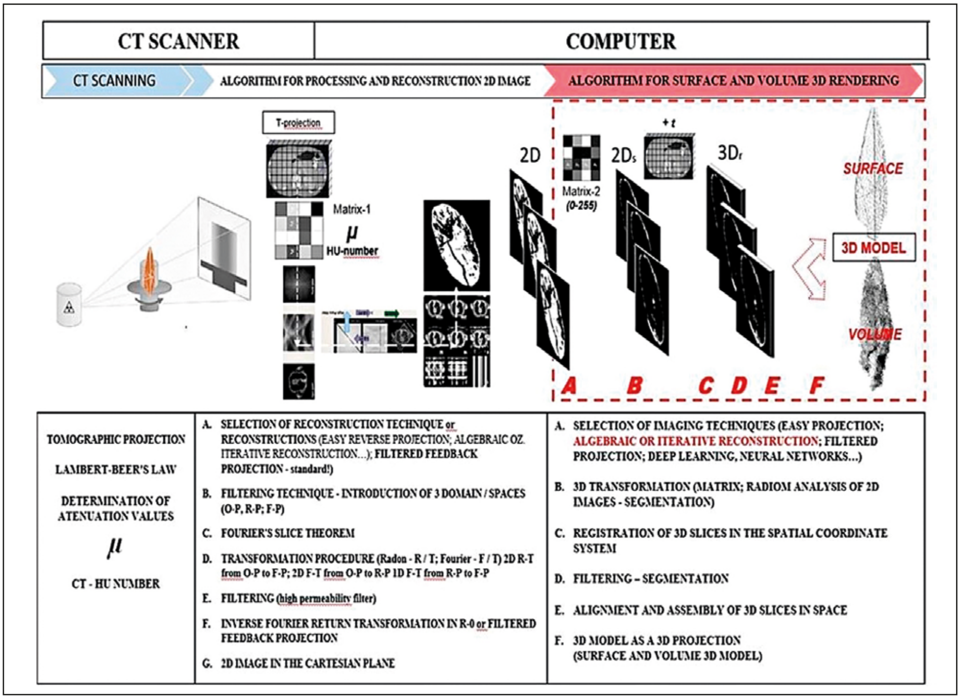

Fig. 3 – Workflow of the algorithm for the reconstruction of the volume 3D model from microtomographic 2D images.

information about its condition. The 3D anatomical-morphological structure of the point clearly shows the conditions and risks requiring solutions for a more permanent preservation and protection of the artefact.

2.4 *Methodology*

Surface 3D models do not provide us with complete information about the actual state of an artefact. Only a volume 3D model can provide this information. This was the fundamental reason why we approached the development of an iterative algorithm for the reconstruction of a 3D model from microtomographic 2D images. In the phase of computer processing of microtomographic 3D slices, we developed two algorithms (Fig. 3): a direct algorithm for the reconstruction of a 3D volume model and a segmentation algorithm for the reconstruction of a 3D volume model. Both algorithms were developed using the software package for numerical analysis MatLab. The surface and volume 3D models are rendered with the open-source MeshLab and CloudCompare software.

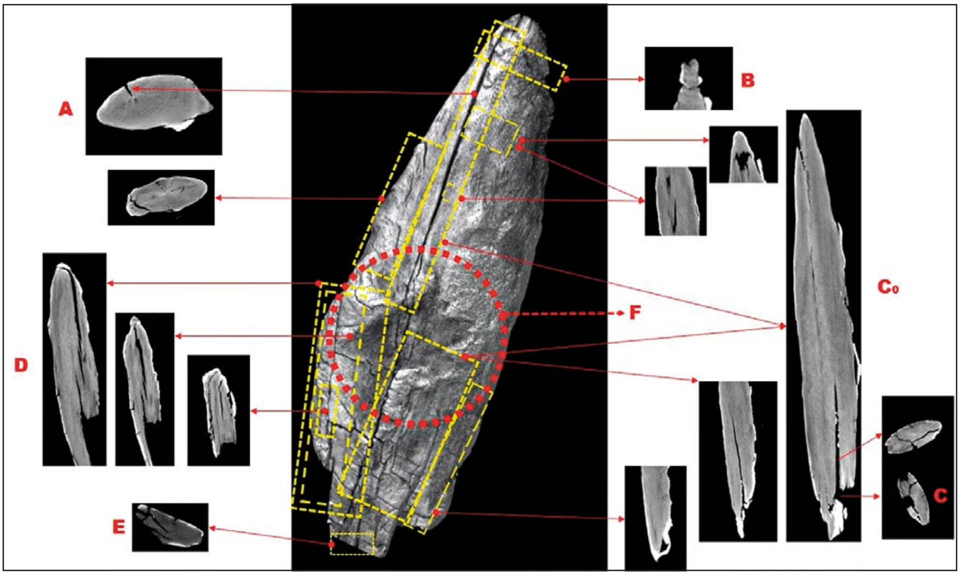

Fig. 4 – Determined volumetric and anatomic-morphological characteristics of the volume 3D model of the point.

2.5 *Results*

With the volume 3D model, we were able to indisputably identify, investigate and document the internal structure of the artefact. Deformation changes (cracks, fractures, decay) are distinctly evident and located (Figs. 4-5). The critical points of the anatomical structure of the artefact are visible and non-invasively located in the volume 3D model (Fig. 5). Two pronounced internal deformations were found: a longer crack (Fig. 5 C_o, A) and a more pronounced fracture (Fig. 5 C_o, C). A crack (Fig. 5 A) with a depth of 2 to 22 mm was found in the upper part of the point. A 9.1 cm long crack runs all the way to the middle of the point along the core band. This crack is not critical if the dynamics of tensile and strain stresses do not continue. It only affects the slight bending of the upper part of the point. 4 mm below the tip of the point (perpendicular to the upper crack) the critical point of the transverse fracture of the object is indicated (Fig. 5 B). Due to internal damage at this point, there is a possibility that the tip of the point (4.2 mm) may break off in the event of careless handling or under the influence of external factors.

If the tendency of the crack to spread continues across the middle of the point along the core strip (Fig. 5 A, F, C_0) in the direction or transversely to the direction of the observed major fracture (note that this crack propagation

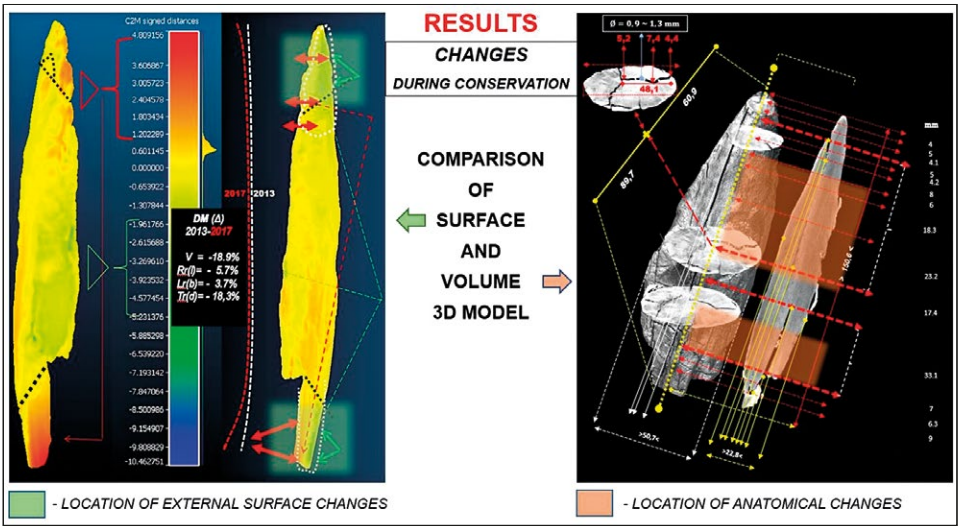

Fig. 5 – Micro locations of anatomical characteristics and deformations (fractures, cracks, openings) of the Palaeolithic wooden point.

tension is currently not detected) to the lower and planting part of the point – which is currently 18 mm away from said crack (Fig. 5 C, C_0, F) – we could face the risk of breakage of the point. A pronounced fracture in the lower part of the point (Fig. 5) runs along the entire width. Its length is 3.3 cm and runs between the planting part and the middle of the point (Figs. 4, 5 C_o, C). This is a critical fracture of the artefact. Numerous cracks have been found on the lower wing parts of the point in the longitudinal direction of the anatomical structure. There is a risk of chipping.

Significant changes found on the surface 3D models in 2009 and 2015 or 2017 may have been the result of various invasive processes to which the point was exposed during the conservation processes (phase of stimulated intensive swelling and heat treatment - drying). The current state of internal dynamic changes indicates that the drying process has slowed down.

3. Discussion

With the volume 3D model, we were able to accurately identify, investigate and document the internal structure of the artefact. Deformation changes (cracks, fractures, decay) are clearly visible and located. The identified critical points (a longer crack extending from the top to the middle of the point and a pronounced transverse fracture in the lower part stand out) have a decisive influence on the external change (deformation-bending) of the top and the lower part of the point. Numerous minor cracks, deviations or even natural changes in the internal texture are also found in the volume 3D model of the point. If data on the internal condition of the point (openings, fractures, deviations, decomposition) were available before conservation, the conservation process could be adapted to the condition of the point or it could be decided to protect it by avoiding its exposition to environmental changes in a special container with a watery environment (aquarium), for example. Undoubtedly, the process of intensive conservation (soaking and especially rapid drying) has influenced the external and internal changes of the point, which will need to be repaired over time to avoid possible disintegration or breakage of the artefact.

Complementing the computer volumetric method of deformation monitoring of 3D models of the considered artefact with both algorithms can provide archaeologists with quality data and information for a comprehensive analysis of the object before and after the conservation procedure. Furthermore, it can provide conservators with the necessary information to select the most appropriate methods, techniques and means to stabilize valuable archaeological objects.

4. Conclusion

The volume 3D model together with the surface 3D model provides substantially more information about the state of the original artefact. The model can be successfully for the selection of conservation techniques (Van Grieken, Janssens 2004; Jungblut *et al.* 2013; Payne 2013; Erič *et al.* 2018), for analysis and evaluation, in the visualization of the spatial representation of the artefact, in additive archaeology (Reilly, Beale 2015) and in the timely planning of procedures for storage and protection of the artefact. The 3D models supplemented with this information and data will gain in importance in the coming years not only in the field of cultural heritage preservation but also in industry, medicine, etc., as 3D is becoming one of the fundamental standards of the 4th Industrial Revolution (Schwab 2017). The importance of 3D models and computer spatial and surface 3D visualizations includes the London Charter, the Seville Principles, and ratified international treaties among the archaeological and cultural heritage protection standards.

A more frequent use of non-invasive computed tomography in archaeology would be appropriate, especially when dealing with sensitive remains and for the production of volume 3D models which should be included into documentary archaeological collections. Spatial and surface 3D rendering from 2D CT images not only expand our knowledge about the screened objects but they also enable further analysis, identification, expansion in the field of archaeometry, enabling better quality 3D rendering and addition.

For archaeologists, conservators, and restorers, computed tomography can provide timely and reliable additional information for the planning, selecting and implementation of more efficient ways to preserve cultural heritage remains. Artificial intelligence, deep learning, convolutional neural networks, and other challenges of computer vision open up the still insufficiently researched possibilities of implementing computed tomography in archaeology and in preserving valuable remnants of cultural heritage.

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ABSTRACT

The article emphasizes the importance of anatomical-morphological analysis of a volume 3D model reconstructed from microcomputer tomographic 2D images for archaeological documentation and treatment, non-invasive archaeological analysis, and a more optimal selection of conservation methods and techniques. The object of µCT reconstruction is a 40,000-year-old Palaeolithic hunting weapon found in 2008 in the Ljubljanica River near Sinja Gorica (Vrhnika, lat.: *Nauportus*, Slovenia). This wooden point (yew; lat.: *Taxus baccata*) is so far just one of only eight known Palaeolithic wooden artifacts found in Europe. Between 2013 and 2017, the point was conserved using a traditional waterlogged wood processing technique with melamine resin. Using computer volumetric analysis of five surface 3D models, taken before, during and after the conservation, it was found out that volumetric changes and deviations of the point have occurred (bending, weight, volume, surface cracks and changes). Surface changes of the 3D models did not answer the question: what are the causes for the resulting changes after the conservation process? Only anatomical-morphological analysis of the internal structure of the point could answer this question. To this end, we developed an

iterative segmentation algorithm adapted to archaeological analysis for the reconstruction of a volume 3D model from microtomographic 2D images. In this way, we successfully supplemented the data of the surface 3D model and confirmed volumetrically and graphically the current and critical state of the internal anatomical structure of the artifact (cracks, fractures, etc.). The case study confirmed the exceptional importance of the use of microcomputed tomography as a non-invasive technique in archaeological analysis and in the planning and selection of procedures for conservation, restoration and storage of sensitive archaeological heritage remains *in situ* or *ex situ*.

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FROM MINERALS TO ARTEFACTS: THE ROLE AND CHALLENGES OF 3D MODELLING

1. Introduction

In the historical context in which we find ourselves today, amidst an ongoing pandemic that strongly limits the freedom of individuals, 3D and augmented reality can play an important role in freeing the art and culture that are presently 'trapped' in museums, thus allowing them to be accessible from everyone's homes. During recent years, we have witnessed an increase in 3D modelling, and more specifically the use of photogrammetry, as a tool to virtualize objects and artefacts usually stored and not on display in exhibitions. The new technologies and software available are now within everyone's reach and budget, making the use of augmented reality (Pikov *et al.* 2015; Capuano *et al.* 2016) and, more generally, an approach to studying through the virtual, easily accessible. Today, it is indeed possible to view and 'handle' practically any object, artefact, or mineral of interest, while remaining comfortably seated at home several thousand kilometres away. This has been made possible thanks to the creation of three-dimensional models based off the original object and its virtual projection (Shcherbinin 2018).

The construction of 3D models can be achieved by the composition of a series of many photographs (of the object or area of interest) taken from different angles, using either common cameras or more complex and remotely manoeuvrable systems, such as Unmanned Aircraft System (UAS), making it a versatile instrument applicable to different fields, e.g., from the documentation of Cultural Heritage (McCarthy *et al.* 2014), to forensic medicine (Thali *et al.* 2003). With photogrammetry, it is in fact possible to extrapolate metric information starting from two-dimensional data such as images (Forlani *et al.* 2015). The photographs are then reworked by a specific software (there are many on the market) for 3D modelling and reconstruction (Kersten *et al.* 2018; Monna *et al.* 2018).

It is also possible to use laser scanners for the close-range construction of three-dimensional objects, which provide a high-quality and relatively quick data acquisition, but involves a much higher expense than the cheaper and more versatile three-dimensional photogrammetry (Andrés *et al.* 2012). 3D modelling has proven itself to be an affordable and almost ready to use method to create 3D models of objects of any sort and shape complexity and make it visible and usable by everybody with Internet access.

Although photogrammetry has existed for many years, it is a constantly changing method in continous development, and these characteristics make it a technique with unlimited resources. Unfortunately, although 3D modelling is an effective and economical tool for the virtualization of museum objects and artefacts, in our recent work (Aquino *et al.* 2020a) we have shown that its ease of use is not without specific problems. In fact, some of the studied objects with reflective or transparent surfaces hindered the camera from focusing accurately and consequently generated problems in the construction of the 3D model. These limitations, together with the problems related to the processing of small components with highly complex shapes, have also been reviewed in the literature (Esmaeili *et al.* 2016).

This work primarily concerns the data acquisition and 3D modelling of objects (Medina *et al.* 2020) of varying complexity, coming from different museums and areas of Tuscany. We also focused on photogrammetry as a three-dimensional modelling tool for Cultural Heritage (Pavlidis *et al.* 2007), and on data acquisition and scanning problems encountered during the preparatory work.

2. Materials and methods

In this work, we have considered and studied some stone objects, minerals, and artefacts from different areas of Tuscany. For simplicity, we will report only a few as examples: among the mineral samples, we chose a single crystal of calcite and a single crystal of feldspar, both kindly provided by the Natural History Museum of the University of Florence, and an aggregate of brown calcite crystals from the Natural History Museum of the University of Pisa; among the rock samples, we chose a piece of limestone from Monte Morello Formation (formerly Alberese) from a private collection and a small stone head, belonging to the Targioni Tozzetti collection of the Natural History Museum of the University of Florence.

The calcite crystal (inv. MSN-Fi G47378) is a sample of Icelandic spar 8×5×5 cm in size, with pink colour and a milky translucent transparency, coming from Durango, Mexico; the feldspar crystal (inv. MSN-Fi G41641) is an orthoclase crystal 16×5×5 cm in size belonging to the Ponis collection and coming from a Brazilian pegmatite. They represent, among those we have studied, the simplest of geometric shapes. The block of limestone is a marly limestone coming from Mt. Morello, in the surroundings of Florence, widely used in the past to produce lime (Aquino *et al.* 2019; Fratini *et al.* 2020; Lezzerini *et al.* 2020). The carved stone head, from the Etruscan period, presumably coming from Volterra, is made of a calcarenite, like the 'Panchina' stone, a highly porous stone with medium sized grains, rich in organogenic carbonate fragments (Lezzerini 2005; Aquino *et al.* 2020b).

