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Editorial to selected papers from the 2023 IMEKO International Conference on 'Metrology for Archaeology and Cultural Heritage' – part 2

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Dear Readers,

This Special Issue collects the extended version of some of the contributions presented at the 2024 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.

Due to the large number of articles received in this Special Issue, the journal has decided to present them in three different issues. The first part was published in the June 2024 issue, the second will be presented in this issue (September 2024) and the third, which should be the final one, in the December 2024 issue.

Bouhamed [1] addresses the evaluation of the conversion of the Bardo Museum in Tunisia. The fil rouge followed by the Author is traced starting from two questions: a) How can we objectively evaluate the conversion of the Bardo museum, which was originally built as a seat of power and residence purposes and converted into an exhibition space? b) What criteria can be used to evaluate it while respecting International Council on Monuments and Sites (ICOMOS) international charters? With the spatial syntax methodologies even enriched by a tailored survey with discrete "wayfinding" observation, the Author tries to the answer to previous questions and, as results, provides solid basis for considering improvements to the visitor journey at the Bardo Museum and opening new perspectives of the use of this method addressable to a wider variety of reconversions.

Marconi [2] discuss the synthesis of titanium dioxide (TiO_2) nanoparticles, highlighting their photocatalytic activity and potential applications in various fields, including cultural heritage conservation. The morphological and structural characterization of the samples was carried out through Scanning Electron Microscopy (SEM) and X-Ray Diffraction (XRD). The photoactivity of the nanostructured titania was evaluated by measuring the photodegradation of Methylene Blue (MB).The connection between the article's argument and cultural heritage protection lies in TiO_2's role as a self-cleaning, antimicrobial, and pollution-mitigating material. By preventing the soiling of architectural surfaces and protecting stone artworks from

organic pollutants, TiO_2 nanoparticles preserve the aesthetic and structural integrity of heritage sites. Their ability to reduce environmental contaminants ensures long-lasting conservation, minimizing the need for harsh chemical cleaners, which can damage delicate materials. Thus, the development of green synthesis methods for producing these nanoparticles aligns with the goals of sustainable heritage protection.

D'Urso et al. [3] present the contents of a geodatabase developed from the outcomes of survey operations carried out, in several stages since 2015, within the archaeological context of the Roman city of *Aquinum*, in southern Lazio. The proposed geodatabase integrates traditional topographic surveying techniques with total station, GPS and GNSS geodetic receivers with photogrammetric surveys and terrestrial laser-scanner (TLS) measurements, including the realization of HBIM (Historical Building Information Modeling) models, to investigate some specific historical-archaeological evidence useful to understand the Roman and medieval urban structure of the city. The survey activities and accurate, multi-temporal and multi-scalar processing of historical artefacts and archaeological findings are described, to provide the basis of an integrated project on advancing knowledge of the history and evolution of ancient *Aquinum*.

De Carlo et al. [4] present a new step of a larger investigation on the interaction between pigments and inorganic substrates - basic lead carbonate, titanium dioxide, and zinc oxide – aiming to study their stability and reactivity over time obviously matching with the pigments historical employed in cultural heritage world. In this case, the study was focused on artificial ageing of monoazo and isoindoline yellow pigments. The work considers the reactivity of these pigments, as individual pigments, in combination with linseed oil, and in presence of highly reactive inorganic white pigments: basic lead carbonate, titanium dioxide, and zinc oxide. Accelerated aging was induced via UV irradiation and high humidity rate in a custom-built chamber using both simple and bilayer paint mock-ups to simulate the technique of overlaying films in paintings. After an analytical study of the physicochemical variations realized using some techniques as colorimetry, Fourier-transform infrared spectroscopy, Raman spectroscopy, and photoluminescence spectroscopy, the results highlighted as the accelerated aging induces a greater colour change in monoazo yellow pigment than in isoindoline one when in powder form. Conversely, when oil is present in the samples as binder, the colour variations are similar for both samples suggesting that the large part of the chemical/physical changes occur in the organic binder.

Bassel et al. [5] provide a broad overview about how the International Atomic European Agency (IAEA) Physics Section is engaged in the field of heritage science, promoting the safe, reliable, and effective use of ion beam, X-ray and neutron-based techniques for the characterization and preservation of cultural and natural heritage through its global networks and partners. The paper shows the role played by the IAEA Physics Section in the development and application of accelerator-based analytical techniques, which are a powerful tool to gain better insight into cultural and natural heritage objects and materials. The various activities and diverse mechanisms implemented at the IAEA Physics Section including the NSIL laboratory to enhance capabilities, transfer knowledge and foster networking were highlighted. Finally, a comprehensive overview of the equipment encompassed with data related to scientific publications and case studies from IAEA global networks and collaborators is even presented.

