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Editorial to selected papers from the 2023 IMEKO International Conference on 'Metrology for Archaeology and Cultural Heritage' – part 1

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Dear Readers,

This Special Issue collects the extended version of some of the contributions presented at the 2023 IMEKO International Conference on Metrology for Archaeology and Cultural Heritage, held in Rome (Italy) from the 19th to the 21st of October 2023. This international conference brought together experts with different expertise but united by the interest in the characterization and conservation of Cultural Heritage (CH).

The conference promoted exchanges of ideas and information, encouraging collaborative networks, and updating innovations in archaeometry for archaeologists, conservators, and restorers, as well as for chemists, physicists, and engineers. Considering the wide interdisciplinarity of the CH field, the Conference participants addressed numerous topics, focusing their attention on the most important metrological issues.

The Conference was conceived as a meeting place aimed both at promoting interdisciplinary works between researchers belonging to different scientific sectors and at showing and sharing the latest innovations in the field of measurements applied to cultural heritage. MetroArchaeo2023 has also been an opportunity for intersectoral exchange between researchers and professionals coming from public structures such as museums, galleries, libraries, archives and small and medium-sized enterprises

In this special issue, we present original and high-quality research papers dedicated to the knowledge of materials and promoting emerging methodologies, applications, and technological solutions for measurements, in the field of CH. In the following, the published papers will be individually presented.

Villalobos [1] proposes specific modifications to the current method of the stratigraphic analysis as well as an adaptation of the diagram scheme to each case study of conservation. The main goal findable in the study is the elaboration of a detailed and comprehensive diagram that encompasses the entire monument, rather than one for each individual section of the monument. In order to get this, the Author divides the process in steps. In the first, the identification of the main stratigraphic units and their classification based on their primary function (structural or decorative) is promoted. In the second step, according to their roles within the entire system to obtain a simpler stratigraphic sequence, the simplification of the current relationships of the architectural units into three groups is suggested. At the end, the new incorporation of pathology-related information and the addition of the missing elements as a reconstruction process is realized. These adjustments allows the diagram to arrange all data gathered from heritage analysis and will permit historians, architects, archaeologists, and others to engage in a global reading of the built. The stratigraphic diagram will serve as a tool to visually represent the analysis and synthesis in a coded manner, which will be comprehensible to both the researchers and the scientific community.

Caridi et al. [2] show as the elemental and molecular composition of three different bronze sculptures by Giuseppe Renda (one of the most famous interpreters of the Neapolitan Verism in the 19th and 20th centuries), respectively named "La Fortuna", "Scugnizzo" and "Non mi toccare", was performed. The Authors underline as the activity has been done for the first time and in a completely non-invasive way, through a combined approach involving portable X-ray fluorescence (XRF) and μ-Raman techniques. At the same time, the Authors underline as the analysis of the investigated artefacts was aimed at improving the knowledge of the Southern Italy bronze art of the second half of the 20th century; this was done also in order to support the definition of optimized conservation strategies to be used by restorers in view of planning best restoration/cleaning interventions to minimize the conservation problems that could affect the durability of the precious artefacts.

Leccese et al. [3] analyses as the development of intervention approaches that lessen biodeterioration and enable the realization of cultural heritage is crucial for the improvement of secondary archaeological sites. A challenge faced by tiny archaeological sites is the emergence of spontaneous vegetation, particularly ruderal plants. The paper describe the development of a weeding system that applies precision agriculture techniques. Drones can be used to identify vegetation that is considered noxious and to apply herbicides where and when they are really needed. Additionally, the efficacy of the treatments can be tracked by using multispectral sensors.