The 3D modelling technique used for this work is photogrammetry, a method of 3D reconstruction that uses numerous images and data processing

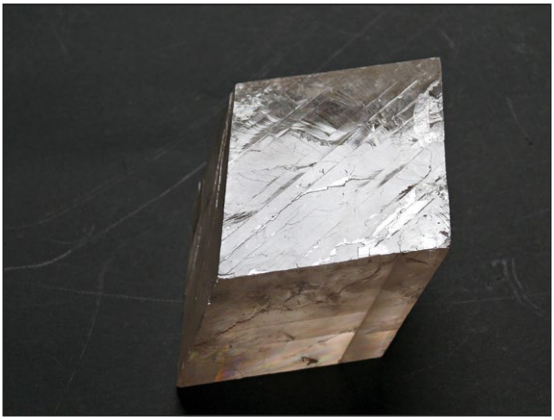

Fig. 1 – Calcite, var. Iceland spar (MSN-Fi G47378). The transparent and reflecting surfaces are clearly visible.

software as working tools. For this work, we therefore collected a series of photos (not less than one hundred images per object) to build the archive from which to process our three-dimensional model. The equipment used for capturing images and building our starting database were a LEICA V-LUX 1 and a NIKON D500 camera, equipped with a high-performance LEICA DC VARIO-ELMARIT 1:2.8-3.7/7.4-88.8 ASPH zoom lens and a Nikon 16-80mm f/2.8-4 VR lens, respectively. In particular, we used the LEICA camera to capture photos of the calcite, feldspar and limestone. In total, over 300 photographs were taken of these objects in natural light conditions and using a dark blue shelf as a support base. The photographs were taken at different angles while rotating 360° around the object: first at 0°, then at about 15°, 30°, 45°, 60°, 75° and finally vertically at 90°, following the model schematized in Fig. 2.

Additionally, the studied object was rotated in different positions in order to ensure the coverage of all surfaces during photo acquisition. The photographs of the limestone head, on the other hand, were taken in the photographic laboratory of the Natural History Museum of the University of Florence with professional photographic equipment and screened artificial light coming from about 80°. The head was positioned on a white graduated rotating plate placed in front of a uniform white photographic background. The photographs were taken using the NIKON D500 on a tripod by varying the height in order to respect the previous angles except for the photos taken from above, which were handheld. Once the pictures were captured from all angles, the object was turned upside down. This procedure allows the software to correctly align all of the images by elaborating the recognition

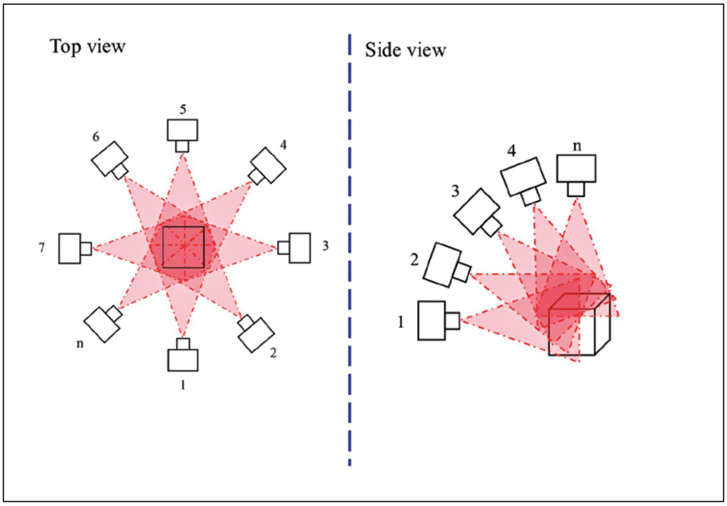

Fig. 2 – Schematic model of photo acquisition procedure.

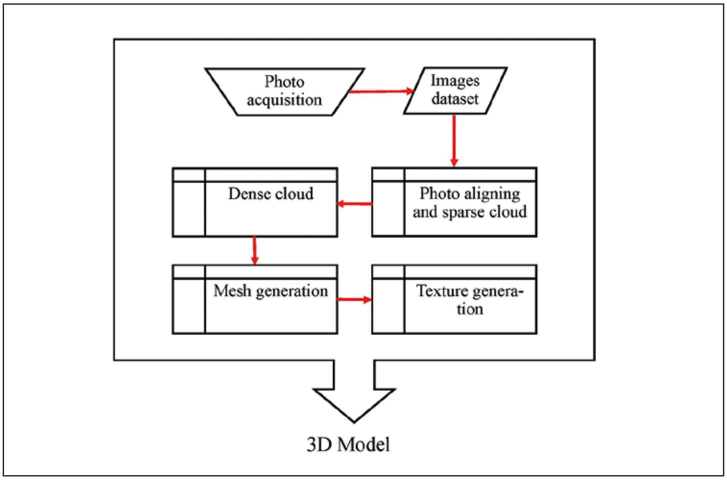

Fig. 3 – Schematic flow-chart of 3D model reconstruction.

of the common points (CP) for each surface and of each image, enabling the construction of the 3D point cloud. To this end, it is essential to ensure a minimum image overlap of at least 60%.

Once we obtained the necessary photographic database, we proceeded to create the three-dimensional model for each of the studied objects. The software

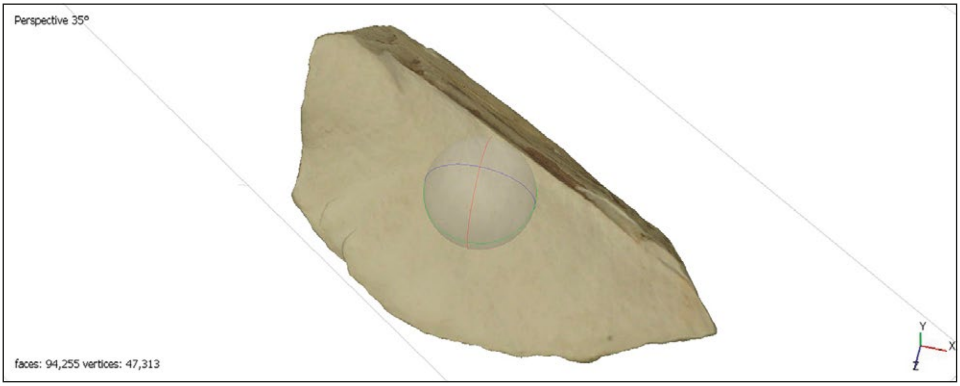

Fig. 4 – Texture model of the selected limestone block. The lack of transparent and reflecting surfaces and a simple geometric shape allowed for an easy processing of the 3D model.

used for processing the photographic archive was Metashape, produced by Agisoft, version 1.6.4. The processing was carried out using high-performance workstations. The work phases began with the alignment of the photos, the construction of the dense point cloud and of the mesh, and finalized with the construction and application of the textural model as schematized in Fig. 3. This process is partially automatic, except for the verification of the requirements at the end of each step which does not normally require manual editing. Each model took between 30 to 45 minutes to complete processing.

3. Results

The three-dimensional model of the limestone (Fig. 4) together with those of the feldspar and of the aggregate of brown calcite crystals (Fig. 7) turned out to be easiest to process. Thanks to their simple, albeit particular geometric shape, together with the lack of reflective surfaces and their opaque colour, no final finishing work was necessary. The 3D model is a faithful representation of the original sample.

The calcarenite head, given its greater complexity compared to the other studied objects, required a larger amount of photos in order to build the archive. However, the substantial number of photos, the opaque colour, and the absence of transparent or reflective surfaces were not enough to achieve a perfect three-dimensional model reconstruction. Moreover, probably due to the use of a different image acquisition method compared to that of the crystals (here a turntable was used as a support surface), both the dense point cloud and the mesh have included some portions of the support base into the creation of the final model (Fig. 5).

Fig. 5 – Carved calcarenite head, Etruscan period (MSN-Fi): 3D model with traces of the white background used.

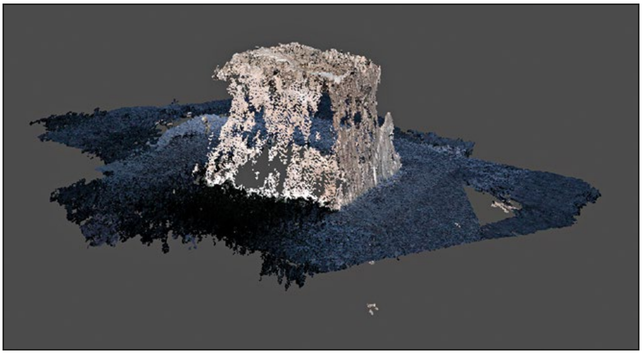

Fig. 6 – Calcite crystal 3D model affected by deficiencies in the point cloud. Note that the software has not been able to detect the difference between the crystal and the surface on which the crystal was laying.

These defects are generated due to the inability of the software to distinguish the specific characteristics of each neighbouring photo and to recognize the same characteristics to establish the control points. This may be due to human error both in planning the photography setup and in taking an excessive number of pictures without proper angle variations. This problem could be overcome by using a support surface with irregular visual characteristics instead of a surface with uniform colour.

As reported in literature, further problems in the construction of 3D models were encountered in the objects with transparent or reflective surfaces,

Fig. 7 – Aggregate of brown calcite crystals.

specifically in the case of calcite. In fact, the calcite crystal we studied under direct light conditions, both natural and artificial, gave rise to numerous effects of flicker and shimmer, caused not only by its reflective and transparent surfaces, but also by the growth planes and internal inclusions of the crystal (Fig. 6). We managed to partially solve the problem by utilising a light shield and by switching to the manual focus setting on the camera. Seemingly, the growth planes of the crystals, especially in the case of high transparency, do not allow a correct focusing, as it focuses on the portions that are more internal than on the surface of the crystal.

4. Conclusions

Although the complexity of studied objects was quite similar, the feldspar crystal was the easiest object to digitize, followed by the calcarenite head. In general, we noticed that, especially for the more complex objects, it is better to have higher quality images than just a higher quantity. Having a large number of photographs can lead to errors in the creation of the dense point cloud and, therefore, of the mesh. We have also noticed that both the type of lighting and of work surface used, affect the subsequent ability of the software to process the photographic archive. In order to avoid photo editing either in the phase following the creation of the model, or even before processing, a simple way to get around the problem is to insert a visual disturbance onto the work surface, such as a pen.

Furthermore, the software will recognize the disturbance as part of the background and not of the studied object, thus proceeding to its elimination. So, the tool of photogrammetry for the purposes of constructing three-dimensional models is low-cost, easy-to-access, and saves time during the editing process, making it an efficient and advantageous technique for the reconstruction of objects, artefacts and items of cultural interest that can then be made available for public display, or remote access.

Some of the current practices for resolving issues regarding the image acquisition of objects with numerous transparent and/or reflective surfaces involve the application of harmless matting lacquers that can be easily removed from the object, or taking photos with the aid of a circular polarizer, which although it does not completely remove reflections, it effectively attenuates most of them. Nevertheless, for the future, it will be necessary to develop faster and more efficient methods for the image acquisition of objects for the purposes of 3D modelling.

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ABSTRACT

Over the past decade, we have witnessed an increase in the use of technology, through the creation of virtual itineraries and exhibitions, as a tool to guarantee and increase the usability of museums and more generally of artistic and historical works. In fact, it often happens that many works of art and artefacts of archaeological and cultural importance are not accessible to the public, either because they are kept in museum deposits or because they are difficult to access. In a context such as the current one, however, with an ongoing pandemic that forces most of the population to remain at home, the virtualization of museums, and historical and cultural heritage, becomes the main tool for exploring and enhancing culture. Among the various methodologies used for the creation of three-dimensional models, photogrammetry stands out for ease of use and low cost. This article analyses the use of photogrammetry in 3D modelling, focusing on pros and cons as a rapid, low-cost tool, which makes artworks virtually accessible to the public via museum websites and social network forums.

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IMAGING AS A FIRST STEP FOR CULTURAL HERITAGE AND ARCHAEOLOGY ANALYSES

1. Introduction

The ubiquitous diffusion of modern smartphones has brought, as a collateral effect, the ready availability of relatively good imaging systems that can be used in any circumstance, and in particular in field research, exploiting the intrinsic portability of the smartphone. Although the quality of the images acquired with a smartphone cannot be compared with the ones of a medium-quality professional camera, in many occasion even a smartphone camera can be useful for non-trivial applications, as the 3D-reconstruction of art and archaeological objects, and even the modelling of large architectonic or archaeological structures.

2. 3D modelling with a smartphone

A smartphone is more than enough for reconstructing photogrammetrically a medium size archaeological excavation, with results that might be practically indistinguishable from the models obtained using aerial photogrammetry. In these applications, in fact, the technical limitations of the smartphone cameras are compensated by the software used for reconstructing the 3D model of the object/site, to obtain excellent results with minimum efforts (Fig. 1). There are several excellent open source (VisualSFM), free (3DF Zephyr free), as well as relatively cheap commercial software (3DF Zephyr, Agisoft Photoscan) which can be usefully exploited for this purpose.

3. Multispectral imaging with commercial cameras

With a slight increase in the cost of the equipment, but still remaining in the field of 'conventional' photography, a low-cost amateur or semi-professional camera can be easily converted in a multispectral camera, by removing the infrared filter in front of the CCD/CMOS detector. The results can be amazing, since the detector of a conventional camera is sensitive in a spectral range (from 350 to 900 nm, usually), much wider than the visible. Once freed from the IR-cut filter, it is possible to exploit the sensitivity of the detector to obtain multispectral information in reflection – UV, visible and IR reflection – and fluorescence – UV-VIS, VIS-IR (also known as VIL), VIS-VIS (VIVL) and UV-IR (UVIL) fluorescence.

The use of modified camera, even compact and semi-professionals, possibly associated with conventional cameras, allows considerably expanding

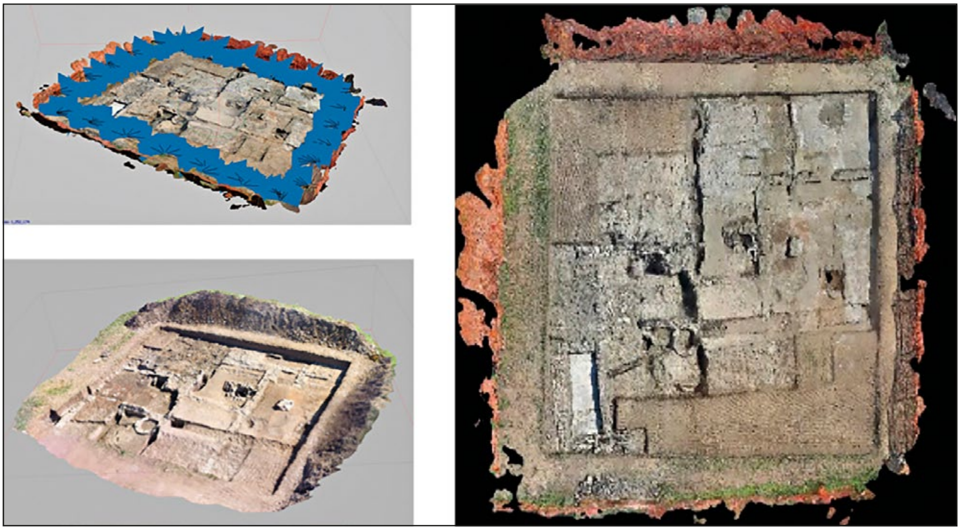

Fig. 1 – On left side: top 3D-model of the archaeological excavation in Luni (2017-Photos by J. Lucchesi, smartphone); bottom 3D-model taken by a drone; on right side: orthophoto of the site, from the model obtained on the ground with the smartphone.

the range of information obtained. Up to 3 bands in reflection and 4 in fluorescence may be easily acquired; through the use of common image software digital channel blending (false colours) can be performed to obtain first level information about metameric pigments. Affordable professional LED, characterized by a balanced irradiation and very low amount of parasitic emissions, in combination with suitable filters, allows splitting the VIVL into two sub-bands, while the VIL can be modulated to obtain further information beside traditional identification of specific pigments.

Moreover, the flexibility of a commercial camera allows producing images in diffuse reflectivity, transillumination, grazing light and specular reflection mode, also providing the reconstruction of dynamic lighting of large surfaces using the RTI (Reflection Transformation Imaging) technique. Although RTI is designed to give the best results in visible light, application in multispectral mode enrich the diagnostics performance: in fact, it is applied in the field of UV fluorescence, UV reflection and IR, as well as in the field of VIL luminescence.

Conventional and modified portable flashes represent the preferred in-field use irradiation sources. Consistently to the sensitivity characteristics of the camera sensor, flashes can reduce or suppress the ambient light disturbance, even without more complex procedures as digital subtractive masks. Flashlight also produces infrared emission and, if subjected to simple modifications,

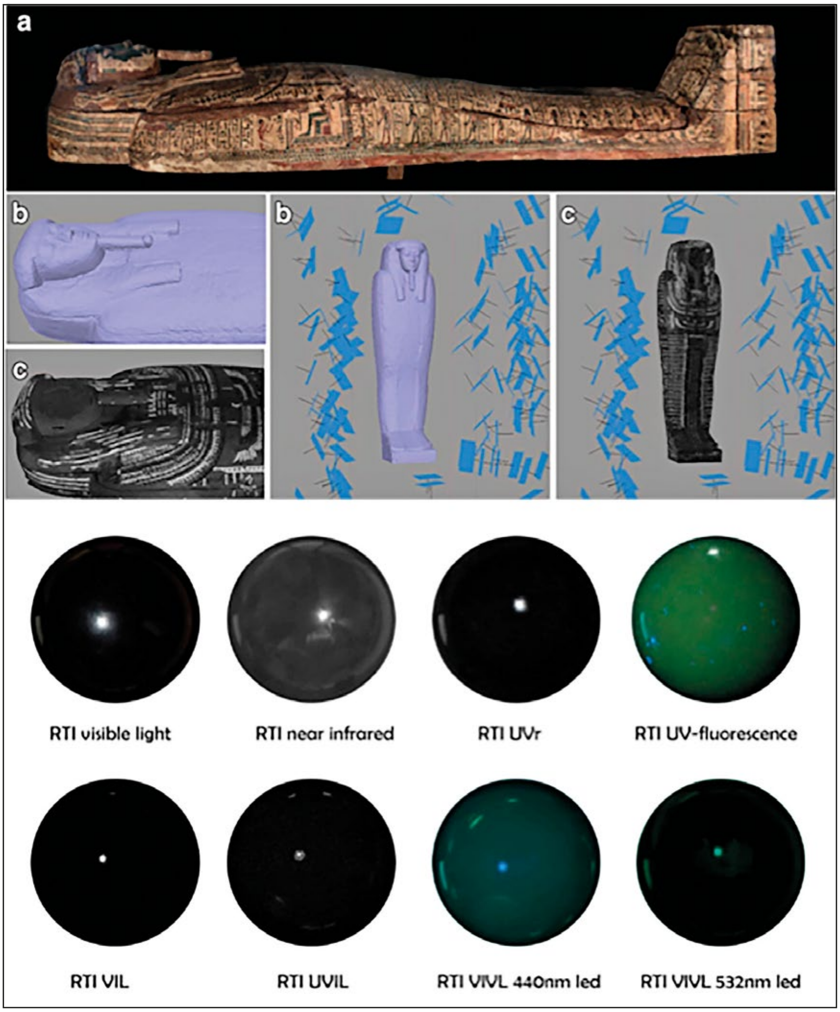

Fig. 2 – Top: Pasherienaset's sarcophagus (Ligurian Archaeological Museum in Pegli, Genoa, Italy): VIL 3D model in b) polygonal view and c) texturized view; bottom: RTI's reference spheres in multispectral mode.

provides an intense UV radiation. In the VIL field, the combination with a proper gradual filtering allows the acquisition both of correct images and of 'peculiar' shots, with a commensurate introduction of parasitic infrared light. These are aimed to produce RTI-VIL and 3D-VIL photomodeling, based on native integrated texturization and performable even through museal glass cases (Triolo *et al.* 2020).