Alberico et al. [6] present a characterization of wall paintings found in a Roman *domus*, located in the actual city of Santa Maria Capua Vetere (not far from Naples) corresponding to the ancient Capua. After the archaeological discussions, the results of analysis based on optical and electronic microscopies, vibrational spectroscopies including Fourier transform infrared and micro-Raman imaging, and mass-spectrometry coupled to gas and liquid chromatography applied to samples taken from different walls of the villa are shown. The conducted analysis has shown that in the preparation of the wall paintings, resins and animal glue have been extensively used, so they can be classified as *a secco* paintings, where the colour was applied directly on dry mortar, moreover the rich palette and the abundance of binders suggests an aristocratic *villa*.

Morshed Hamza [7] presents an interesting discussion explores the importance of the preservation and extraction of data about heritage collections with limited resources. In the study cases presented, the two daggers allow to demonstrate how conservation is important when you identify the significant value of collections. Three case studies of the Museum of Ras Al Khaimah that represent different periods are presented. The results shows as by adopting integrated preservation approaches, using technology and the right methodology of preservation and conservation, it is possible to extend the lifespan of collections and make them more sustainable.

De Santis et al. [8] investigate the potential of a novel integrated system for the strengthening and monitoring of existing structures. The proposed technology combines Composite Reinforced Mortar (CRM) reinforcements and Fibre Bragg Grating (FBG) sensors and is named as CRM-FBG. Direct tensile tests were conducted as the first step of prototype development and were aimed at evaluating the performance and feasibility of the CRM-FBG system. Measurements provided by FBG sensors were compared to Digital Image Correlation data. The paper is focused on prototype development, scientific validation in laboratory, and prospective field pilot applications and the outcomes of the laboratory experiments showed the reliability of the proposed technology, with interesting prospective applications for the retrofit and structural health monitoring of the built heritage.

Cennamo et al. [9] investigate the correlation between the degradation processes of cultural heritage and the environmental parameters of a semi-underground room (*nymphaeum*) found in the Archaeological Park of Baia (Italy) dating back to the third century. Relative humidity and temperature, hourly registered, were used to derive daily and annual profiles and the effects of microclimate induced degradation were investigated employing various techniques, such as Ion Chromatography for the chemical characterisation of deposits and Thermography, for the individuation of biological layers. The data obtained showed that the underground environment, partially submerged by rising brackish water, was affected by the presence of biodeteriogens, whose distribution and growth is strongly favoured, above all, by the environmental parameters and by the substrate characteristics. All the data were then cross-referenced to obtain a complete knowledge of the conservation frameworks of the environments, essential to identify the most compatible and effective restoration methodologies to be applied in the conservation of the *nymphaeum*.

Starting from a case study, Chellini et al. [10] aim to illustrate a scalable rendering system using open-source Web3D apps and platforms, allowing access to information, 3D models, and descriptions to enhance the experience of artworks. The paper is

a strong example on how, three-dimensional technologies play a crucial role in the philological reconstruction of archaeological contexts, providing valuable insights into the temporal evolution of archaeological sites and enabling the visualization of possible scenarios related to archaeological contexts that have significantly changed over time.

Russo et al. [11] deals with the problem of the creation of physical replicas of statues that, although is not a novel concept, continues to present various aspects worthy of investigation. Surely, there is the need to optimize digital models for their physical experience while retaining distinctive features but there is even the problem of the development of a robust pipeline for constructing reliable physical copies concerning morphometrics and materials. Both stages necessitate experimentation and comparisons, allowing for the validation of processes to achieve scientifically accurate results. Using the case study of the head of Sant'Elena, the article proposes comparing different processes of physical and digital 3D acquisition and reproduction of the artwork so proposing a metrological comparison among a real artefact, its digital twin, the derived physical copy, and the optimized virtual model within this development framework. The metrological validation aims to measure the model's reliability and the overall process, establishing a tested method for defining physical copies.

Trocchi et al. [12] present the first virtual histology performed in X-ray Microscopy-based imaging (XRM) on a sample of crowns of cremated deciduous teeth from the Tophet of Motya (Sicily, 6th century BC). The observation of the Neonatal Line (NL) in enamel tissue offers important information on the community demographic profile, age-at-death classes and life histories of the buried individuals. Results are consistent with previous studies on other human remains found in the main Tophets in Mediterranean basin and highlight the importance of using non- invasive techniques to collect and analyse data that are useful for the interpretation of newborns and infants.

Brienza [13] presents an interesting application case study of geomatic. He tested a Trimble Catalyst DA2 smart system for centimetric georeferencing at the *Curiae Veteres* in Rome (Italy), at the Sun Temple of Niuserra, in Abu Ghurab (Egypt) and inside the ancient site of Eridu in Iraq. The idea was to check the accuracy of this tool, especially when associated to detailed and close- range survey activities, related to landscape archaeology and stratigraphic excavations. The results show that although the instrument cannot replace more precise measurement tools (such as total station or laser scanner), in the field of georeferencing can be alternative to more expensive and complex GNSS systems, and it proved to be quite effective in systematic archaeological survey of large areas, especially in association with digital aerial photogrammetry made by UAV-UAS.

