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BOOK OF ABSTRACTS

Gaming the Castle: A Serious Game for the Valorization and Fruition of Norman Castle

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Introduction

The attending museums and/or heritage sites for seeking education or learning opportunities has been recently surpassed by a new form of experience, based on the idea that visiting is itself a form of cultural production [1]. Recently, heritage-making is now conceived as the main aim of museums or archaeological sites visits, viewed as an embodied set of practices or performances in which visitors continually re-interpret cultural meanings, investing emotionally in the fruition of the past and negotiating identity and sense of place. The way in which institutions responsible for the enhancement and communication of archaeological heritage, at the national, international, and community levels interpret heritage-making is documented by relatively recent studies [2], which emphasize the complex nature of the act of visiting as a "commitment to remembering certain histories" [3], according to the model of the three L theory (Learning and Lifelong Learning) [4]. Just in this scenario, museums have become a sort of "facilitators of memorable experiences" [5] more than simple service providers. In this perspective, gamification recently assumed a significant role in knowledge dissemination and visitor's involvement, by providing the opportunity of participating to the construction of a precise narrative of the heritage at the issue. In this context, we propose a point-and-click Serious game settled at the Norman Castle of Aci Castello (Catania, Italy) to promote learning about the historical location. Serious games represent a genre of video games designed to convey messages or experiences that extend beyond pure entertainment. In our case, the primary objectives are to promote the Norman Castle of Aci Castello and educate players on its historical and cultural significance. The game strikes a balance between learning and enjoyment by engaging players in solving environmental puzzles set within an escape room format. The virtual game environment meticulously mirrors the real rooms of the castle, offering an immersive experience. Players navigate these virtual spaces, collecting objects such as historical documents, which are used to solve puzzles and simultaneously gain knowledge about the castle's rich history.

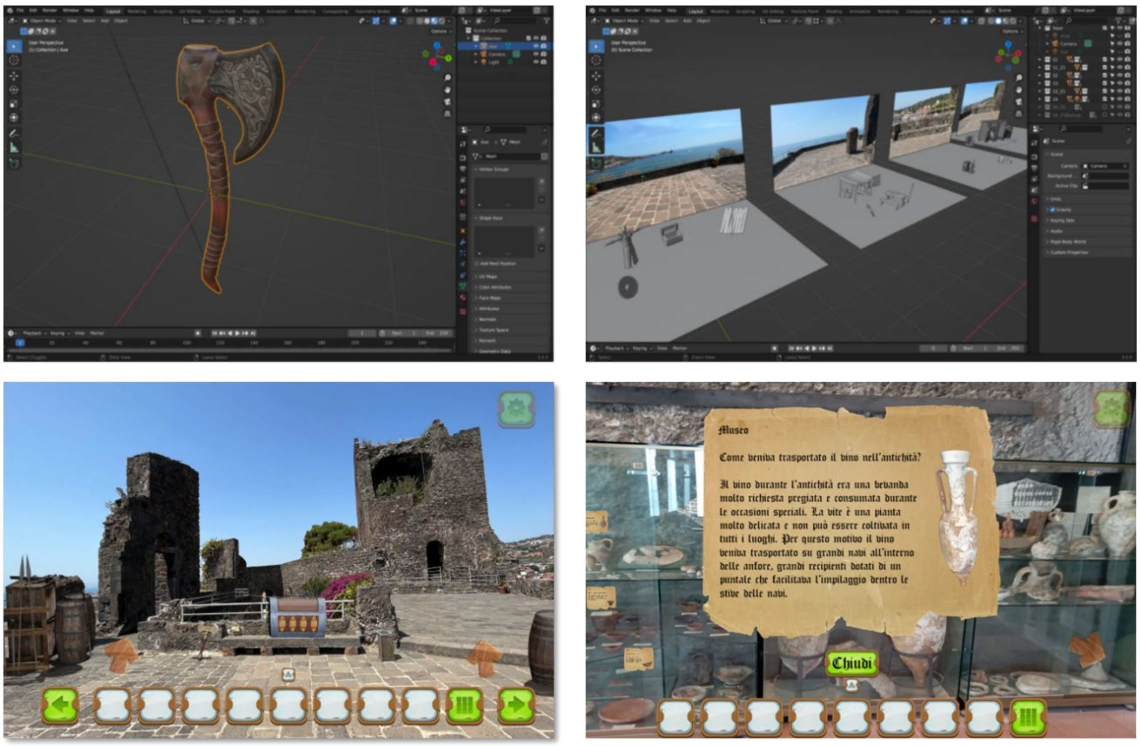

Fig. 1 - Top-Left: An example of object modelled for the game; Top-Right: the development process of the scenes; Bottom-Left: a screenshot of the final game where the player can see a real environment with superimposed 3D model and GUI; Bottom-Right: a screenshot of the final game where the player is reading information about an artifact to be used to solve some puzzles.