4. Multispectral imaging with dedicated cameras

A further reasonable increase of the budget would allow the upscaling of the imaging system with the use of a full multispectral system. The use of a specialized multispectral system, while retaining the full portability of the alternative based on modified commercial cameras, would add the possibility

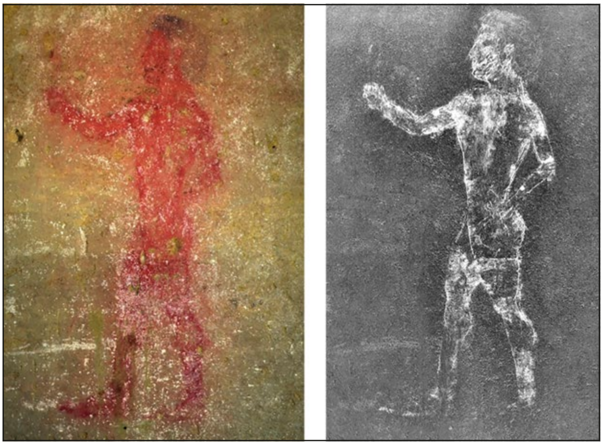

Fig. 3 – On left side: visible image of a Etuscan painting (Tomb of the Monkey); on right side: the image recovered after application of the MHX method.

Fig. 4 – On left side: visible image of a Etuscan painting (Tomb of the Monkey); on right side: the image recovered after application of the MHX method.

of controlling and optimizing by software the image acquisition process. Moreover, the use of a multispectral camera would permit to extend the sensitivity of the system beyond 1 micron in the infrared, and to catch minimal signals in UV-VIS and UV-IR fluorescence analysis, thanks to the possibility of acquiring long-exposure images with minimal thermal noise.

The use of an internal filter wheel for spectral selection is particularly useful for the acquisition of hyperspectral series. A 10-places internal filter wheel can be exploited for covering the visible range (from 400 nm to 650 nm) with 6 filters of 50 nm bandpass and the IR from 750 to 1050 with other 4 filters with 100 nm bandpass. However, in order to have the possibility to use external filters in case of need, it is customary to leave one filter place empty. In this case the alternative could be between removing the lower wavelength visible (400 nm) or IR (750 nm) filter. This is a matter of choice, to be decided according to the forecast needs of analysis.

This kind of hardware is at the basis of the MHX method, developed by CNR in the last years. The acronym stands for Multi-illumination Hyperspectral eXtraction and exploits the use of high spectral purity illumination

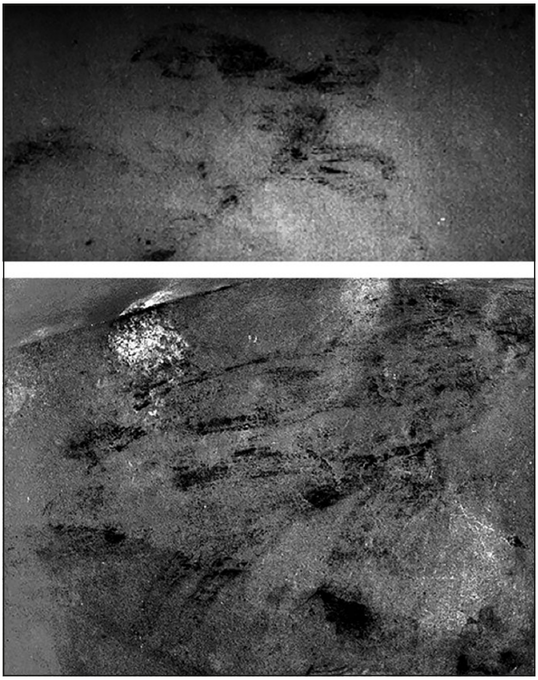

Fig. 5 – Application of the Infrared True Color method to merge the images in Fig. 4 for recovering a faithful chromatic apparence of the painting.

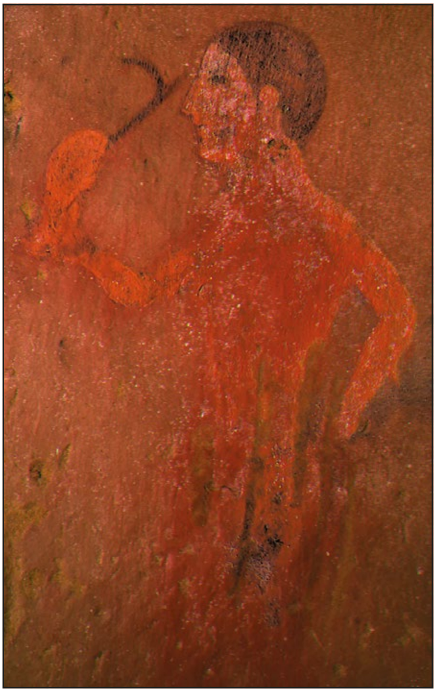

Fig. 6 – Top: the caracal hunting the deer; bottom: the wild boar. Tomb of the Blue Demons (Tarquina, Italy).

sources for the acquisition of hyperspectral images, that are subsequently elaborated with advanced statistical methods for the extraction of hidden information (Salerno *et al.* 2014; Legnaioli *et al.* 2018).

The MHX method has been successfully used in many archaeological and cultural heritage contexts and represents at the present the most advanced approach in the field of multi/hyperspectral image analysis for Archaeology and Cultural Heritage. Particularly important are the results obtained on the Tomb of the Monkey, in Chiusi (Siena, Italy). The Tomb of the Monkey, one of the most beautiful Etruscan painted tombs in Tuscany, was studied by the authors, who realized in 2014 a full 3D model (Giancristoforo *et al.* 2014) and examined in detail the two red painted figures in the front chamber, whose details seemed to be irrecoverably lost. As a result of the application of the MHX method, the readability of the two figures was greatly improved (Legnaioli *et al.* 2013), as shown in Fig. 3 and Fig. 4.

The application of the True Color Infrared (TCI) method developed by the Laboratory of Applied and Laser Spectroscopy in Pisa (Grifoni *et* *al.* 2019) allows a faithful merging of the MHX image, which by its nature does not carry the colour information, with the visible image, as shown in Fig. 5. It can be observed that the merging of the two images improves the readability of the image while maintaining a faithful chromatic appearance.

A further successful application of the MHX method was obtained on the Tomb of the Blue Demons (Tarquinia, Italy). In this case, a megalography covering the whole entrance wall, completely vanished and invisible at naked eye, was brought again to the light (Adinolfi *et al.* 2019). After the application of the MHX method, through the acquisition of reflectance and fluorescence hyperspectral images and the use of statistical separation methods for their analysis, a full hunting scene appeared. Two hunters were depicted to the left, in the process of killing a huge wild boar, assaulted from the back by a hunting dog. On the right part of the megalography, another hunter chase a deer, recognizable from his large antlers, while a wild cat (caracal) trained to hunt, lies in wait on the top of a rock (Fig. 6).

5. Conclusion

Imaging techniques are usually considered as a simple extension of traditional photography. In some sense, this is true, because at the basis of these techniques is the acquisition of (a set of) images, eventually resolved in wavelength. However, the potential of imaging techniques, for documentation and study, goes well beyond the one of conventional digital photography. What is particularly important is the fact that relevant information can be recovered using relatively cheap equipment (from a medium quality smartphone to a modified commercial camera, to possibly a full dedicated hyperspectral system), coupled to a proper (eventually open source) software. For these reasons, a large expansion in the use of these techniques in Cultural Heritage and Archaeology applications can be easily forecast.

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ABSTRACT

Imaging systems are the basic tools of the trade for art historians, conservators, and archaeologists, when they are called to document the results of their work. However, photo cameras and imaging systems are also powerful research tools. These systems, in fact, are inherently portable and give the possibility of acquiring high-resolution, spectrally resolved digital images that can be elaborated exploiting the most advanced algorithms of information science. In this contribution, we will outline the many possibilities opened by the available instrumentation and techniques, to suggest the use of image analysis as the first step of the diagnostic process in Cultural Heritage conservation and study.

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OPTICAL MICROPROFILOMETRY OPTIMIZED FOR SURFACE ANALYSIS AND 3D PRINTING OF ARCHAEOLOGICAL OBJECTS

1. Introduction

Non-contact 3D optical systems are gaining more and more importance in many fields varying from quality control to robotics (Sansoni *et al.* 2009). Thanks to their ability to measure the surfaces in contact-less non-invasive way, these methods are ideal in the field of cultural heritage when the surface of the object is the central and essential part of the artwork itself. The primary aspect concerns clearly the aesthetic appearance of the object that is the crucial part for professionnals and non professionnals in the field of cultural heritage. However, the cultural assets, and in particular the archaeological objects sustain and reveal the passage of time: if on one side the signs confer to the object the charm of history, on the other side they can reveal deterioration processes. In fact, the surface is often the most vulnerable part of the object because it is in direct contact with the environment and exposed to many external agents that can cause different degradation processes. For instance, porous materials can absorb water and the pollutants with the formation of salts. The crystallization process leads to efflorescence or subsurface mechanical stresses that can irreversibly modify the surface. Even surface cleaning or restoration processes eventually produce morphological and microstructural changes at smaller scales (Striova *et al.* 2016; Daffara *et al.* 2017).

The surface of an artwork has an intrinsic multi-scale nature being a superimposition of a large number of spatial wavelengths. Beside the surface texture, also the surface deformation, namely the small deviations from the main shape of the object, may provide to archaeologist important insights on an archaeological artifact. Moreover, cultural objects in general are unique entities made of different materials: the main challenges in artwork conservation and diagnostics are due to irregularity of the structure, polychromy and the need to obtain high-accuracy data in order to catch even the smallest details or defects. In this context, the digitalization is gaining importance not only for the documentation but also for providing useful information for monitoring time and spatial variations or supporting restoration decisions. The basic and the first step is the artwork's data acquisition: accurate measurements are necessary for an accurate representation of the object (Gaburro *et al.* 2017b).

In this paper we present the versatility of optical scanning micro-profilometry as a tailored technique to *in situ* diagnostics and documentation of archaeological objects. The method is based on laser interferometry, specifically, on the conoscopic holography principle, and thus it is a possible technique to acquire the 3D archaeological surface with micrometric resolution. Thanks to the adaptability of the conoscopic holography sensors and the scanning system, this technology is able to operate with irregular shapes, composite materials, and polychrome surfaces, thus leading to a multi-scale and multi-material approach in surface analysis (Gaburro *et al.* 2017a).

A further advantage of scanning profilometry, as argued in this paper, is that the acquired data can be used to create the mesh file in order to produce an accurate replica of the artwork using 3D printing technologies. 3D printing process could be a considerable support in the field of archaeology where the replication of objects could play a key role in a number of core activities (Balletti *et al.* 2019). In addition, these technologies are gaining attention in the entire field of cultural heritage and 3D printers are now easily accessible to museums and institutions. Thanks to the possibility to reproduce the artworks, 3D printed object can be used for restoration and conservation, haptic fruition and many other purposes (Balletti *et al.* 2017). Moreover, as described in literature (Wilson *et al.* 2018, 2020) museums have progressively focused their attention to a more user-centered fruition in which the visitors make use of a range of senses beyond sight. In this contest, it is pointed out that the most valued aspect for the printed replica is to be realistic and to represent the original object at the best. 3D printing has gradually gained better levels of accuracy and the resolution achieved is now compatible with the resolution of optical acquisition systems, in particular the scanning profilometer based on conoscopic holography, the use of which for 3D archaeological replicas is an innovative application.

2. Optical scanning profilometry based on conoscopic holography sensors

The conoscopic holography technique is based on the recording of the interference pattern formed from an object beam and a reference beam using a coherent light source. The backscattered laser beam is split into two by an optically anisotropic crystal, which has a refractive index that depends on the incidence angle and the polarization state of the ray. This property allows the two rays to share the same geometric path but to have a different optical path length. Therefore, after the two beams exit the crystal, they can interfere to each other and the characteristics of the generated pattern depend on the distance of the sampled surface from the light source (Sirat 1992; Álvarez *et al.* 2009).

Each probe can be then equipped choosing between several lenses to perform surface acquisition in different working range that is the maximum z-displacement that can be acquired. The different combination of sensors and lenses allows the analysis of reflective materials with micrometric accuracy in millimetric scales, namely with a working range of 1 mm up to a working range of 9 mm. While for diffusive material it is possible to obtain a working range that varies from 0.6 mm up to 180 mm maintaining a sub-millimetric accuracy. The sensor measures a single point hence for reconstructing a surface the probe must be moved following a controlled path. The scanning setup that we assembled for performing the scanning is composed by a motion system with linear axis stages orthogonally mounted to form the acquisition grid (X, Y axis). The axes have a maximum travel range of 300 mm that allows acquiring significative regions, i.e. small archaeological objects, or selected parts with well defined macroscopic features (e.g. incisions, reliefs, scratches, etc.). The probe operates in pulse-mode, receiving pulses from an external trigger sent by the scanning system: for each pulse the probe acquires the distances from the lens to the sampled object. The software reconstructs a 2D array of distances from the data recorded knowing the number of measurements for each line and the direction of motion.

We designed two different set-ups suitable for different applications. In the first one the probe is in a still position while the micrometric stages are fixed on an optical table and move the sample. This configuration is particularly useful when there are small archaeological samples that can be analysed in the laboratory like ancient coins, earthenware, shards, bone fragments, etc. Instead, the second set-up is suitable for *in situ* measurements, i.e. when the object cannot be moved, as for example in the case of mural painting, fixed relief or large tridimensional objects that is advisable to not move outside the museum. In this case the probe is mounted and moved by the two motorized linear stages while the object remains stationary.

3. Experimental applications and discussions

3.1 *Laboratory application: fragment of amphora*

We present a first application of the technique in a laboratory environment on a curvilinear surface: a portion of an archaeologic amphora (Fig. 1, left). The scanning setup is conveniently of the first type with the probe in still position equipped with the ConoPoint-3 with a 75 mm lens. The working range is 18 mm with a stand-off distance of 70 mm and a laser spot size of 47 μm. We acquired a selected region of interest of 55.2×80.1 mm with a scanning step (X-Y sampling grid) of 100 μm and a scanning speed of 10 mm s^{-1}.

From this example we can notice that the signal of the surface of this object can be described as superimposition of different frequency components. In fact, the common approach in surface metrology is to separate the surface in three main components: the roughness, i.e. the irregularities at smaller scale that exhibit a random nature, more related to the behavior of the material;

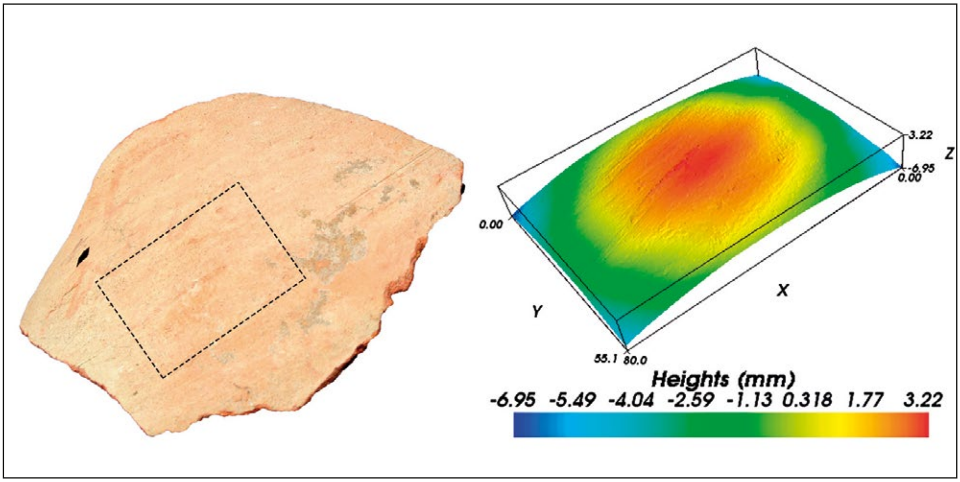

Fig. 1 – Left: part of the amphora with the scanned ROI of 55.2×80.1 mm^2 (black dashed line); right: surface map of the ROI.

the waviness, i.e. the more widely spaced variation often associated with the traces left by the tool used for shaping the object; and the form, i.e. the 3D shape of the object. In the case of the region of interest (ROI) of the amphora we decompose the signal using a polynomial fitting to separate the shape from the texture, while the roughness is separated from the waviness using a Gaussian filter.

The importance of the surface signals separation lies not only in the possibility of having an insight on the production process of the object but also an insight in the conservation history of the object, assessing changes due to degradation processes or cleaning methods. It should underline, anyway, that in case of historical artefacts is not always possible to apply the rigid metrology classification. Analysing the pattern, we can see that the waviness contains some of the signs left by the potter at lower frequency that have an average spacing of 16.4 mm and an amplitude of 462 µm (maximum peak-to-valley distance). Besides this signal, a higher frequency signal is visible. This is probably due to a finishing with dried straw brushes. This signal has an average spacing of 1 mm and an average amplitude of 35 µm.