Mancini et al. [14] present a contribute to assess the contribute of Building materials (BMs) in terms of alpha exposure. Six samples of different materials, already characterized in terms of radiological content by means of a gamma spectrometry, have been analysed in order to determine the specific exhalation rate of ^{222}Rn, the radon emanation coefficient and excess in indoor radon concentration. The results confirm that BMs of natural igneous origin can play an important role in terms of alpha radiation dose and internal exposure due to the inhalation of the alpha particles emitted.

Following the paths of previous studies on a little area called Borbona placed in the province of Rieti in the central part of Italy, Cozzolino et al. [15] present a systematic study carried out combining archaeological explorations, photogrammetric surveys and geophysical prospections. All data have been stored in a Geographic Information System, which enabled spatial analysis and the creation of thematic maps. The aim of the research was to discover the unknown territory and trace its origins and the research reserved some surprising and unexpected discoveries as the identification of ancient habitats and significant Roman architectural fragments. The research aimed to pass on the history and culture of Borbona to future generations and promote a sense of belonging.

Cecchitelli et al. [16] present a study focused on 3D deposition technology called Fused Deposition Modelling (FDM) to assess the quality of printed replicas of archaeological human remains. In the paper, a cranial model of an 8-year-old patient for simulating the remains of an archaeological skull, has been 3D printed (3DP) starting from data coming from a Computed Tomography (CT). Eight copies have been printed and subjected to CT scanning to compare them to the original model through an objective measurement method based on image analysis. The proposed method investigates print variability and considers potential sources of error to assess the dimensional compatibility of the model before and after printing. Results showed an increasing error, up to 15 %, with higher levels of model detail. These results are discussed with reference to a metrological approach, highlighting the need for further research into optimizing 3D printing quality control, including through the definition of a standardized protocol to obtain archaeological replicas faithful to the originals.

Scopinaro et al. [17] explore the interpretation of degradation and alteration phenomena as stratigraphic units, showing the preliminary results of ongoing research concerning new investigative methods and tools useful to formalize transformative processes on built heritage, in a chronological perspective. Merging conservation sciences with archaeology, the study introduces a new section of the Extended Matrix (EM) method: the Transformation Stratigraphic Unit (TSU). This work aimed to assess a new method for documenting and investigating cultural heritage, by generating scientifically reliable reconstructive hypotheses, and by analysing and comparing the mutual interaction of different degenerative phenomena and their relationship. The used workflow, still tentative, utilized open source tools and is designed to be replicable and it has been applied to the case study of the architectural complex of S. Pietro in Segni (RM).

Bartolo et al. [18] present a study on two Renaissance polyptychs that were produced by Antonio and Giovanni de Saliba, referred to in this study as the Taormina Polyptych (1503–04) and the Rabat Polyptych (1510–15). The polyptychs stratigraphically studied using stereoscopic microscopy (ST), optical microscopy with polarized reflected light on cross-section (MORL), selective staining tests on cross-section (SST), Fourier-transform infrared spectroscopy (FTIR), and X-ray fluorescence spectroscopy (XRF) joined to a digital reconstruction of the polyptychs allowed to obtain very interesting results.

Caruso et al. [19] applied Pulsed thermography for reading written scraps, used for the making of bookbinding of ancient manuscripts, located between the end papers and the covers. Since the readability of the hidden text depends on several geometrical, optical and thermal parameters characterizing the typology of paper and the ink employed. a comprehensive mathematical model was developed by the authors for analysing the influence of the various involved parameters. In particular, two indices were introduced, namely the signal contrast and the distortion index, used to quantitatively characterize the hidden

text readability. Several numerical simulations are reported for assessing the dependence of the contrast and distortion from various parameters appearing in the model. Moreover the Authors present a preliminary application to the analysis on original books.

Ahmmed et al. [20] tried to understand the composition and chronological sequence of mortars from the Roman villa of Frielas in Portugal. By the analytical characterization of the materials in terms of binder and aggregates, obtained many analytical techniques as X- diffraction (XRD), thermogravimetry (TGA-DTG), optical microscopy and scanning electron microscopy coupled with energy-dispersive spectroscopy (SEM-EDS), acid attack and granulometric analysis interesting evidence was provided for the raw materials used and their local provenance. The production techniques have been compared to ancient recipes from Vitruvius. Samples were categorized based on aggregate differentiation, revealing a uniform composition of mortars with a calcitic areal binder and siliceous aggregates such as quartz and feldspar. The binder-to-aggregate ratio varied among samples, challenging the ideal proportions suggested by Vitruvius. Despite this, the mortars exhibited hydraulic characteristics. Overall, the mortars showed uniformity in chemical, mineralogical, and microstructural composition, suggesting contemporaneous manufacturing. The study suggests that while Vitruvius' rules were not strictly followed, masons likely relied on their expertise and available materials for construction purposes. This research provides valuable insights into ancient construction practices and may inform future efforts in structural conservation and restoration of the site.

We hope you will enjoy your reading.

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Section Editors

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