Petritoli et al. [4] deals with the examination of the route of the Via Severiana, traced in the imperial period, from a historical and technical point of view. The results were compared with the Tabula Peutingeriana, which is considered one of the first synthetic representations of general viability. The Authors have explored the development of the various sectors of the via Severiana, considering the various utility and presence on the territory, using the Tabula Peutingeriana as a benchmark. Subsequently, they have examined the precision of the positioning of the various landmarks along the via Severiana and the movement of the inhabited centres as a function of density. Modern technologies, including Geographic Information Systems and mathematical models, allow to help the archaeologists to overlay ancient maps like the Tabula Peutingeriana onto contemporary maps, aiding in the identification of locations and understanding ancient landscapes.

Fioriti et al. [5] propose an innovative video processing methodology for application to vibration data of historic masonry structures. The proposed methodology is based on graph theory and topology analysis applied to magnified videos in search of effective parameters for early-warning signals before the collapse of structures in case of earthquakes. The method was validated through seismic tests of a brick-masonry mock-up representing a vault of the mosque in the Palace of the Dey, Algiers. In particular, the seismic tests were carried out at increasing earthquake intensity up to the final collapse of the mock-up. After processing the videos of the seismic tests by motion magnification method, the magnified video frames were transformed into a graph of the structure. Finally, several graph indices were calculated and monitored during the vibration. The monitored parameters were analysed in search of potential threshold values suitable to generate an early warning signal. In particular, the inverse algebraic connectivity provided an early warning signal in the order of a few seconds before collapse. This was validated by comparison with an analogous signal provided at similar time by an accurate displacement lab measurements system based on optical markers positioned at several points of the tested mock-up.

Zakirov et al. [6] show as the use of geophysical methods has become an integral part of the work at all stages of archaeological research allowing to contribute to the efficient and rapid detection of buried objects. The paper shows how electrical tomography (ERT), Ground Penetrating Radar (GPR) was happily and efficiently used within the boundaries of the settlement of Khayrabadtepa, which is a monument of the Kushan period in the territory of Northern Bactria.

Barone et al. [7] focus their attention on vibro-acoustic properties conceived for specific uses or performances, as theatres, cathedrals or other public spaces starting a pilot experimental activity, aiming at characterizing the vibroacoustic fingerprint, i.e. the vibro-acoustic site-specific features, of a historic building private chamber music concert room, located in the centre of Napoli (South Italy). This work, based on the integration of different sensors and modelling tools, has allowed to observe the site-specific vibroacoustic features not only in relation to the geometric features of the space, but also in relation to the surrounding urban landscape morphology. Consequently, the results have evidenced the presence of a site-specific vibroacoustic fingerprint, related to how the structure and the surrounding urban morphology were planned. The applied integration of a unifying model, previously validated in the literature, and of broadband vibroacoustic measures, has allowed to evidence some quantitative elements, that, characterizing the interaction between spaces and the people living them, constitute a possible basis for interpreting the heritage intangible components (design according to functional and/or symbolic purposes) in relation to different structural urbanistic and architectural elements (tangible heritage).

Adesso et al. [8] signal as archaeological settings are intrinsically dynamic, undergoing transformations over time that significantly affect the archaeological record. Post-depositional phenomena often distort our understanding of ancient contexts, complicating the identification of the original arrangement and hindering the interpretation of archaeological findings. This issue is particularly pronounced in funerary contexts, such as burials, which are susceptible to various natural and human-induced alterations. The study shows the potential of analysing funerary contexts within a processual framework and reconstructing them in a dynamic 3D environment. By employing metrically and morphologically accurate 3D reconstructions, it becomes possible to simulate, isolate, and analyse post-depositional phenomena. The precision of 3D simulation increases significantly when considering factors such as gravity. The goal of this study is to assess changes resulting from transformative phenomena, with a specific focus on creating a sequential representation that elucidates the burial's transformation processes, spanning from deposition to excavation phases.