3.2 *3D printing*

From the analysis of the dimensional ranging of the features encountered on the object that we want to reproduce, we can tailor the printing so that these meaningful details are not lost in the process. Most of the profilometers do not store the data as a point clouds or mesh so that they cannot be printed directly. We developed our own tools for creating a mesh from the 2D-arrays of distances collected using the microprofilometer following this workflow:

– from the scanning step we generate a grid of equally spaced point;
– once we have obtained the point cloud data with the triplet (X, Y, Z) representing the vertices of the mesh for creating a 'watertight' solid, we generate the faces and hence a cuboid with the same dimension of the scan and we substitute the top face with the scan;
– eventually, we can programmatically create and export the mesh to a STL file using Trimesh (TRIMESH). An STL describes the surface geometry of the 3D object and it is the typical file format used by 3D printing and computer aid manufacturing.

The figure below (Fig. 2, left) shows the 3D printed object that we tested and printed using the best possible resolution (0.05 mm) of a commercial printer that employs the stereolithography (SLA) technology. To optimize the use of the printing material we can decide to extrude the surface for only a small distance, avoiding printing the entire thickness of the object. For maintaining the strength of the surface, in case we can print a support grid. In order to test the accuracy of the 3D printing process of the artwork we measured the printed object. As example, the following figure (Fig. 2, right) shows the comparison of the amplitude distribution function of the higher spatial frequencies, i.e. waviness+roughness, which are the components mostly affected by the printing process.

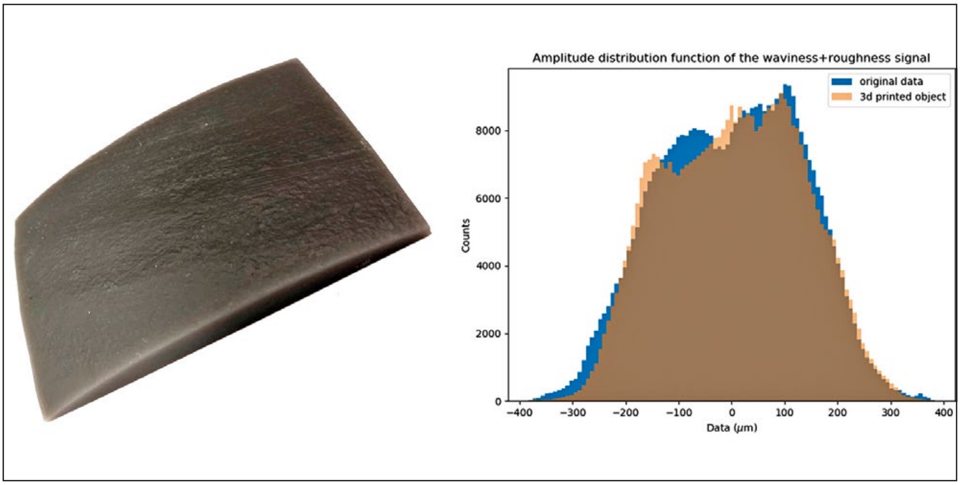

Fig. 2 – Left: 3D printed ROI of the amphora. Right: comparison of original surface data and 3D printed replica.

3.3 *Museum application: surface analysis of an Etruscan bronze mirror*

The second application aims to show the potentiality of the micro-profilometer for *in situ* surface analysis in an out-of-lab environment. The interdisciplinary case study regards an Etruscan mirror that was investigated in collaboration with the Museum of Archaeological Sciences and Art of the Department of Cultural Heritage of the University of Padua.

3.3.1 Historical description of the object

The object that has been investigated is a round bronze mirror, it has a diameter of around cm 14 and it is an Etruscan artefact, dated to the mid/second half of the 4th century BC (Inv. BT154). It belonged to the Neumann Collection in Trieste until the whole collection passed to the University of Padua in 1925. In the following year the archaeological section came to the University Museum of Archaeological Sciences and Art in which it is still today. As the large part of that collection, the mirror's original place of finding is unknown.

The mirror was made by using a die casting and subsequently it was decorated with a carved decoration representing a mythological figure. Unfortunately, part of the mirror's plain surface and of the tang to connect it with the handle (not preserved) are missing. On the surface there are also several traces of corrosion and scratches. With regard to the decoration (Fig. 3), the lower part of a winged figure is preserved. It is a winged woman, dressed in classical clothes and wearing footwear. She is represented while walking to the left between two large flowers at her feet. The winged woman is perhaps a Lasa, a figure of the

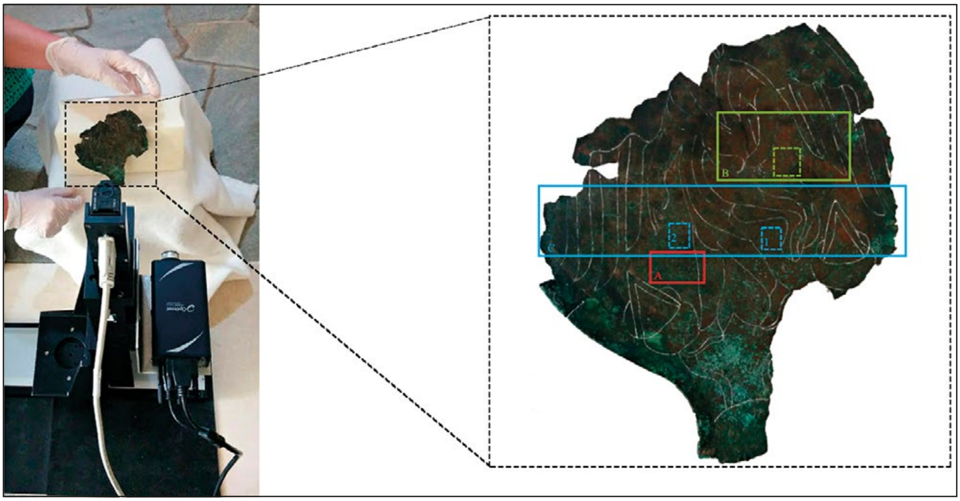

Fig. 3 – Left: *in situ* measurements of the mirror; right: the considered object with the investigated ROIs.

Etruscan pantheon who is represented on several Etruscan artefacts, especially on the mirrors. There are many interpretations of this mythological figure: she continues to raise questions and her role in the Etruscan religion remains disputable. Recent comparisons of the nameless figures of winged women to Lasa suggested that the name Lasa should not be applied to any winged female figure and it would be more suitable to use the term 'Pseudo-Lasa'. In addition, the meaning of this figure should probably be treated as connected with the female world (Spiller 1970; Korczyńska-Zdąbłarz 2011).

3.3.2 Data acquisition and analysis

Fig. 4 shows the surface intensity map of the ROIs acquired by the micro-profilometer equipped with the ConoPoin3 and a 75 mm lens. The scanning step (X-Y sampling grid) was set at 50 μm and the scanning speed at 10 mm s^{-1}. We can compare the roughness computed as the standard deviation of the sections, after the removal of the form, in ROIs A, B, and C (Tab. 1). The ROIs exhibit different textures probably due to different deterioration and cleaning processes.

	ROI A	ROI B (detail)	ROI C (detail 1)	ROI C (detail 2)
Roughness (μm)	16	34	24	30
Max peak-to-valley (μm)	212	177	208	225

Tab. 1 – Measured surface parameters of the investigated ROIs.

From ROI A we can estimate the mean height of the corrosion spot around 71.5 μm. The various ROIs highlight the incisions of the decoration with a measured width that varies from 50 to 650 μm and a measured depth that varies from 237 to 41 μm. Moreover, ROI B presents a significant crack that causes a shift along the z axis. The maximum plane displacement measured in the investigated section is 0.93 mm. From ROI C the average deformation is evaluated after the removal of the tilting plane. As can be seen in following plots (Fig. 5), the object shows a maximum displacement along the x axis near 2 mm, with the greater curvature in the middle.

4. Conclusions

In this work we presented the potential of scanning conoscopic holography applications on archaeological objects. Among the main potentialities of the technique there is the possibility to perform contact-less and full-field measurements with a micrometric precision, taking advantages of a versatile configuration setup that allows both laboratory acquisition of samples than measuring *in situ* artworks of large dimensions or too frail to be moved. Specifically, the system modularity allows the possibility of setting different spatial samplings

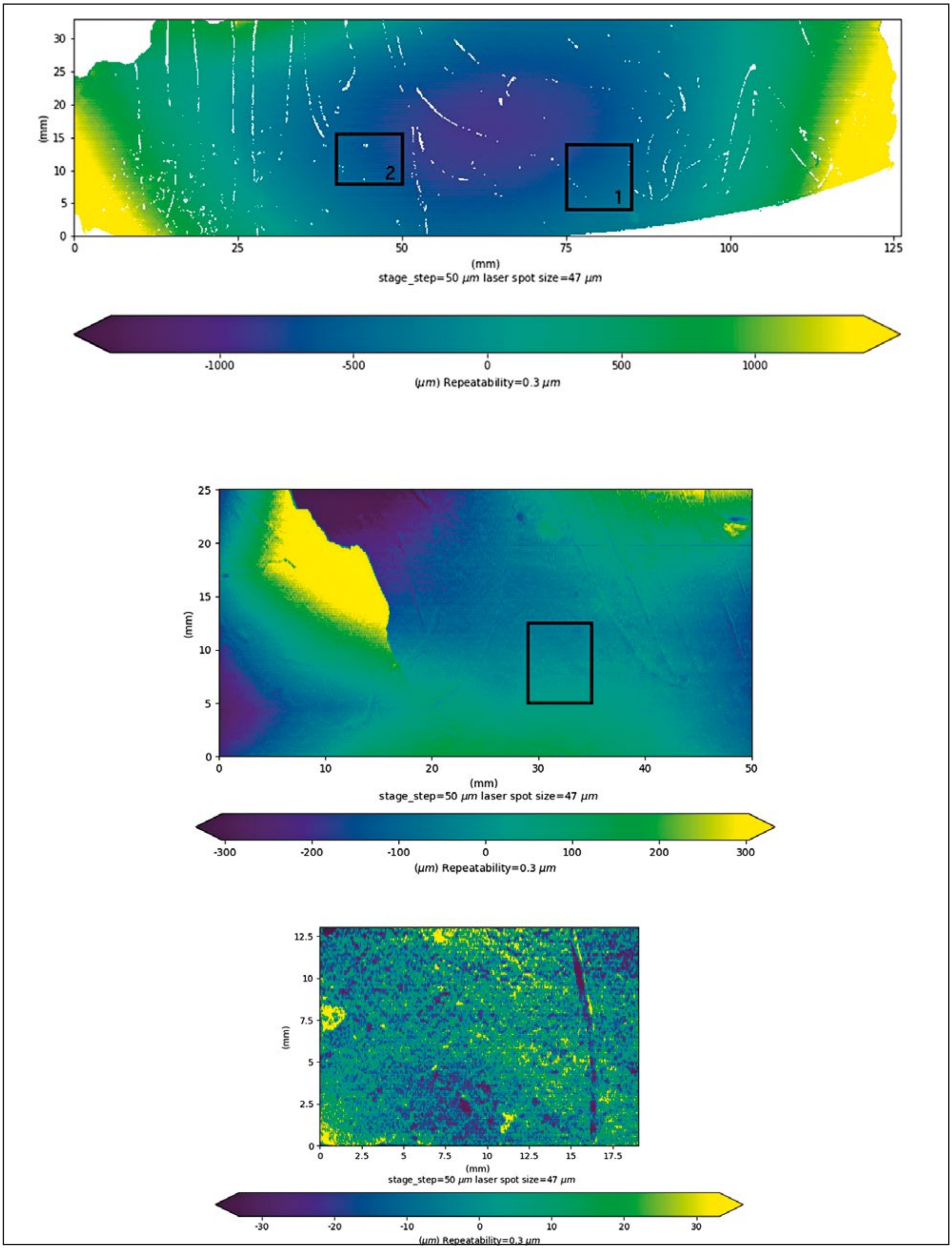

Fig. 4 – Top: ROI C acquired by the microprofilometer with the two regions used for roughness analysis (1:10×10 mm^2, 2: 10×7.5 mm^2). Middle: ROI B acquired by the microprofilometer with the region (6×7.5 mm^2) used for roughness analysis. Bottom: ROI A acquired by the microprofilometer.

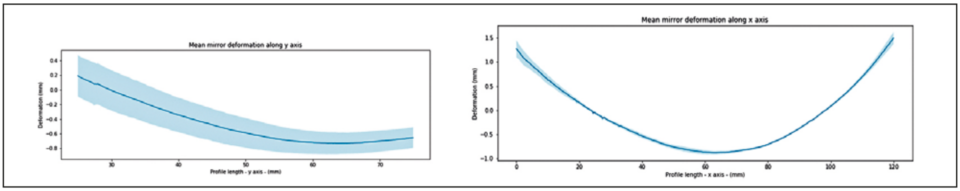

Fig. 5 – Mean curvature of the mirror measured along the x axis (left) and the y axis (right) of the central part of ROI C, using respectively 200 rows and 1000 columns.

for different needs by coupling different lenses and laser probes. Then, there is the advantage of using a single-point sensor and scanning techniques that enable the creation of profiles and surface maps with custom 'field of view'.

The micro-metric resolution is of fundamental importance for the acquisition of the material surface texture in an archaeological object, allowing the analysis of the roughness and waviness components for different aims, from the study of the historical features to the monitoring of the conservation status. Furthermore, the 2D array can be elaborated to obtain the file format suitable for 3D printing technology with the possibility to create an accurate and high-resolution replica of the artwork. The 3D printed replica of objects offers new possibilities for the museums or in the field of experimental archaeology, especially if it starts from accurate and precise acquisitions. Obviously, this adds new levels of challenges, but at the same time, it can lead to the opportunity to develop a multidisciplinary research. Here, the optical micro-profilometry for 3D printing and surface analysis was demonstrated in two case studies: a laboratory application on a fragment of an amphora, and an Etruscan bronze mirror investigated *in situ*, in collaboration with the Museum of Archaeological Sciences and Art of the University of Padua.

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ABSTRACT

In this paper we investigated the application of the optical scanning micro-profilometry based on conoscopic holography sensors for the acquisition and the surface analysis of archaeological objects with a micrometric resolution. The portability of the setup developed and its modularity allow to work *in situ* with a multi-scale and multi-material approach. In addition, we have developed our own tools to create a mesh from the 2D-arrays of distances collected with the resulting possibility to obtain a replica of the artwork using 3D printing technologies. We test the micro-profilometer on two case studies: a fragment of an archaeological amphora, also presenting the workflow to obtain the 3D printed object, and an Etruscan bronze mirror, analyzing its surface.

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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).

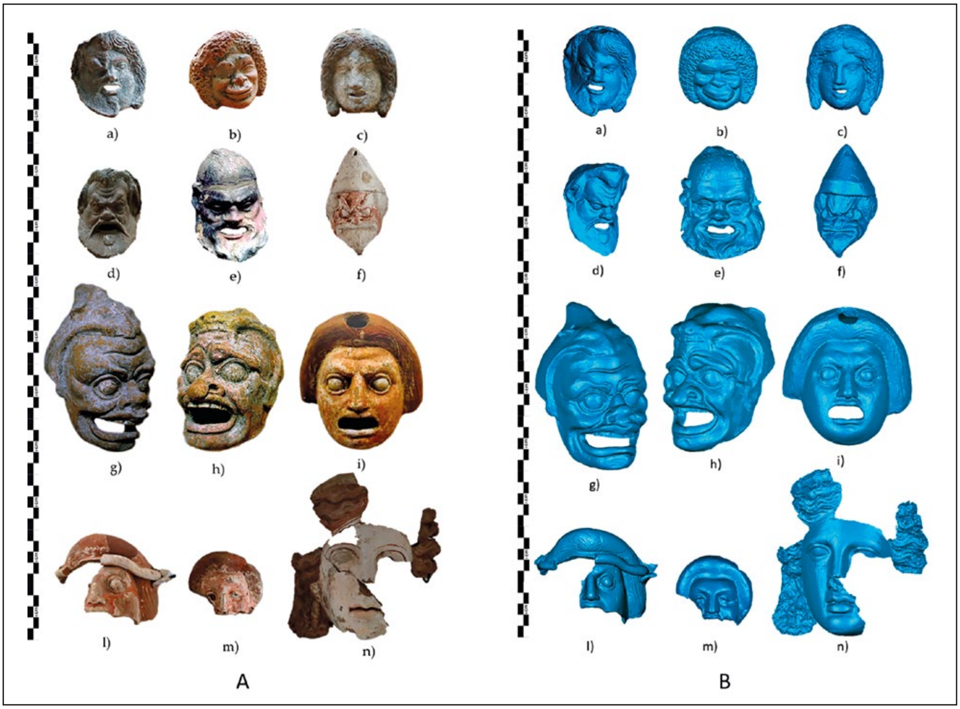

Fig. 1 – Theatrical masks taken in exam: a) n. inv. 11114-E (h. 7.8 cm); b) n. inv. 10827 (h. 6.9 cm); c) n. inv. 11114-B (h. 7.2 cm); d) n. inv. 9729 (h. 7.9 cm); e) 9219 (h. 11.5 cm); f) 13558 (h. 11 cm); g) 14585 (h. 16 cm); h) n. inv. 14584 (h. 13 cm); i) n. inv. 6766 b (h. 13 cm); l) n. inv. 11248 (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 co-ordinate 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 co-herent 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.