Development Process

The development of this serious game involved several critical stages, ensuring that the final product was both educational and engaging:

1. **Environment Acquisition**: The first step involved capturing the physical environment of the castle. This was achieved through high-definition photographs of various rooms and external areas, which served as the foundation for creating detailed and accurate virtual scenes.
2. **Game Design**: The game design phase focused on crafting a seamless navigation experience grounded in the castle's historical narrative. This included defining puzzles and enigmas that players must solve to progress. Every object within the game was carefully chosen and designed to enhance user interaction and contribute to the storyline.
3. **Objects Design and Modelling**: Using Blender, a powerful 3D modelling software, each object was meticulously crafted to fit into the virtual scenes. This process ensured that the objects were not only visually appealing but also contextually relevant to the game's historical setting.
4. **Development with Unity**: The game was built using Unity, a popular game development platform known for its versatility and robust feature set. The project structure was designed with maintainability in mind, facilitating easy updates and the addition of new features. Unity's object-oriented programming approach, utilizing C#, allowed for efficient handling of user interactions and game logic.

Project Structure

The project's architecture was developed to ensure long-term maintainability and ease of expansion. Key components of this structure include: A *JsonManager* responsible for managing game data, storing it in a local JSON file that acts as the game's database. This file maintains the state and structure of all in-game objects. Thinking about the future, this component of the game can be easily replaced by a Json remote database to allow real-time synchronisation for supporting online multi-player An *InventoryManager* to component handles the player's inventory, enabling the selection and interaction of collected objects within the game scenes. A *HandleObject* script for managing player actions, triggering events within the scenes and communicating with the InventoryManager to save and retrieve game objects. The *ChangeSide* and *ChangeRoom* scripts implement the navigation system in a reusable way, allowing players to move between different sides of a room or from one room to another, enhancing the exploration experience.

User Interface, Environments, and Puzzles

The graphical user interface (GUI) and game environments are designed to provide an intuitive and immersive user experience. The integration of augmented reality (AR) further enriches the gameplay by blending virtual objects with the real world, making them appear as though they exist within the player's physical environment. This feature allows players to interact with historical artifacts and solve puzzles in a more engaging manner. For instance, certain interactions trigger a zoom-in effect on specific game objects, revealing intricate puzzles that players must solve. One such example is a chest that, upon closer inspection, reveals a code. Players uncover this code through clues embedded in the storyline, which they must piece together to progress, unlocking new objects and furthering their understanding of the castle's history.

Conclusion

The development of this serious game aims to transform the way visitors engage with the Norman Castle of Aci Castello, blending education with entertainment. By leveraging advanced technologies and thoughtful game design, we create an interactive narrative that not only promotes historical knowledge but also offers a memorable and engaging experience for players. As the project evolves, it promises to set new standards in the application of gamification within the cultural heritage sector, making history accessible and enjoyable for a broader audience.

Acknowledgements

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[1] B. DICKS, *Heritage, Place and Community*, Cardiff, 2000.

[2] G. BAGNALL, *Performance and Performativity at Heritage Sites*, in *Museum and Society* 1(2), 2003, 87–103; S. MACDONALD, *Accessing Audiences: Visiting Visitor Books*, in *Museum and Society* 3(3), 2005, 119–136.

[3] S. MACDONALD, *Difficult Heritage: Negotiating the Nazi Past in Nuremberg and Beyond*, London, 2009.

[4] E. PAPPALARDO, *Il turismo della nostalgia. Modelli di fruizione dei beni archeologici tra passato a presente*, in *La complessità della cultura: Flussi, identità, valori*, cur. D. PRIVITERA, F. PATERNITI, Milano, 2019, pp. 241-252.

[5] D. ROSS, G. SAXENA, F. CORREIA, P. DEUTZ, *Archaeological tourism: a creative approach*, in «Annals of Tourism Research», 67 (2017), pp. 37-47; R. PRENTICE, V. ANDERSEN, *Creative tourism supply: Creating culturally empathetic destinations*, in *Tourism, Creativity and development*, cur. G. RICHARDS, J. WILSON, New York, 2007, pp. 89-106.

Preliminary Study on the Effectiveness of Sodium Alginate for Stabilizing Waterlogged Archeological Wood

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Nowadays, in many fields of cultural heritage preservation, the scientific community focuses on the use of natural and non-toxic materials. Biopolymers, which mostly derive from bio-sources, including plant biomass, microorganisms, and agro-wastes, exhibit many desirable features, including biodegradability, biocompatibility, renewability, and high tensile strength. These properties make them particularly suitable for the conservation of cultural heritage materials. [1] Despite the variety of conservation agents, the preservation of waterlogged archeological wood still presents significant challenges due to the diverse requirements for an effective consolidant. Traditional consolidating agents such as polyethylene glycol, while effective in stabilizing wood dimensions, have shown numerous disadvantages, including long treatment durations, increased weight of treated objects, further chemical degradation of the wood, and sensitivity to environmental conditions. [2] Therefore, there is a need to search for new, more reliable alternatives to preserve wooden artifacts for posterity effectively. Chitosan, bacterial cellulose, lignin, and cellulose nanoparticles are just a few of the many biopolymers recently tested for the consolidation of waterlogged wood, but further research is needed to identify the most effective product for this purpose.[3–6]