Del Barba et al. [9] provide an overview of a virtual reconstruction case study, focusing on the late antique walls of Aquileia M2, applying the Extended Matrix methodology and its associated workflow. Specifically, they consider virtual reconstructions in archaeological practice and address their scientific challenges. The report address the issue of their scientific mapping, briefly touching on existing methods before delving into the details of the Extended Matrix, chosen as methodology for the project. The theoretical foundations and open-source computer tools enabling its comprehensive application are even described. Finally, the focus is on an illustrative case study of the complete workflow: reconstructing a portion of Aquileia's defensive wall, M2. Following essential historical-archaeological contextualization, the research results leading to the reconstruction hypothesis, along with some steps to achieve the final model, its visualization through a web app, and potential future development scenarios are presented.

Granget et al. [10] present the methodology and initial findings of the SNSF Sinergia project CORINT. The project's objective is to elucidate the corrosion mechanisms affecting iron-based structures entrapped in various porous media. This paper focuses specifically on iron archaeological artefacts (IAAs) in soil. A novel multimodal quantitative imaging technique, which integrates neutron and X-ray computed tomography (NX-CT), is under development for non-destructive examination of corrosion processes. The method involves registering and fusing neutron and X-ray tomography data, followed by Gaussian mixture model (GMM) clustering for phase segmentation.

Imaging was conducted on two IAAs, Vrac C and BdC1. Additionally, random cross-sections of these samples underwent analysis through optical microscopy, μRaman spectroscopy, and SEM-EDS to characterize and correlate corrosion layers with NX-CT results. This study yields valuable insights into the corrosion of IAAs, enabling the non-destructive investigation of corrosion processes in porous media. The implications extend beyond the preservation of cultural heritage, to the examination of long-term corrosion behaviours in contemporary iron structures, steel within concrete, and nuclear waste disposal plans.

Casazza et al. [11] use a FEM-based simulations to provide preliminary indications on the expected dynamic behaviour of a heritage asset, supporting the identification of metrological parameters, in terms of sensors positioning and signals expected features. The used FEM, referred to a prototype of a Doric column was designed, reproducing the parameterization (i.e., shape, measures, materials, etc.) of a previous FEM model, implemented and validated on the basis of experimental tests performed at the National Technical University of Athens. The results shed light on optimal sensor positioning and expected signal amplitudes, demonstrating the model's effectiveness in crafting tailored monitoring solutions for preventive conservation. The study underscores the importance of integrating Finite Element Modelling (FEM), avoiding the usual initial parallelization of model design and its experimental validation, into the creation of 'phygital' systems that blend physical monitoring with digital twins. This approach not only enhances the accuracy of conservation efforts, but also suggests a promising direction for future research aimed at applying this methodology across a diverse range of heritage structures to support proactive preservation strategies.

Rodríguez Alcalá et al. [12] signal as virtual modelling is a growing discipline which has become an important tool in the context of heritage preservation. and its usefulness is not limited only to the reconstruction of artifacts and built structures, but it also can be an essential tool for the reconstruction of historical events. Utilizing virtual modelling it is possible to create an interactive educational experience aimed at a large audience. Praeteritas Urbes, in collaboration with the National Institute for Anthropology and History's (INAH) Museo Regional de Palacio Cantón in Mérida, Yucatán led a multidisciplinary group of researchers in the reconstruction of an important historical event for the history of the colonial period in the Maya area: the Auto de Fe of Maní held on July 12, 1562. The article discusses the methodology and the workflow used to complete the project, starting from the architectural reconstruction of the former convent of St. Michael the Archangel in the Maya town of Mani, as well as the virtual recreation of the historical characters, the built space, and the recreation of the scenario of this historical event. An important part of the project involved the digitalization of the museum's collection of archaeological pieces used for the special exhibition on the Auto de Fe of Maní entitled, Ídolos: Resistencias y Persistencias.