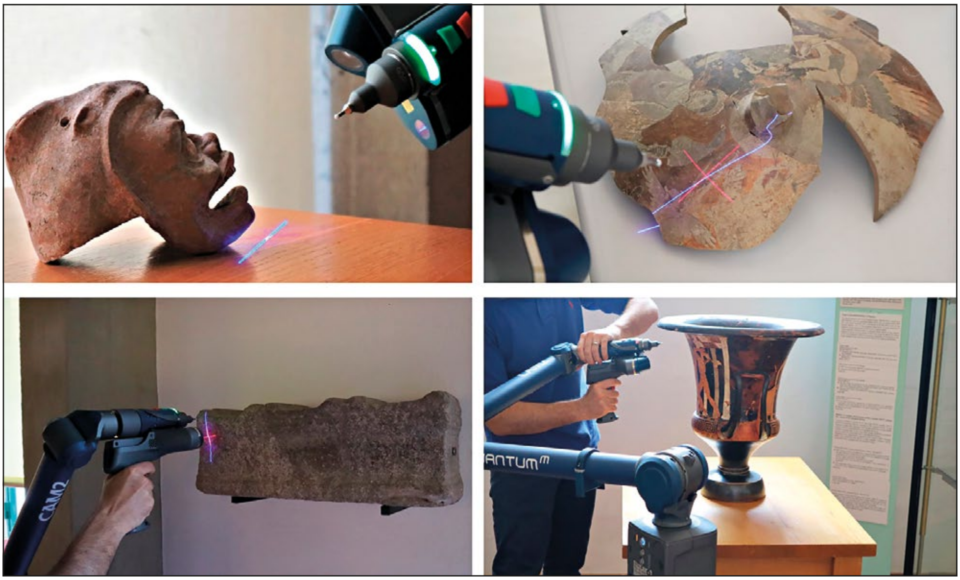

Fig. 3 – Laser arm scanning in progress.

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

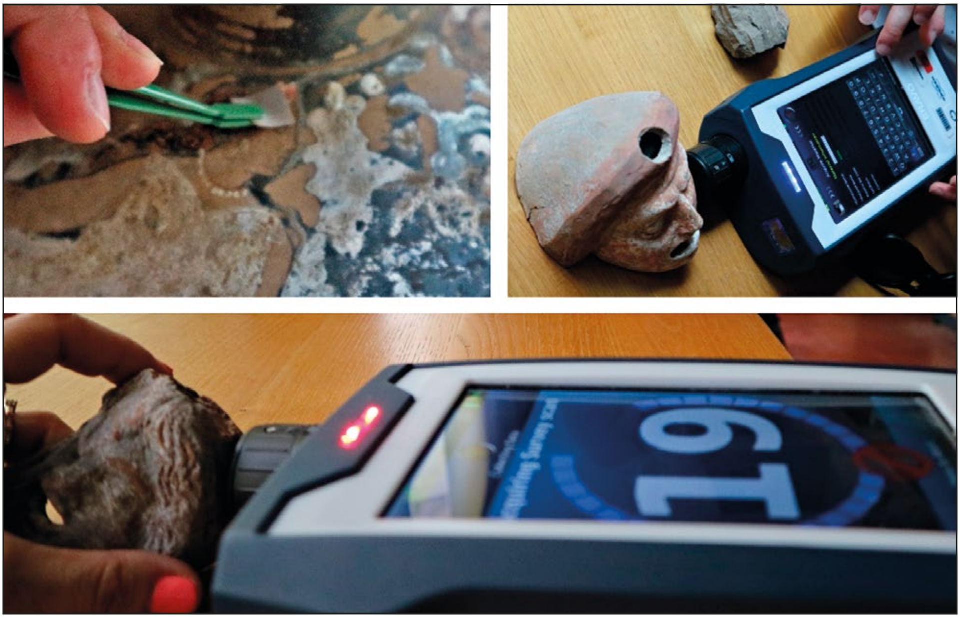

Fig. 4 – Measurement through Raman spectrometer.

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)

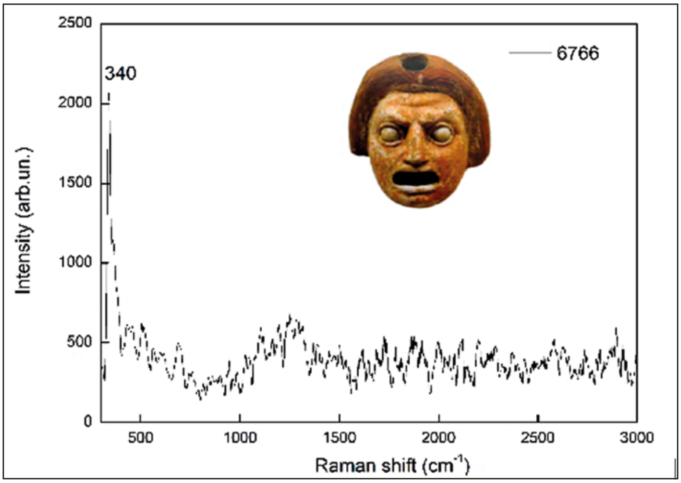

Fig. 5 – Raman spectrum of the clay mask No. 6766.

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.

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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.

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ARCHITECTURAL AND SCULPTURAL DECORATION OF ROMAN CENTRAL ADRIATIC ITALY: AN ARCHAEOLOGICAL AND ARCHAEOMETRIC APPROACH TO REGION-WIDE MARBLE TRADE

1. Introduction

Roman culture is particularly known for its impressive architectural and sculptural creations. While these buildings and objects have often been studied for their architectural and art historical value, their potential to inform us about contemporary economy, and society in general, is still often been overlooked. Roman society was highly hierarchical and its wealthy members were constantly striving to showcase, maintain and increase their status and prestige. For the elite class, monumental architecture and sculpture were some of the most powerful means to this end. This resulted in ancient cities being lavishly adorned with marble statuary and marble(-clad) architecture, mainly through benefaction by members of the elite. The importance of marble for Roman society, its durability, provenancing and chronological data make marble studies a promising research subject for archaeologists and historians interested in the economy of Antiquity. Marble objects were traded in huge quantities and over long distances in the Roman period, much like other objects (wine, olive oil, pottery, etc.), and so reflect wider economic patterns (Russell 2013).

In this paper, we wish to focus on: 1) the provenance and use of marbles in central Adriatic Italy from a diachronic and regional perspective; 2) how marble imports relate to the regional urbanisation process; 3) how the marble trade fits in the wider trade networks of the region.

2. Roman urbanism in central Adriatic Italy

The study area stretches out over c. 1600 km^2 in central Adriatic Italy (Fig. 1) and includes the northern part of *Picenum* and the southern part of *Umbria et ager Gallicus*; the fifth and sixth districts respectively of Augustus' *Provincia Italia*. The study area is centred on the Roman town of Ancona, a major port of the Roman Adriatic, and is bordered by the *via Flaminia* to the North and the *via Salaria* to the South. The western and eastern boundaries are marked by the Apennines and the Adriatic shoreline. Roman presence in central Adriatic Italy was the result of a long and turbulent annexation process between the late 4th century BCE and the second quarter of the 3rd century BCE. Of specific importance for the spread of Roman culture in the region was the construction of the *via Flaminia* (Renzulli *et al.* 1999) and the

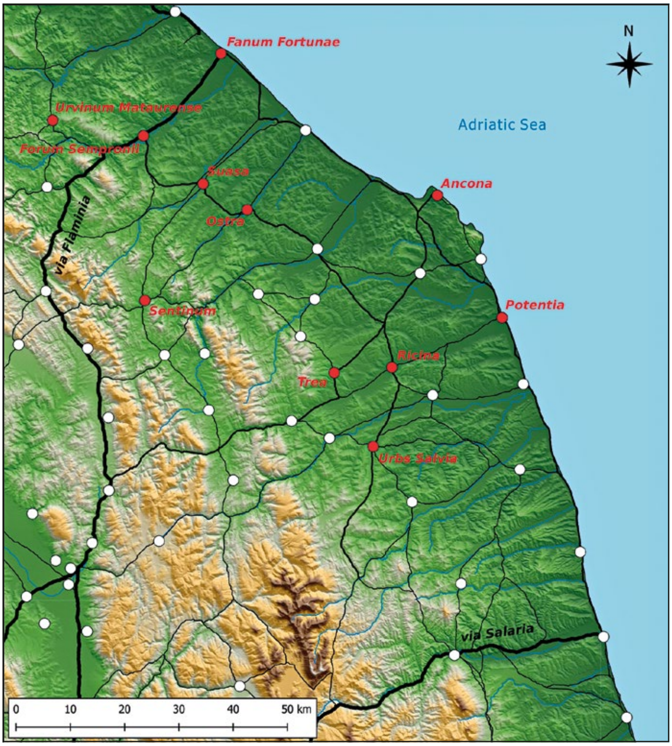

Fig. 1 – Map of central Adriatic Italy in Roman times, with indication of the case study sites (in red) and the Roman road system.

extension of the *via Salaria* in the late 3rd century BCE, two main road arteries of Roman Italy, as well as the foundation of several colony towns from the 280s BCE onwards. Following the Roman reorganisation of the *ager Picenus* and *ager Gallicus* after the Social War (91-88 BCE), many urban centres received the status of *municipium* (especially after the middle 1st century BCE) and several new towns were established with urban structures that reflected the new political-administrative situation of the region (Vermeulen 2017).

These events resulted in central Adriatic Italy becoming one of the most densely urbanised regions of the Roman world with urbanisation rates comparable to those for *Latium* and *Campania* in Italy and *Baetica* on the Iberian Peninsula (de Ligt 2012a). Already in the Late Republic, but especially in the Early and Middle Empire, many towns in the region were monumentalised (Vermeulen 2017) and received lavish marble decoration.

Typical for the Roman period urbanisation of central Adriatic Italy was the apparent oversizing of public space compared to the relatively small town

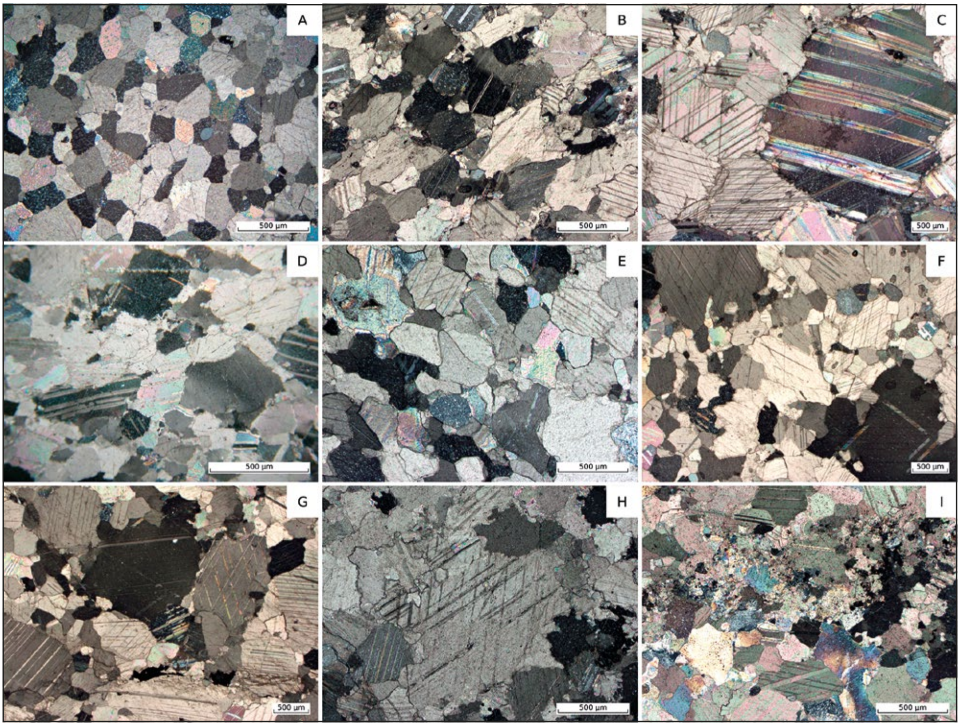

Fig. 2 – Photomicrographs under crossed polars of the white and greco scritto-like marble varieties used in Roman central Adriatic Italy: A) Carrara (Apuan Alps, Italy); B) Dokimeion (Afyon, Turkey); C) Naxos (Greece); D) Pentelikon (Greece); E) Paros-1 (Stephani, Paros, Greece); F) Paros-2(3) (Lakkoi, Paros, Greece); G) Proconnesos (Marmara, Turkey); H) Thasos-3 (Cape Vathy, Thasos, Greece); I) Hasançavuslar (Ephesos, Turkey).

centre (Bekker-Nielsen 1989; de Ligt 2012a, 2012b; Van Limbergen, Vermeulen 2017). This suggests that the towns acted as a kind of service centres not only for their inhabitants but also (and especially?) for the surrounding countryside (Vermeulen 2017).

3. Marble data and provenance methodology

This contribution is based on marble data from eleven towns in central Adriatic Italy (Ancona, *Fanum Fortunae*, *Forum Sempronii*, *Ricina*, *Ostra*, *Potentia*, *Sentinum*, *Suasa*, *Trea*, *Urbs Salvia* and *Urvinum Mataurense*), with a chronological context spanning the late 2nd century BCE to roughly the 3rd century CE. Systematic material studies and archaeometric provenance analyses for six sites were complemented with published marble data for the region (Capedri *et al.* 2001; Attanasio *et al.* 2003; Amadori *et al.* 2012, 2014;

Antonelli *et al.* 2014; Taelman 2017; Taelman *et al.* 2019; Taelman, Antonelli in press).

A representative selection of samples of white and 'greco scritto'-like marbles of each site was analysed using a widely accepted multi-technique archaeometric approach combining mineralogical-petrographic observations and stable C-O isotopic analysis. Samples were selected to maximize lithological, contextual and chronological variability. For each sample, microstructure, maximum grain size (MGS), calcite boundary shapes and accessory minerals were determined in thin section under a polarising microscope (Fig. 2). The presence of dolomite was evaluated through X-ray diffraction (XRD). Ratios of stable carbon and oxygen isotopes ($\delta^{13}C$ and $\delta^{18}O$) were determined using a Gasbench II preparation line connected online to a ThermoFinnigan Five Plus mass spectrometer in a continuous flow mode. Samples were reacted with 100 % phosphoric acid at 70 °C. Stable isotope results are expressed in δ (‰) values, relative to the international PDB standard. Petrographic, mineralogic and isotopic results were compared with data from literature (Antonelli *et al.* 2009; Yavuz *et al.* 2011; Antonelli, Lazzarini 2015).

Polychrome marbles were identified macroscopically on the basis of the specific knowledge of the authors and by comparison with reference samples (Gnoli 1988; Borghini 2004; Price 2007).

4. Marble provenance

4.1 *Early imports*

The earliest evidence of marble use in central Adriatic Italy are a group of twelve funerary *stelae* with Greek inscriptions and carved in Delian tradition of the later 2nd and early 1st centuries BCE from Ancona. Archaeometric analyses identified the reliefs as carved in marble from Paros (Lakkoi variety), Carrara, Proconnesos and in local limestone from the Scaglia Rossa formation (Fig. 3) (Antonelli, Lazzarini 2013a). The stylistic and iconographic similarity of the Ancona *stelae* with contemporary productions from Delos and the prevalence of Parian marble (8) suggests a direct import of the *stelae* from the Aegean probably in a finished state and demonstrates a close connection between central Adriatic Italy and the Greek world, in particular Delos. The presence of *stelae* in Carrara (2) and Proconnesian (1) marble, as well as in local limestone (1), that are stylistically very similar to the Parian examples, suggests not only material import but also craftsmanship mobility through itinerant sculptors from Delos or local craftsmen trained by Delian sculptors (Antonelli, Lazzarini 2013a). The identification of Carrara and Proconnesian marble provides also the earliest evidence for the distribution of these marbles outside central Tyrrhenian Italy and Asia Minor, respectively.

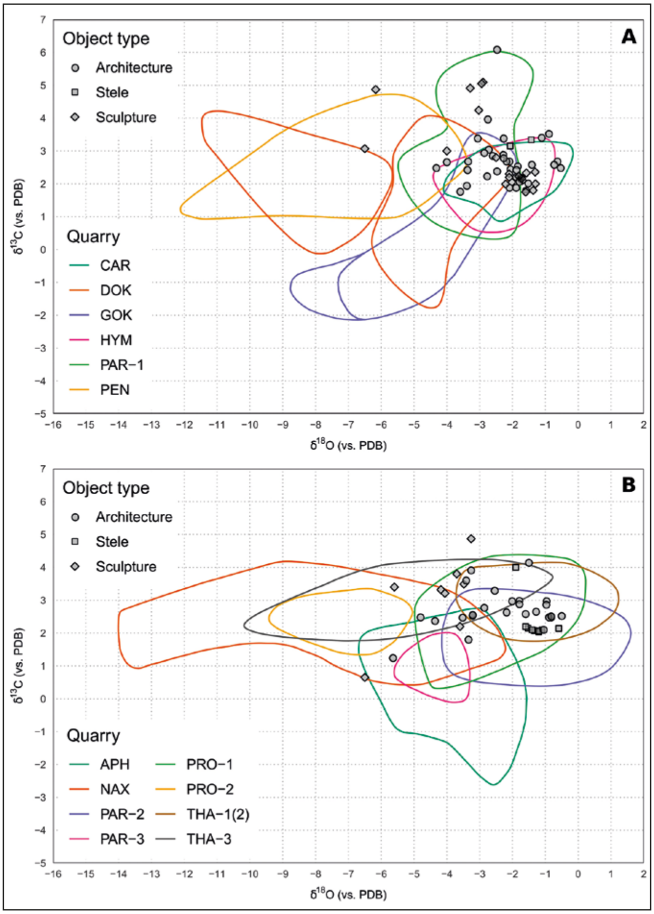

Fig. 3 – Stable isotope diagrams of the marble objects from central Adriatic Italy. (A) Fine-grained marbles (MGS ≤ 2 mm); (B) Medium- and coarse-grained marbles (MGS > 2 mm). Quarry abbreviations: APH = Aphrodisias, CAR = Carrara, DOK = Dokimeion (Afyon), GOK = Göktepe, HYM = Hymettos, NAX = Naxos, PAR-1 = Paros-1, PAR-2 = Paros-2, PAR-3 = Paros-3, PEN = Pentelikon, PRO-1 = Proconnesos-1, PRO-2 = Proconnesos-2, THA-1(2) = Thasos-1(2), THA-3 = Thasos-3. Quarry fields from Antonelli, Lazzarini 2015.