Bubola et al. [13] signal as the mechanism for the degradation process, defined as a result of progressive and cumulative decay, depends on environmental variables and their changes thus producing the management of indoor microclimate in museums has recently received growing attention. This research focuses on assessing the state of conservation of 34 gypsum-based plaster replicas of Trajan's Column at the Museum of Roman Civilisation and on the microclimate monitoring of Room LI, where they are conserved. The decay assessment of the studied plaster casts was performed using a multidisciplinary analytical approach to characterize the constituent materials and to identify the main degradation patterns by i) on-site investigation with non-destructive methodologies; ii) chemical and petrographical characterization on collected micro samples. Microclimate variables (temperature, relative humidity and dew point) were measured along seven months to define the actual environmental conditions and the response of the materials to the microclimate.

Alfio et al. [14] point out the historical architectural heritage is often exposed to a high risk of damage due not only to natural events, but also to poor maintenance or neglect. In order to preserve it, it is necessary to conduct a series of multilevel and multidisciplinary studies capable of supporting the design choices for all the figures working in this field. The Authors signal as the use of appropriate geomatic techniques and the choice of suitable sensors based on digital acquisition, allow the elaboration of accurate, high-performance 3D models with high quality photorealistic content. Starting from the generation of a point cloud (TLS survey or integration of different digital sensors), in this paper is illustrated a methodology that allows the elaboration of an accurate 3D model for two different case studies from the point of view of architecture and survey data acquisition. In order to analyse these architectures from a structural point of view, the 3D model is optimized and transformed from a TIN model into a polygonal model (Quad-Mesh). This process represents a new approach in the management of complex architectures, capable of responding optimally to the computational capabilities for FEM (Finite Element Model) analysis, for the structural characterization of the elements under investigation.

Spagnuolo et al. [15] examine the importance of microclimatic monitoring and non-invasive diagnostic techniques in cultural heritage sites for the identification of critical environmental conditions and the development of appropriate conservation measures. In particular, the research focuses on the microclimate analysis in the 'Sala delle Madri' of the Archaeological Museum of Capua, Italy, which houses a collection of important Roman and Greek sculptures. The study reveals that the microclimatic conditions in the 'Sala delle Madri' are not constant throughout the monitored year and the environmental parameter are influenced by seasonal variations and natural phenomena. A preliminary diagnostic investigation has been performed on the sculptures located in this room to document the state of conservation of the sculptures and to plan a specific analytical protocol aimed to characterization of both original and restoration materials, verifying the influence of the microclimatic conditions, due to high temperatures and NO2 levels. Moreover, X-ray fluorescence analysis (XRF) was performed on two archaeological coins to characterize the alloy composition and to document corrosion products and to understand degradation phenomena. This research highlights the necessity for the implementation of conservation measures to mitigate the negative impact of environmental conditions and prevent further damage to the archaeological findings displayed at Capua Museum. This study therefore contributes to the wider awareness of the importance of preserving cultural heritage and the role of monitoring systems in achieving this goal.

Cerafogli et al. [16] show the results of NYMPHA project which is aimed to develop an eco-friendly solution using microalgae-derived polysaccharides to remove biological patinas from cultural heritage wooden materials, addressing sustainability and health concerns. To validate its efficacy, the product underwent testing on diverse woods such as silver fir, beech, and sessile oak, selected for their distinct anatomical

characteristics. The analytical methodology involves three key steps: 1) determining the optimal extraction and application method through spectro-colorimetric measures and UV imaging; 2) evaluating surface colour stability; and 3) assessing the product's effectiveness before and after exposure to a biological attack using spectro-colorimetry. Results indicate that the NYMPHA product can induce a colour variation on some wood surfaces. Moreover, although it is reported that algae can have biocidal effects, in this experiment, this action is not observed probably due to the absence of sulphates in the polysaccharide molecule extracted from this specific strain. This emphasizes the necessity for further research and to explore new solutions beyond controlled laboratory conditions, specifically on naturally degraded materials.