4.2 *Statuary marble*

Marble decoration became popular in the region in the Late Republic and even more so in the Julio-Claudian period, in the form of marble statuary imports from mainly Paros and Carrara (Fig. 4a). Greek marbles (Pentelic, Thasian and especially Parian, both the lychnites and non-lychnites varieties)

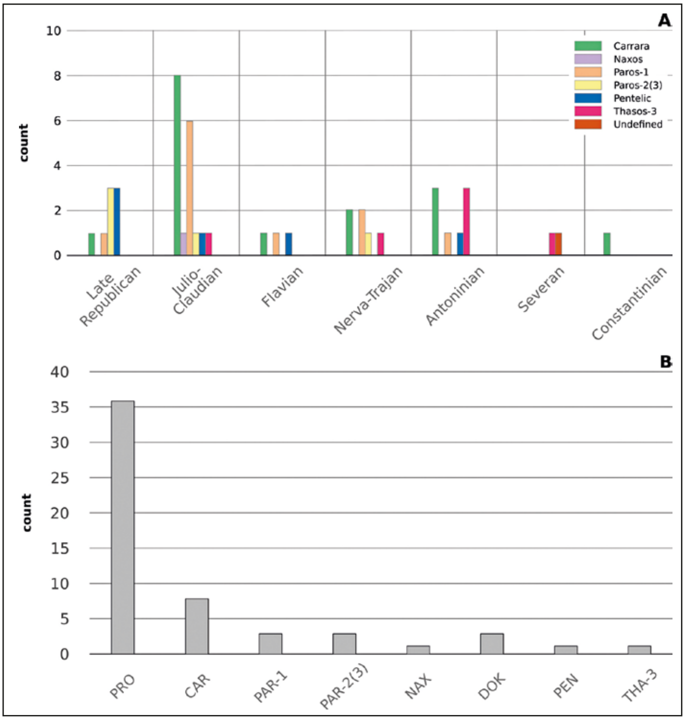

Fig. 4 – A) chronological distribution and suggested quarry provenance of the Roman white marble statuary in central Adriatic Italy; B) provenance of the white marbles samples used for architectural purposes (all samples date from the Flavian period to the 2nd century CE). Quarry abbreviations are PRO = Proconnesos, CAR = Carrara, PAR-1 = Paros-1, PAR-2(3) = Paros-2(3), NAX = Naxos, DOK = Dokimeion (Afyon), PEN = Pentelikon, THA-3 = Thasos-3.

seem to have been reserved mainly for religious statuary and imperial portraiture. Marble for non-imperial official statuary, such as *togati* and private portraiture, were almost exclusively obtained in the Carrara quarries (Figs. 3, 4a). The dominance of Parian and Carrara marble can be explained by the relative early chronology of the statuary, with most statues dated to the Julio-Claudian period.

4.3 *Architectural marble*

Widespread use of architectural white and polychrome marbles in the region started in the Flavian period and peaked in the 2nd century CE when many new monumental buildings were erected and existing buildings were renovated. Large-scale use of architectural marble is, for example, attested

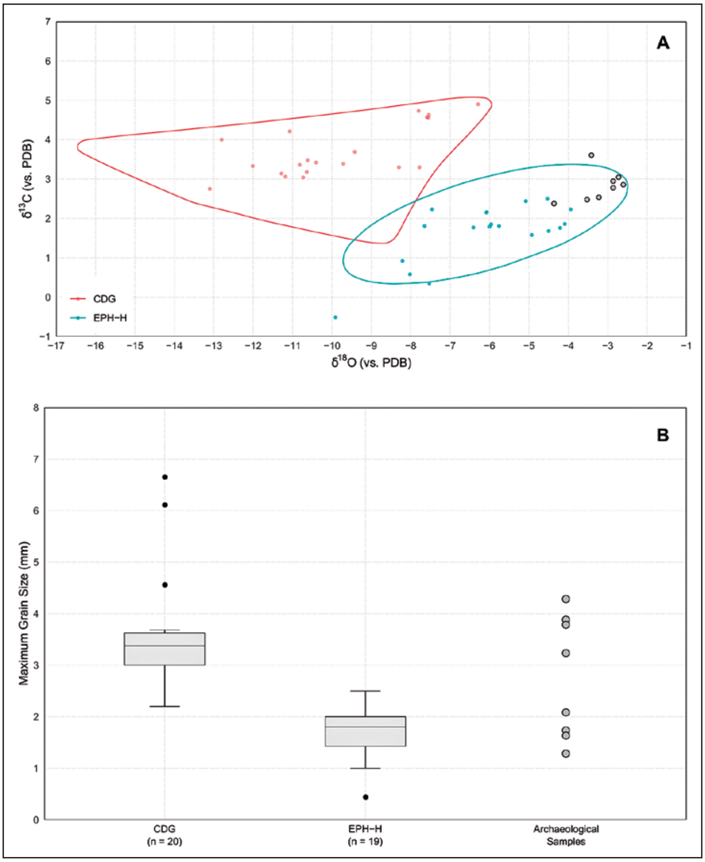

Fig. 5 – Greco scritto-like marble objects from central Adriatic Italy: A) stable isotope diagram; B) boxplot of maximum grain size. Quarry abbreviations: CDG = Cap de Garde, EPH-H = Ephesos - Hasançavuslar. Quarry data from Antonelli *et al.* 2009 and Yavuz *et al.* 2011.

in the house of the Coiedii in *Suasa*, the marble renovation of the theatre of *Urvinum Mataurense* (Taelman *et al.* 2019) and the marble decorations of towns like *Trea* (Taelman 2017) and *Urbs Salvia* (Antonelli, Lazzarini 2013b). Proconnesos and Carrara were the earlier suppliers for architectural white marble (Figs. 3, 4b). The Arch of Trajan in Ancona (114-115 CE) stands out as an example of Proconnesian marble use for this purpose (Attanasio *et al.* 2003). Other cases of the early use of this marble for architectural purposes are the two bath complexes in *Sentinum* (Taelman, Antonelli 2021) and the theatre in *Urvinum Mataurense* (Taelman *et al.* 2019). Pentelic, Dokimeion, Parian and Thasian (dolomitic variety) marbles were used at times for more elaborated parts such as capitals and pediments (Fig. 3).

Imported polychrome marbles were mostly giallo antico, greco scritto, portasanta, africano, breccia di Sciro, breccia corallina, cipollino verde, fior di pesco, pavonazzetto and rosso antico. More rare and prestigious imports were serpentino, porfido rosso and granito verde della sedia di San Lorenzo, as well as Iberian and Aquitanian imports (at *Urbs Salvia*) such as brocatello and cipollino mandolato respectively (Antonelli, Lazzarini 2013b).

Particular noteworthy are the presence of breccia medicea at *Urvinum Mataurense* – which represents the earliest major *in situ* use of this marble in a Roman context (Taelman *et al.* 2019) – and the identification of rosso ammonitico at *Urbs Salvia*, *Sentinum*, *Suasa* and *Urvinum Mataurense*. The latter, a brown red-to-salmon-pink nodular limestone with abundant ammonites and other fossils of Jurassic age, is the only decorative stone that can be traced back to the region, specifically to the central Adriatic Apennines (Capedri *et al.* 2001).

For the greco scritto-like marbles, analyses suggest the Hasançavuslar quarries, near Ephesos, as the most like source (Fig. 5a). The mineralogical-petrographic data of the central Adriatic samples of greco scritto exclude an Algerian origin for the marble from Cap de Garde whereas the ratios of stable oxygen and carbon isotopes fit the data set well in terms of the quarries exploited in Hasançavuslar, in the Ephesos region. Nonetheless, today, detailed petrographic descriptions of a sufficiently large set of samples of the Hasançavuslar marble are still unpublished (greatly limiting the comparative studies) and a different origin (Kavala in Greece, other sites near Ephesos, or Proconnesos and other localities of the north-western coast of Anatolia in Turkey) (Antonelli 2006; Antonelli *et al.* 2016) cannot therefore be completely ruled out, especially considering the maximum grain sizes of some central Adriatic samples (some samples have a MGS between 3.25 and 4.30 mm) (Fig. 5b).

5. Marble trade in central Adriatic Italy and the wider Roman economy

Rome's penetration into central Adriatic Italy from the early 3rd century BCE onwards profoundly changed the focus, nature and scale of trade in the Adriatic. Early Greek relations with non-Greek areas of Italy had been limited, but by the end of the 3rd century BCE would be replaced by an increasingly intense trade corridor with the northern Adriatic. Of key importance were Rome's actions to combat Illyrian piracy in the Adriatic (leading to the First Illyrian War in 229 BCE), thus securing trans-Adriatic trade. These events, together with the encroachment of the middle Adriatic area – apace with the start of urbanisation and the installation of a Roman elite in the region – led to increased (trade) contacts between central Adriatic Italy and the Aegean in the Late Republic. This evolution can be seen in the imports of luxury goods such as the *stelae* in Parian marble in Ancona, probably via the important trading hub of Delos (which became a free-trading centre in 167 BCE), where epigraphy also attests to the presence of rich individuals from Ancona (Antonelli, Lazzarini 2013a).

However, the best evidence of this close interaction between the Adriatic and the Aegean in the Late Republic are the abundant material remains (amphorae) of the wine trade that developed between them. Drinking wine was fashionable in the Adriatic since at least the mid-6th century BCE (due to the Hellenization process), and this habit found passionate consumers in the many Italic and Illyrian elites (Sacchetti 2012). So too in Adriatic Italy, where the arrival of Greek wines (perhaps from Corinth) predates the Roman conquest (Gamberini 2014; Monsieur, Carboni 2017), but intensifies with the influx of Roman colonists from the mid-3rd century BCE onwards, with Rhodian wine becoming a particular popular commodity (Marengo, Paci 2008; Paci 2010). In the 2nd/1st century BCE, the central Adriatic area itself also became an important wine exporter (in Greco-Italic and later Lamboglia 2 amphorae), with Delos again as a major destination (Lindhagen 2013; Van Limbergen 2018).

The link with the Eastern Mediterranean is also illustrated by the importance of Proconessian marble. Already in the late 2nd and the early 1st centuries BCE, Proconnesian imports started to appear, making it among the earliest uses of the material in Italy and probably in the Roman West. At the beginning of the 2nd century CE, Proconnesos even became the region's main architectural marble supplier. Interestingly, as is shown in particular by the Arch of Trajan, the architectural use of Proconnesian marble in the region seemingly predates that of the rest of Italy. For example, in Rome, the material is attested in large quantities only after the Trajanic-Hadrianic period (Bruno *et al.* 2002). The reason for the dominant use of Proconnesian marble in architecture perhaps lies in the ease of overseas transport for Proconnesian imports with respect to the difficulties of sailing around the Italic Peninsula or the transport overland of Carrara marble.

Overall, it seems that central Adriatic Italy was strongly integrated in the Mediterranean marble trade, with imports from Italy, Greece (mainland and Aegean islands), Asia Minor, Egypt and North Africa. The relative ease with which the region obtained such a wide variety of marbles is undoubtedly related to its strategic geographic position along important and century-old trade routes between the Mediterranean, in the South, and the Danubian provinces, in the North. This research so highlights the role of the Adriatic as a unique transit hub in ancient geopolitical trade networks, from those of

Greek merchants in the 4th/3rd century BCE in search of rare natural resources in central and northern Europe, to Roman supply lines for the troops in *Dalmatia*, *Noricum* and *Pannonia*.

6. Conclusions

The intense Romanisation of central Adriatic Italy in the Late Republic resulted in a densely urbanized landscape with typical Roman architecture. In the later 2nd century BCE, and even more so from the late 1st century BCE/early 1st century CE, the elite invested in marble objects (mainly *stelae* and statuary in the beginning) to embellish their towns. From the late 1st century CE and during the 2nd century CE, there was a shift towards architectural munificence, resulting in the renovation of monumental public buildings and the application of marble decoration. In this phenomenon of marmorisation of the urban landscape, the link with the Eastern Mediterranean is obvious. Moreover, it is clear that central Adriatic Italy was able to profit from its position along some of the main trade corridors of that period, i.e. those that connected the Mediterranean with the Danubian provinces.

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ABSTRACT

During the Late Republic and Early Empire, central Adriatic Italy was one of the most urbanised regions in the Roman world and most cities were extensively equipped with monumental buildings, often lavishly decorated with imported marbles and sculptures. This contribution presents the results of an archaeological and archaeometric study of the architectural and sculptural marbles used in this central Adriatic area. The determination of the geographical origin of white and polychrome marbles was carried out through macroscopic examination and laboratory investigations (optical petrography, X-ray diffraction, oxygen and carbon stable isotopes). The analyses revealed the presence of a wide range of lithotypes from Italy, Greece (mainland and Aegean islands), Asia Minor, North Africa and Egypt, including varieties of white marble from Carrara, Proconnesos, Pentelikon, Thasos, Paros and Dokimeion.

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HIGH RESOLUTION GEOPHYSICAL SURVEYS TO CHARACTERISE NORBA ARCHAEOLOGICAL SITE (NORMA, CENTRAL ITALY)

1. Introduction

The integrated geophysical study is part of the 'Norba Project', jointly developed between the University of Campania "Luigi Vanvitelli", the Municipality of Norma (Latina) and the Institute of Heritage Science (ISPC, ex ITABC-CNR). The archaeological site of Norba is located in the Latium Region, about 90 km South of Rome, in Italy. The ancient town of Norba rises on a high plateau overlooking the Pontine plain (Fig. 1a). As stated in previous studies, the town has been founded in the archaic age and its most important period was between 450 BC and 81 BC when it was destroyed. A limited occupation may be detected in the Late Republic/Empire on the so-called Major Acropolis, and only occasionally in other areas of the city. Reoccupation during the early Medieval period was more pronounced, and centered around two temples that were then transformed into churches, but only for a short period.

The site remained uninhabited and since 1960 it has been bound by a provision of Archaeological Superintendency. This is one of the reasons for which the archaeological site is still so well preserved today. The city represents one of the best examples of urban town planning, but its plan does not follow a strict scheme. In fact, Norba's plan is articulated by minor differences in sectors and building blocks depending on the morphological configuration, despite the massive effort that was made to regularize the mountain with impressive terraces and earthen fills.

Many urban elements are still visible today as well as cisterns, wells, ambulatories, underground passages and preserved sections of Roman paving; polygonal walls, with a perimeter of over 2.5 km and several gateways such as the Porta Maggiore, are still observable. The bastion at the Porta Maggiore still stands to 13 m in height. During the last ten years, the site has undergone many studies, followed by circumscribed archaeological excavations, which allowed a regular urban layout, marked by terraces in polygonal walls, several buildings and other important archaeological features to be brought to light. The conservation of the polygonal walls and other structures has attracted to Norba, since the beginning of the 18th century, the attention of the

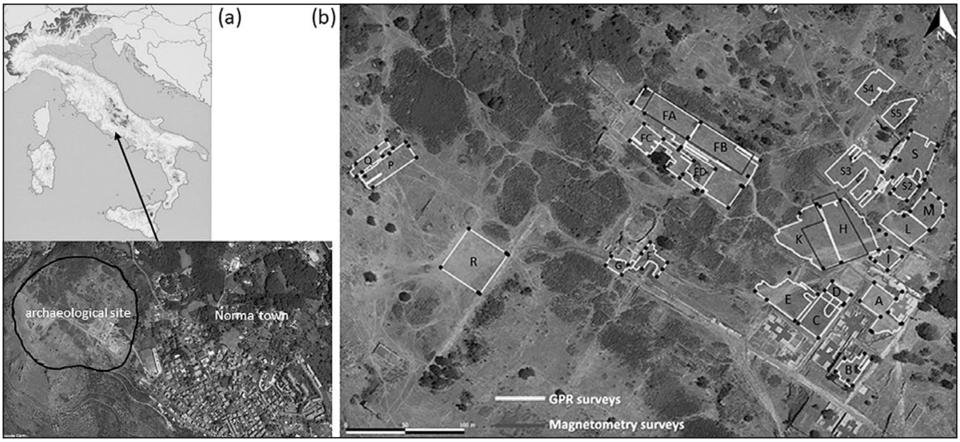

Fig. 1 – a) location of the archaeological site; b) location of the investigated area.

historians and archaeologists. Archaeological excavations were conducted by Savignoni and R. Mengarelli at the beginning of the 20th century in order to date the wall, which was earlier imagined to be Mycenaean or Pelasgian. These scholars' investigations had the great merit of bringing the walls into the Roman era; it has also been used for the experimentation of the first examples of aerophotogrammetric restitution. Thanks to the work of Latium Region and the Municipality of Norma, now the whole site is part of an archaeological park.

Geologically, the area is part of the Lepini Mountain ridge and is characterized by the presence of shallow water platform environments; the prevailing lithology outcropping in the area are Jurassic-Cretaceous dolomitic and micritic limestones.

The 'Norba Project' started in 2017 with new acquisition and processing of extensive geophysical surveys to investigate unexcavated portions of the archaeological site with the aim to enhance the knowledge of the urban plan of the ancient town. Ground Penetrating Radar (GPR) and the Gradiometric (fluxgate differential magnetic) methods have been applied to investigate this site during 2017 and 2018.

2. Methods

The geophysical surveys were carried out using the Ground Penetrating Radar (GPR) and the Gradiometric (fluxgate differential magnetic, MAG) methods in the area shown in Fig. 1b. In white are indicated the areas that were investigated using the GPR method; while in black

Fig. 2 – GPR time slices at the estimated depth of 0.90 m for all investigated areas.

are indicated the areas investigated with the Gradiometric method which overlaps two of the areas investigated with GPR. The Gradiometric survey was employed with the aim to compare and integrate the data sets obtained with GPR.

For the measurements, a SIR3000 GPR system (GSSI) equipped with a 400 MHz (GSSI) bistatic antenna with constant offset was employed. The horizontal spacing between parallel profiles at the site was 0.25 and 0.50 m. In the investigated areas, 1199 parallel adjacent profiles across the site were collected alternatively in forward and reverse directions, employing the GSSI cart system equipped with odometer. All radar reflections within the 90 ns (two-way-travel) time window were recorded in the field as 16-bit data and 512 samples per radar scan.

Part of the area surveyed with GPR has been investigated employing the Gradiometric method (Fig. 1b). These surfaces were divided in squares of 20×20 m and of 10×10 m where the gradient of the vertical component of the earth magnetic field was measured using a fluxgate gradiometer FM256 (GEOSCAN Research, UK) along parallel profiles with a horizontal spacing of 1 m and with a sampling interval of 0.5 m along the profile.

Furthermore, the perimeters of all selected areas have been surveyed with the use of a Differential Global Positioning System DGPS OMNISTAR 5220 HP in order to have the correct positioning and georeferencing.

3. Processing and results

3.1 *Ground Penetrating Radar data*

GPR reflection profiles were analyzed for preliminary identification of the buried features and for calibration of the instrument. Reflection data, collected along the profiles with 0.25 and 0.50 m spacing, were processed using standard techniques (Neubauer *et al.* 2002; Leckebusch 2003, 2008; Piro *et al.* 2003; Conyers 2004; Goodman *et al.* 2004; Linford 2004; Piro, Campana 2012; Goodman, Piro 2013).

The basic radargram signal processing steps included: 1) post processing pulse regaining; 2) DC drift removal; 3) data resampling; 4) band pass filtering; 5) background filter and 6) migration. With the aim of obtaining a planimetric vision of all possible anomalous bodies, the time-slice representation technique was applied using all processed profiles. All the GPR data were processed with GPR-SLICE v7.0 Ground Penetrating Radar Imaging Software (Goodman 2020).

Reflection amplitude 2D maps (time slices) were constructed within various time (and corrected to depth) windows to show the size, shape, location and depth of subsurface archaeological structures (Neubauer *et al.* 2002; Piro *et al.* 2003; Conyers 2004; Gaffney *et al.* 2004; Linford 2004; Goodman *et al.* 2008; Leckebusch 2008; Goodman, Piro 2013). These images were obtained using the spatial averaged squared wave amplitudes of radar reflections in the horizontal as well as the vertical. The squared amplitudes were averaged horizontally every 0.25 m along the reflection profiles and vertically every 3 ns along the time window (with a 10% overlapping of each slice). The resampled amplitudes were gridded using the inverse distance algorithm with a search radius of 0.75 m. Velocities of 0.10 m/ns were estimated using hyperbolae fitting in GPR-SLICE v7.0 imaging software (Goodman 2020).

The 2D GPR amplitude maps, related to the profiles collected with 400 MHz antenna have been analyzed and our attention has been focused to the following time-windows from 5 ns to 30 ns (two-way-time), corresponding to the averaged estimated depth range from 0.25 m to 1.6 m. Fig. 2, corresponding to 0.90 m in depth, shows an overview of all observed reflections due to the presence of the hypothesized archaeological structures.

Taking into account the large number of the investigated areas and all anomalies that are contained inside each area (Piro, Quilici Gigli 2018b), we focus our attention on the interpretation of anomalies contained in H and K areas. These two investigated areas (H and K)

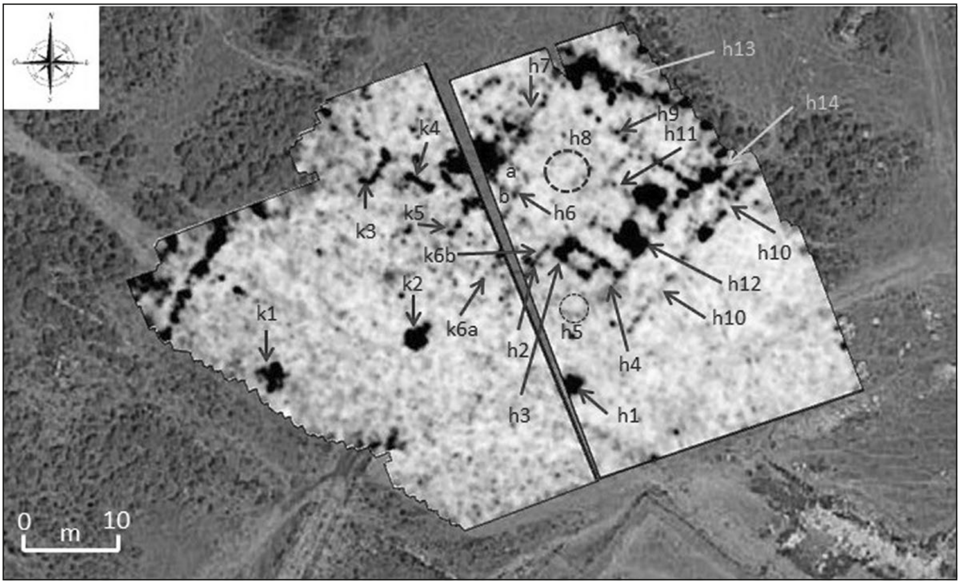

Fig. 3 – GPR time slices at the estimated depth of 0.90 m of H and K areas. The arrows, letters and numbers indicate the observed anomalies.

characterized by interesting anomalies and used as an example of the interpretation method, are presented and described in the following Fig. 3. An analysis of these slices shows that the investigated areas are characterized by the presence of reflections produced from many buried architectural features that are likely walls with different dimensions, cistern and some linear segments of ancient roads.

Fig. 3 shows the anomalies located at the estimated depth of 0.90 m individuated in the area H and K. These areas have been selected to verify the continuation of the street that enters through Porta Maggiore and to confirm the presence of a street with NE-SW direction. The observed anomalies confirm the route of the road to the East of the quadrangular reservoir, that the prospections follow for 25 m in length. The distance between h10 and h14 anomalies indicates a width of 4.3 m. The k6 anomalies show the entrance of a *domus* with a length of 6.3 m and a width of 3.8 m. These dimensions are compatible with those of *domus* like the X. The anomalies k5 and h7 indicate the perimeter of the *domus* on the western side with an overall length of about 23 m and on the eastern side a length of about 18.2 m.

The anomaly h9 can be referred to the back side of the *domus*. Inside there is a series of rooms arranged on a large central space with an average dimension of 113 mq that we recognize which *atrium*. The anomaly h8, in consideration of its dimensions, vertical development till 3 m in depth and a diameter of 4 m, is proposed as a cistern. Overall this interpretation returns the presence of a *domus* with an open entrance along the street that enters from Porta Maggiore and its eastern side arranged along one of its crossroad. The same method of analysis has been employed to interpret all anomalies present in all investigated areas.

3.2 *Fluxgate Differential Magnetic data*

Localization of ancient remains of anthropic origin having high susceptibility contrast against the hosting material is without doubt a magnetic task (Scollar *et al.* 1990; Godio, Piro 2005; Piro *et al.* 1998, 2007; Becker 2009). Significant contrast can also be generated by lacking masses as are cavities or structures with low susceptibility contrast. The gradient array facilitates the detection of shallow and small features. The magnetic data were processed with GEOPLOT 3.0 software (GEOSCAN Research). After de-spiking, filtering and rearranging processes, the data were combined in contour maps of the gradient of the vertical component of total magnetic field (Fig. 4). The contour map representing the results of the magnetic method is characterized by the presence of many dipolar anomalies, in the range -300, +300 nT/m, that can be related to the presence of few localized noised bodies and a portion of walls.

The most significant magnetic result is related to the presence of clear dipolar anomalies, characterized by a prevalence of the positive component of the dipole (Fig. 4), probably due to the presence of small metallic objects in the ground. In the area H and K the intense negative nucleus of the dipolar anomalies can be likely ascribed to a buried structure showing negative susceptibility contrast with respect to the surrounding material. This is particular true in the case of an empty cavity or in the case of walls made with materials with lower susceptibility value respect to the surrounding material.

The magnetic data is currently being processed using the normalized bi-dimensional cross-correlation technique in order to enhance the S/N ratio and to better define the spatial location and orientation of the possible targets (Piro *et al.* 1998). This method is a measure of the similarity between the raw data and calculated synthetic anomalies.

With the aim to have a better understanding of the subsurface, qualitative and quantitative integration methods have been employed in few investigated areas. For the integration process the following

Fig. 4 – Contour map of the gradient of the vertical component Z of the earth magnetic field. Range -300 -+300 nT/m.

techniques have been applied: map overlays and RGB colour composites (graphical integration), binary data analysis and cluster analysis (discrete data integration) and data sum, data product and principal component analysis (continuous data integration) (Piro *et al.* 2018). The results obtained employing the quantitative continuous integration techniques are presented in Fig. 5. The analysis of these figures shows that with the continuous integration techniques as the sum of the normalized different data sets and the PCA it is possible to enhance the capability to locate the searched archaeological structures.

4. Conclusions

Employing geophysical methods to investigate unexcavated areas of Norba site allowed us to recognize features which are compatible with the information given by the archaeologists in terms of architecture and structure type. The detailed analysis of the results obtained

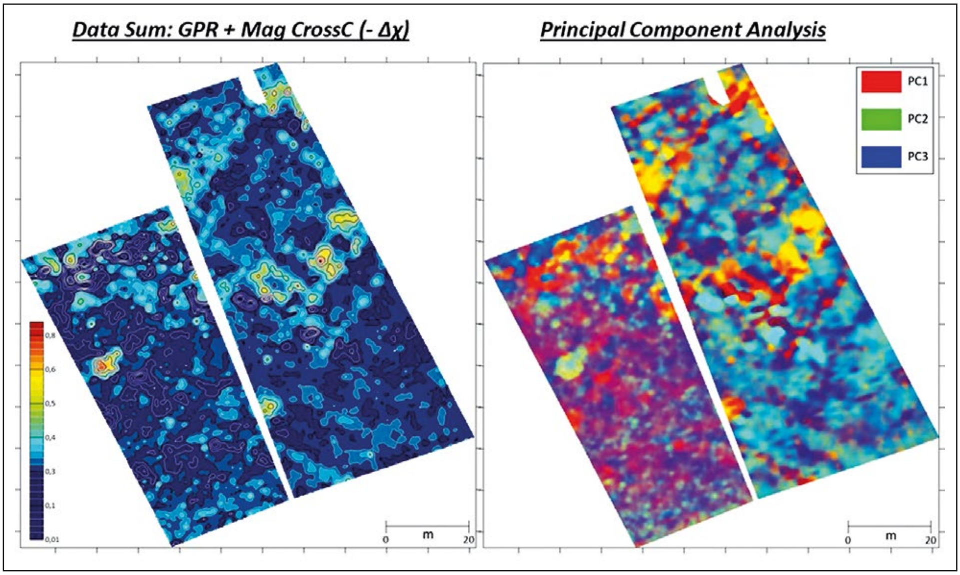

Fig. 5 – Norba, area H-K. Contour maps of the quantitative continuous integration data.

employing GPR surveys, allowed us to recognize the organization of the sectors of the town. Taking into account the environmental conditions and the characteristics of the searched structures, the intrinsic high resolution of the employed methods has allowed the identification and recognition of weak anomalies in the internal part of the buildings.

The integration of different geophysical methods and data analysis has provided an enhancement of different types of data, new analysis and visualization capabilities for future interpretations of archaeological and geophysical features at different investigated area. As expected the integration of different geophysical data sets allow us a high potential to improve the knowledge of the subsurface. As known a single geophysical method might reveal only a portion of the searched buried building. Integrated geophysical data sets may show relationships between the different physical parameters and their contrast between the searched bodies and the surrounding subsoil.

Discrete integrating methods allow application of statistical algorithms to a significant number of geophysical data sets. Continuous data integrating methods generally produce a new data set. This is characterized by the simultaneous presence of all anomalies individuated by the different geophysical methods. In these fused data sets, the anomalous conditions, frequently much less visible in a single data set, can be pointed and analysed. This project is still in progress and new field integrated surveys are planned for the next future.

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ABSTRACT

The site of Norba is located in the Latium Region, about 90 km S of Rome, Italy. The city is one of the best example of urban town planning, with a regular layout dating back to antiquity. Over the years, many studies and archaeological excavations have brought to light important remains of several buildings, which are still very well preserved. To enhance the knowledge of the unexcavated portions of the archaeological site and to locate the position of the unknown and hypothesized buried structures, extensive geophysical surveys employing the Ground Penetrating Radar (GPR) and Gradiometric methods were planned and conducted between 2017 and 2018. For the measurements, a GPR system SIR3000 (GSSI), equipped with a 400 MHz bistatic antenna with constant offset, was used to survey 27 different sectors close to few excavated areas. Taking into account the environmental conditions of the site and the nature of the buried structures, some areas were surveyed with a spacing interval between parallel profiles of 0.25 m while other areas were investigated with a spatial interval between closed parallel profiles of 0.50 m. Furthermore, fluxgate differential magnetic (Gradiometric) surveys were carried out using the geoscan FM256 in two areas, overlapping the GPR areas. In order to have a better understanding of the subsurface, methods of qualitative and quantitative integration of the results have been employed: maps overlays and RGB color composites (graphical integration), binary data analysis and cluster analysis (discrete data integration), and data sum, data product and principal component analysis (continuous data integration). The results obtained from the geophysical surveys were interpreted together with the archaeologists to define the meaning of the structures identified and to enhance the knowledge of the ancient town's layout and mapping.

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NEW DATA ABOUT THE CATHEDRAL OF CATANIA BY GEOPHYSICAL INVESTIGATIONS

1. Introduction

In summer 2015 a multidisciplinary research team began a ground-penetrating radar (GPR) and electrical resistivity tomography (ERT) survey at the Cathedral of Catania (Southern Italy) and its surrounding areas. Part of the survey was aimed at outlining the presence, distribution, burial depth and age of possible buried archaeological remains. Destroyed and rebuilt several times after natural events and accidents, the Cathedral stands on the site of the Roman Achillean Baths and the martyrdom of the patron saint of the city. The current church was built in 1711, on a project by Girolamo Palazzotto. The sumptuous facade in three orders by Giovan Battista Vaccarini is in white Carrara marble, adorned with columns and statues. Noteworthy are the central portal, with 32 finely carved wooden panels, and the three lava apses of Etna, a legacy of the previous Norman Cathedral (Fig. 1).

The interior, with a Latin cross plan, is divided into three naves. The frescoes by the Roman Giovan Battista Corradini stand out in the central apse, with the Coronation of Sant'Agata, while the two columns at the base of the apse arch and the single lancet window are of medieval origin. In the right nave, there is the funeral monument of the musician Vincenzo Bellini, while in the right apse is the sumptuous chapel of Sant'Agata with precious relics. The temple houses the tombs of numerous Norman, Swabian and Aragonese royalty. The use of this site over the centuries makes it challenging to understand the distribution of various features in space and time because the remains of different ages are located at different levels and superimposed on each other. Also, the study area, as well as the largest part of the ancient town of Catania, is highly urbanized today with many nearby buildings from the Nineteenth century making the area fairly 'noisy' for most geophysical data acquisition methods.

Numerous studies have described efficient geophysical methods for archaeological application. Leucci *et al.* (2014) studied the archaeological site of Pisa with the main purpose to test the value of GPR and ERT methods to locate the archaeological stratigraphy. Microgravimetric techniques have been useful in archaeological contexts (Butler 1984; Cuss, Styles 1999; Pasteka *et al.* 2007; Panisova, Pasteka 2009). The applicability of seismic methods for detecting archaeological features has been evaluated by several authors (Woelz, Rabbel 2005; Leucci *et al.* 2007; Forte, Pipan 2008). Magnetic prospection can be successful used on archaeological sites

Fig. 1 – The facade of the Cathedral.

(Ciminale, Loddo 2001; Crew 2002; Linford 2004). Electrical resistivity tomography (ERT) imaging can be used to delineate archaeological features and to locate shallow cavities directly, particularly when cavities are filled with high resistivity contrast material such as voids and more conductive materials (Senos Matias 2003; Leucci 2006; Leucci *et al.* 2007; Scardozzi *et al.* 2020). In the case studied, microgravimetry was very difficult to use because of the many buildings and severe ground vibration due to the heavy traffic. The severe man-made noise made it impossible to use the seismic method. The underground telephone, electricity and water supply networks made it impossible to use magnetic methods. Therefore GPR and ERT were used, which can produce images in three dimensions without being affected by surface obstructions or other features. The GPR and ERT results show that the surveyed area was used also as a burial area over a long period. Other burial features dating from the Roman age (since the third century BC) were discovered.

2. Brief theoretical notes on geophysical methods

2.1 *The GPR method*

GPR method considers that a radar wave, emitted by a transmitting antenna placed directly above the ground surface, propagates in the ground and it is partially reflected by any change in the electrical properties of the subsoil. The reflected energy is then detected by the receiving antenna. Reflection events are produced whenever the energy pulse enters into a material with different dielectrical properties or dielectric permittivity. The strength, or amplitude, of the reflection, is determined by the contrast in the dielectric constants of the crossed materials. This means that a pulse that moves from a material with a low dielectric constant to a material with a high dielectric constant will produce a very strong reflection, while moving from a material with a low difference in constant dielectric will produce a relatively weak reflection. While some of the GPR energy pulses are reflected back to the antenna, energy also keeps travelling through the material until it either dissipates (attenuates) or the GPR control unit has closed its time window. The rate of signal attenuation varies widely and is dependent on the properties of the material through which the pulse is passing.

Materials with a high dielectric will attenuate the electromagnetic wave and it will not be able to penetrate as far. These materials will attenuate the electromagnetic signal rapidly. An example of a very high dielectric constant is the materials with high water content. Metals are considered to be complete reflector and do not allow any amount of signal to pass through. Radar energy is not emitted from the antenna in a straight line. It is emitted in a cone shape. This defines the horizontal resolution of the method. The vertical resolution instead is related only to electromagnetic wave velocity in the materials and the frequency of the transmitter antenna. As the antenna is moved over a target, the distance between the two decreases until the antenna is over the target and increases as the antenna is moved away. It is for this reason that a single target will appear in the data as a hyperbola. The target is actually at the peak amplitude of the positive wavelet (for more see Leucci 2019, 2020).