Paasch et al. [17] show a novel method for the analysis of ancient catapults by comparing two known ancient design formulae for early torsion-based catapults. The hypothesis is that both formulae, one for a bolt shooting catapult and one for a stone thrower, give the optimum design regarding performance and that both express the same optimal design. It is hypothesized that a developed mathematical equation of 3rd order can be used to determine the length and diameter of catapult bolts from bolt point data, for optimally designed catapults, as no such catapult bolt parts so far are known to have been discovered. The method leads to an estimation of the catapult size/dimensions via scaling factors known from ancient sources. Published data from catapult points, known from excavations/literature, were used as the base of the analysis and the development of the mathematical model.

Caratelli et al. [18] show that, within the "Masgaba" project, the National Italian Council for Research contributes to the archaeological mapping of Capri. This initiative involves survey activities, historical-architectural studies, and the creation of detailed graphic documentation integrated into a Geographic Information System (GIS). Surveys employ advanced technologies, such as laser scanning and photogrammetry. The resultant 3D models contribute to site documentation and analysis. This study advocates the use of a methodological approach reliant on precise measurements and thorough planimetric surveys achieved through instrumental techniques to investigate and comprehend archaeological remnants with a high degree of certainty. By combining this with careful examination of walls and construction techniques, historical phases and space functions can be defined. The examination of three archaeological sites in Capri, Grotta dell'Arsenale, Villa of Gradola, and Villa of Damecuta, exemplifies this approach.

Bertacchi et al. [19] analyse a series of sequential steps based on both graphs and calculations from the technical manuals of the Alexandrian area (1st century AD). Although neglected for a long time and lacking recent critical editions, they can be effectively integrated into the operational flow of various scholars studying ancient architecture from the perspective of measurement. Through some case studies from the Roman imperial period, documented with state-of-the-art devices, Authors illustrate the results of this approach integrating new measurement technologies, reverse modelling methods and verification of the results in the light of the texts of Heron of Alexandria focusing on construction.

Valls Mompo et al [20] signal as natural resins are among the multiple organic materials that have been employed since the prehistory as an adhesive or varnish in the manufacturing processes and operative chains of several tool. For this study, a black pitch sample found inside an amphora was compared with several types of natural resins previously analysed by gas chromatography-mass spectrometry (GC-MS). Different preservation states resins were collected or acquired to be analysed by GC-MS. The results obtained show the reliability and strength of the developed method, while also giving a hint about the raw material employed to coat the amphora.

Carlomagno et al. [21] signal as using X-rays, structural and chemical details of specimens can be assessed while preserving artefacts integrity, with the additional benefit of requiring little or no sample preparation procedures. Synchrotron sources produce high-intensity, highly collimated beams whose energy can be easily tuned over broad ranges going from the IR to the X-rays. Their peculiarities include unbeatable spatial resolution, enhanced elemental selectivity, and extraordinary chemical sensitivity. In recent years, synchrotron beams have achieved a significant evolution thanks to several factors, such as advancements in source and optics design, acquisition of higher-level technical and scientific expertise, etc. This has ignited an increasing interest in synchrotron-based techniques, which are expanding more and more, approaching always new frontiers. This work presents the main characteristics of synchrotrons and aims to help the unfamiliar readers in the non-trivial choice between laboratory and synchrotron sources for their scientific investigations.

Centarti et al. [22] explore novel digitization strategies by employing various technological tools for 3D scanning. We focus on a selected case study: the Grotta di San Michele Arcangelo. Range-based techniques using LiDAR-UAV (Light Detection and Ranging set in Unmanned Aerial Vehicles) were used for the cave's exterior, integrated with SLAM (Simultaneous Localization and Mapping) technology was employed for the cave's interior and close-range photogrammetry techniques captured intricate wall decorations. The results yielded precise geometric information crucial for subsequent three-dimensional modelling of architectural and natural spaces. Furthermore, these techniques were integrated to enhance information management, facilitate conservation efforts, and update existing documentation. The resulting comprehensive database is an essential tool for understanding, monitoring, and effectively managing these intricate underground environments.

I hope you will enjoy your reading.

Fabio Leccese
Section Editor

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