2.2 *The ERT method*

ERT is an advanced geophysical method used to determine the subsurface's resistivity distribution by making measurements on the ground surface. ERT data are rapidly collected with an automated multi-electrode resistivity meter. ERT profiles consist of a modelled cross-sectional (2-D) plot of resistivity (Ω·m) versus depth. Resistivity, measured in Ω·m, is the mathematical inverse of conductivity. It is a bulk physical property of materials that describes how difficult it is to pass an electrical current through the material. Two electrodes are used as current (they inject current into the material). The other two electrodes are used to measure the potential difference in a certain point under the surface. In this way measurement of all possible combinations of electrodes in the profile is carried out automatically while the function of individual electrodes changes as emitting and measuring functions alternate.

This measuring algorithm, called dipole-dipole, is the most commonly used in archaeological applications at present (Leucci 2015). Its application is especially recommended in the research of vertical structures (e.g. tombs,

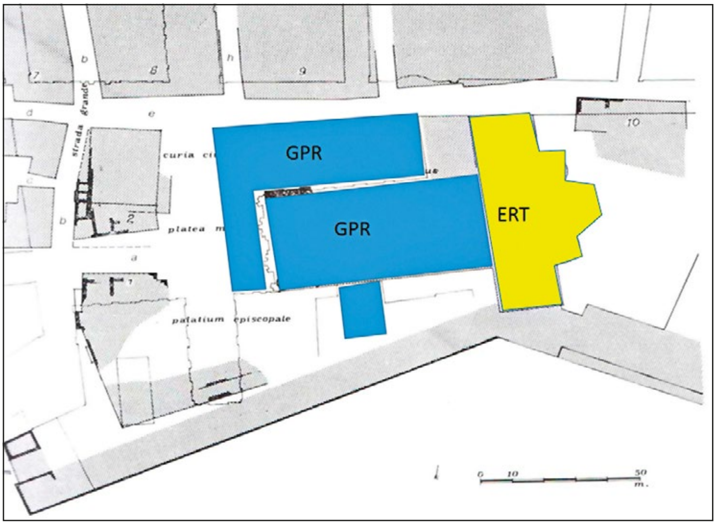

Fig. 2 – The surveyed areas: blue indicates GPR survey; yellow indicates ERT survey.

walls, etc.). Absolute maximal depth in which one can measure electric resistivity is theoretically given by maximum spacing of emitting electrodes (for more see Leucci 2019, 2020).

3. GPR data acquisition and analysis

The GPR surveyed areas are shows in Fig. 2. The GPR survey was carried out with a Ris Hi-mod georadar using the 200-600MHz (centre frequency) dual-band antenna. The frequency was chosen to optimize both the penetration depth and resolution, considering that the targets of the survey were supposedly located between 0.5 m and 5 m below the surface level. Survey profiles were parallel and spaced at 0.25 m. Each reflection profile was processed by standard two-dimensional processing techniques and transformed into pseudo-three-dimensional amplitude maps using GPR-slice Version 7.0 software (Goodman 2013).

The following data processing was performed (Leucci 2020): 1) background removal, whereby the filter is a simple arithmetic process that sums all the amplitudes of reflections that were recorded at the same time along with a profile and divide by the number of traces summed – the resulting composite digital wave, which is an average of all background noise, is then subtracted from the data set; 2) Kirchhoff two-dimensional velocity migration, which is a time migration of a two-dimensional profile

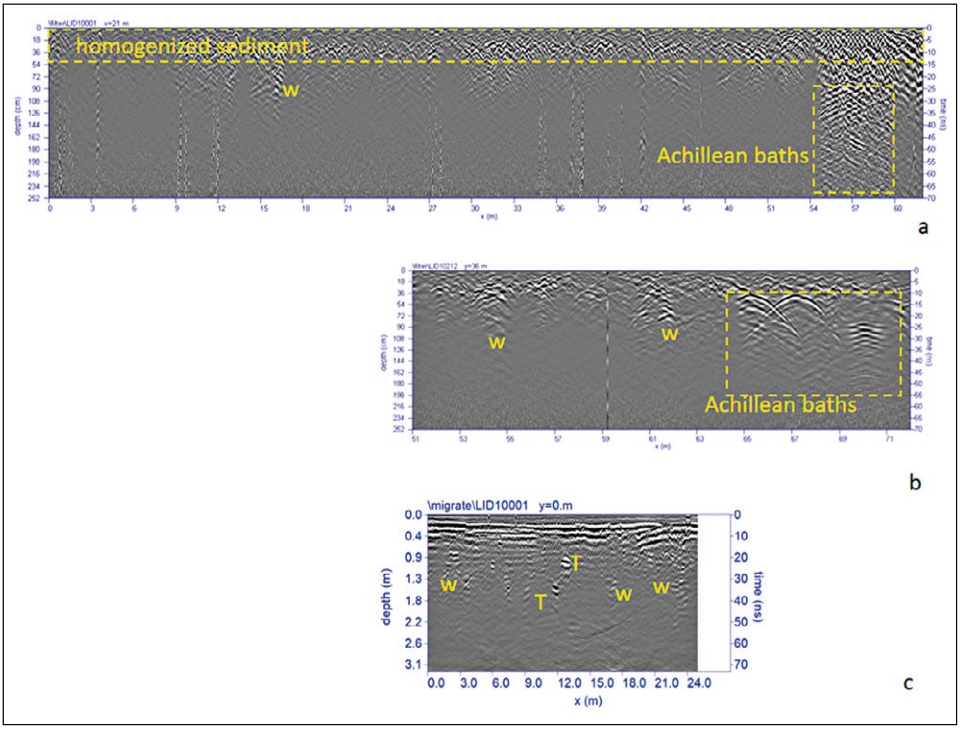

Fig. 3 – Processed GPR radar sections related to the 600MHz antenna.

based on a two-dimensional velocity distribution, is performed. The goal of the migration is to trace back the reflection and diffraction energy to their 'source'. The Kirchhoff two-dimensional velocity migration is done in the x-t range; this means that a weighted summation for each point of the profile over a calculated hyperbola of pre-set bandwidth is performed. The bandwidth means the number of traces (parameter summation width) over which summation takes place.

Each profile was gained manually and the background was removed. This was performed in different time ranges by subtracting a 'local' average noise trace, which is estimated from suitably selected time-distance windows with low signal content. This local-subtraction procedure was necessary to avoid artefacts created by the usual subtraction of a 'global' average trace estimated from the entire section, which is due to the presence of zones with very high amplitude reflections. Estimation of electromagnetic wave velocity was undertaken by hyperbola fitting (resulting in an average velocity of 0.075 m/ns) and reflections were migrated utilizing the Kirchhoff method using this value.

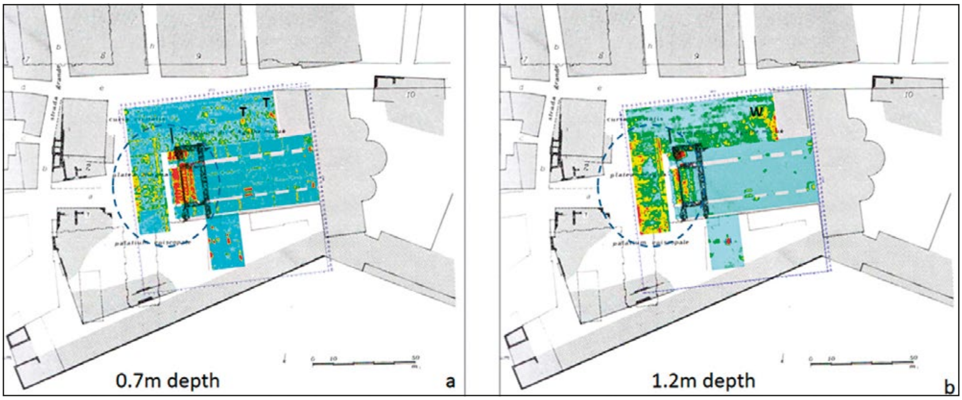

Fig. 4 – Time slices.

Migrated reflections were also visualized as a pseudo-three-dimensional volume in isosurfaces, also using GPR-slice software. The GPR profiles showed jumbled areas with many point-source reflections are probably areas where homogenized sediment was used to fill the base of the church surface (Fig. 3a). Very high amplitude reflection features are visible at the end of the profile (Fig. 3a). These reflection events are related to the well-known Achillean baths. Interesting is the shallow high amplitude reflections evidenced inside the dashed yellow rectangular in Fig. 3b. They are probably related to the top of an unknown extension of the Achillean baths. The reflection profile (Fig. 3c) shows a shallow high-amplitude reflection (T) related to the tomb. Other high-amplitude reflections (labelled W) are also visible. They could be related to the presence of buried walls.

The GPR reflections were also visualized in horizontal amplitude maps. These were constructed by taking an average of the amplitudes over the 5 ns two-way time window, which was squared to produce positive values. The slices shown in Fig. 3 are overlapped to the planimetry of surveyed areas. They visualize the more significant subsurface features between 0.7 m (Fig. 4a) and 1.2 m (Fig. 4b). There is a strong correspondence between the location of the Achillean baths. This evidence of the unknown extension of the baths. High-amplitude reflections (labelled 'T' in Fig. 4a), were interpreted as tombs. In the deeper slice (Fig. 4b) the evidence of the walls (W) is visible.

The spatial relationships between reflections can be visualized in the pseudo-three-dimensional isosurfaces produced from the two-dimensional profiles (Fig. 5). These were produced after Kirchhoff migration and the application of the Hilbert transform, which created a positive-valued envelope of the amplitude of radar reflections. As asserted in Leucci (2019), the selection

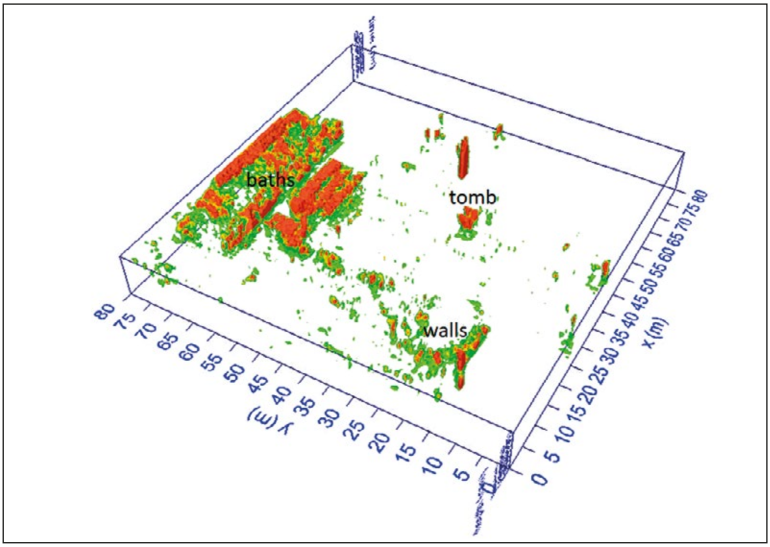

Fig. 5 – Isosurface visualization of the envelope of the processed data.

of a proper amplitude threshold is crucial in the iso-surface method because lowering the threshold value increases the visibility of the main anomaly and smaller objects, but also heterogeneity noise.

Isosurface renders are displays of surfaces of equal amplitude in a three-dimensional volume. It is possible to display any surface between 0 and 100% of maximum amplitudes in the volume. The 100% surface represents the strongest surface in the volume and 0% isosurface represents the weakest reflector. As the amplitude of the reflections, which could be related to features of archaeological interest, assumed different values, to visualize the maximum amplitude events, three isoamplitude volumes were created. This representation allows visualization of the strongest amplitude reflections. Here is possible to see the 3D extension of the Achillean baths, walls and tombs.

4. ERT data acquisition and analysis

ERT surveyed area is shows in Fig. 2. This part was inaccessible to the GPR. To investigate the area below the Cathedral non-standard ERT arrays were used. The electrodes were distributed in such a way as to cover the back of the Cathedral (Chavez *et al.* 2011; Argote-Espino *et al.* 2013; Tejero-Andrade *et al.* 2015; Leucci *et al.* 2017; Leucci 2019, 2020). A dipole-dipole axial array was used. A roll-along acquisition mode considering several L shape profiles was used. The spacing between the current electrode pair, C2-C1, is

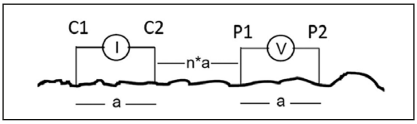

Fig. 6 – Dipole-dipole array scheme.

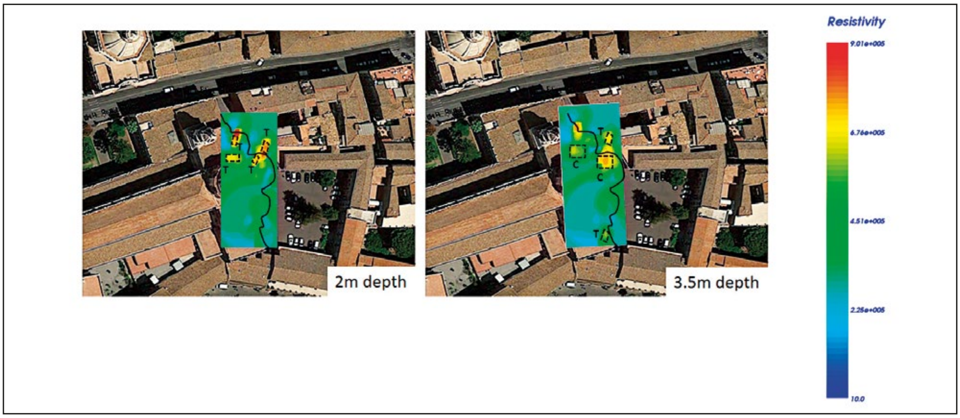

Fig. 7 – Electrical Resistivity Tomography (ERT) resistivity depth slices.

given as 'a' which is the same as the distance between the potential electrode pair P1-P2. This array has another factor marked as 'n' in Fig. 6.

This is the *ratio* of the distance between C1 and P1 electrodes to C2-C1 (or P1-P2) dipole separation 'a'. In this array, the 'a' spacing is initially kept fixed, and the 'n' factor is increased from 1 to 2 to 3 up to about 6 to increase the depth of investigation. The measurements usually start with a spacing of 1a between C1 and C2 (electrodes of current) and also between P1 and P2 (electrodes of potential). The first sequence of measurements is made with a value of 1 for n factor, followed by n = 2, while keeping the C1-C2 dipole pair spacing fixed at 1a. For successive measurements, the n spacing factor is increased to a maximum value of about 6. To increase the depth of investigation, the spacing C1-C2 and P1-P2 is increased to 2a and another series of measurements with different values of n is made.

The dipole-dipole array is very sensitive to horizontal changes in resistivity, and it is effective to map vertical structures as archaeological remains (Loke 2002). Initially, a 2D survey is conducted along each perpendicular line or transect. In the next step, the current electrodes remain at the end of one line, while the potential electrodes are moved, along the line. Then, the current electrodes are moved by one electrode position and the potential electrodes are moved as previously described. The process is repeated until the current and potential electrodes cover the L geometry. This sequence of observations produces a series of apparent resistivity observations towards and beneath the central portion of the array.

Resistivity data were acquired with two reels of 55 m long, the selected distance 'a' between the electrodes was 1 m. After the data acquisition process was performed, the apparent resistivity data were analysed to identify abnormal measurements with a high standard deviation. The investigated volume was computed using the software ErtLab (http://www.geostudiastier.it) which makes use of the Finite Elements algorithm. Fig. 7 shows the slices from 2.0 m in depth to 3.5 m in depth. First, it is possible to note the presence of a heterogeneous subsurface with resistivity values ranging from 2×10^5 to 9×10^5 ohm m. Furthermore, it is possible to note the presence of some anomalous zone labelled T that correspond to tombs. Other anomalies are visible. In particular, high resistivity values are linked to the buried rooms (C).

5. Conclusions

In this paper, the results of a GPR and ERT survey performed in the Cathedral of Catania were presented. The aims of the survey were the assessment of the shallower under floor layers in the church and possibly the identification of the tombs and other structures of archaeological interest. The survey was performed both inside and around the Cathedral. The GPR images below the Cathedral show the presence and distribution of features with shapes, sizes and burial depths that suggest they are of Roman and possibly earlier age. Most of them are interpreted as an unknown extension of the Achillean baths. Other archaeological features are tombs, rooms and walls.

A variety of three-dimensional visualization tools were used to establish a connection between the information of the GPR and ERT data obtained in the surveyed areas and the archaeological features, to find relationships and possible interpretations. High to moderate-amplitude GPR anomalies were identified as tombs in the shallow subsurface, placed just under the external areas of the Cathedral, while in the deeper subsoil anomalies of regular shape were found. These could be interpreted as other possible archaeological structures, probably an unknown crypt.

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ABSTRACT

The town of Catania, located in the southern part of the Sicily region, Italy, holds the remains of an ancient settlement in the city centre. One of the most important buildings is the Cathedral and the buried Achillean Baths. The Cathedral was repeatedly destroyed and rebuilt after the earthquakes and volcanic eruptions that occurred over time. The first building dates back to the period 1078-1093 and was built on the ruins of the Roman Achillean Baths, on the initiative of Count Roger, acquiring all the characteristics of an equipped (i.e. fortified) ecclesia. Already in 1169, a catastrophic earthquake demolished it almost completely, leaving intact only the apse. In 1194 a fire created considerable damage and finally in 1693 the earthquake that hit the Val di Noto destroyed it almost completely. The area around the Cathedral is today highly urbanized, but it was the locus of social and political life over the centuries for people of different cultures who have inhabited the area since the 8th century BC. Therefore, this area contains stratigraphically complex layers of buildings and other remains, which can help understand the use of this area of the town over many centuries. A ground-penetrating radar and electrical resistivity tomography surveys were performed inside and outside the Cathedral of Catania. Data were visualized in three-dimensions using a standard amplitude slice technique as well as the construction of isosurface images of amplitudes. These images reveal the position of architectural features whose shape, size and burial depth suggest they are Roman and earlier in age. The features mapped overlap the development of the Achillean Baths and the presence of some tombs and unknown rooms.

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