One polymer recently tested as a potential waterlogged wood consolidant is alginate – a water-soluble, negatively charged polysaccharide isolated from brown algae. Its linear structure is based on β-1,4-linked D-mannuronic and α-1,4-linked L-glucuronic acid units, which co-polymerize randomly, forming various structures differing in molecular weights and physicochemical properties. An abundance of carboxyl groups present in the polymer enables its interactions with divalent cations and the formation of hydrogels and cross-linked structures. As an anionic polymer, alginate can also interact electrostatically with cationic polymers, forming electrostatic complexes insoluble in water at a stoichiometric ratio. [7,8] The results of a preliminary study on its use as a consolidant [9] show its compatibility with the wood structure. It also improved the thermal stability of residual lignin. Furthermore, alginate is resistant to the effects of sugars and other polymers present in degraded wood, forming a fibrillated network that coats the surface of cell walls, which may potentially enhance its dimensional stabilization effect.

This study explores the effectiveness of sodium alginate in stabilizing the dimensions of waterlogged wood during the drying process. To do so, a waterlogged wooden log excavated from the wet soil at the borderline of Lednica Lake in the Wielkopolska Region, Poland, was cut into smaller samples with the dimensions of 2.5 × 2.5 × 1 cm (in the radial, tangential, and longitudinal directions, respectively). As shown in Fig.1, which presents the characteristic diagnostic features of elm in transversal, radial, and tangential sections, optical microscopy observations allowed us to determine the species of the excavated log as *Ulmus* sp. L. Waterlogged elm samples were then treated with solutions of different alginate concentrations (from 0.5% to 2% w/v).

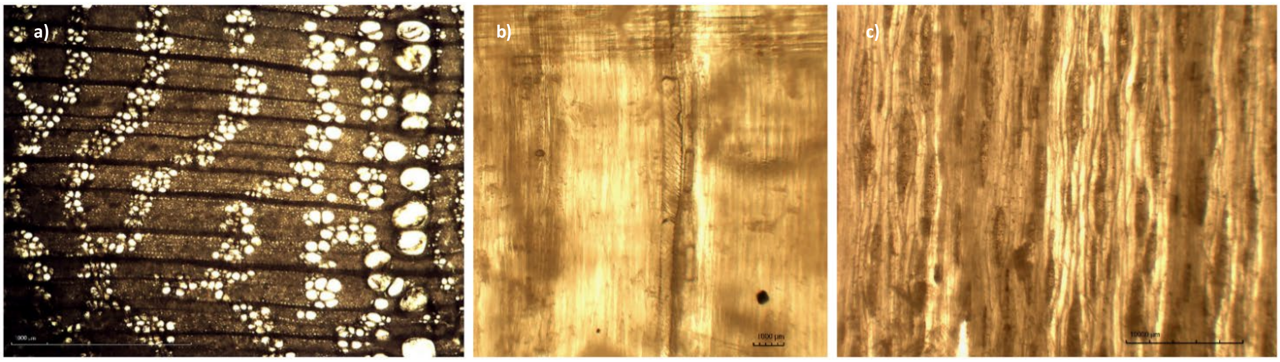

Fig. 1 shows three anatomical sections of wood samples. The transversal section (Fig. 1a) shows a characteristic pattern of earlywood with 1 to 3 rows of big vessels and latewood with smaller vessels grouped in tangential to slightly oblique, bi- to four-seriate

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bands. In the radial section (Fig. 1b), spiral thickenings in vessels can be seen, and in the tangential section (Fig. 1c), bi- to four-seriate rays narrow or a little wider are visible.

To accelerate the diffusion of the consolidant into the wood tissue, a modified oscillating-pressure method was applied consisting of a vacuum of 0.9 bar for 0.5 h followed by 10 bars pressure for 6 h, repeated six times every 24 hours; between the cycles, samples were left in the conservation solution for continuous soaking treatment. After impregnation, the samples were removed from the solutions and air-dried at room temperature of about 25 ± 3 °C for 2 weeks. The pre- and post-treatment weight and dimensions in all three anatomical directions were measured for each sample. Based on the data obtained, the weight percent gain, wood shrinkage, and anti-shrink efficiency (ASE) coefficient were calculated, which are among the most useful parameters to provide information on the effectiveness of the applied treatment and assess the stabilizing effectiveness of a product as a wood consolidant in allowing the wood to maintain its original dimensions also minimizing distortions as the water is removed from the wood tissue during drying.

Preliminary measurements performed after 3 days of the air-drying process are reported in the graphs in Fig.2. The applied treatment slightly reduced the average volumetric shrinkage (Fig.2a) of waterlogged wood when compared to untreated samples. Fig.2b reveals that the ASE increases with the increasing consolidant concentration, and the highest wood dimensional stabilization of 5.75% was achieved for 2% alginate solution.

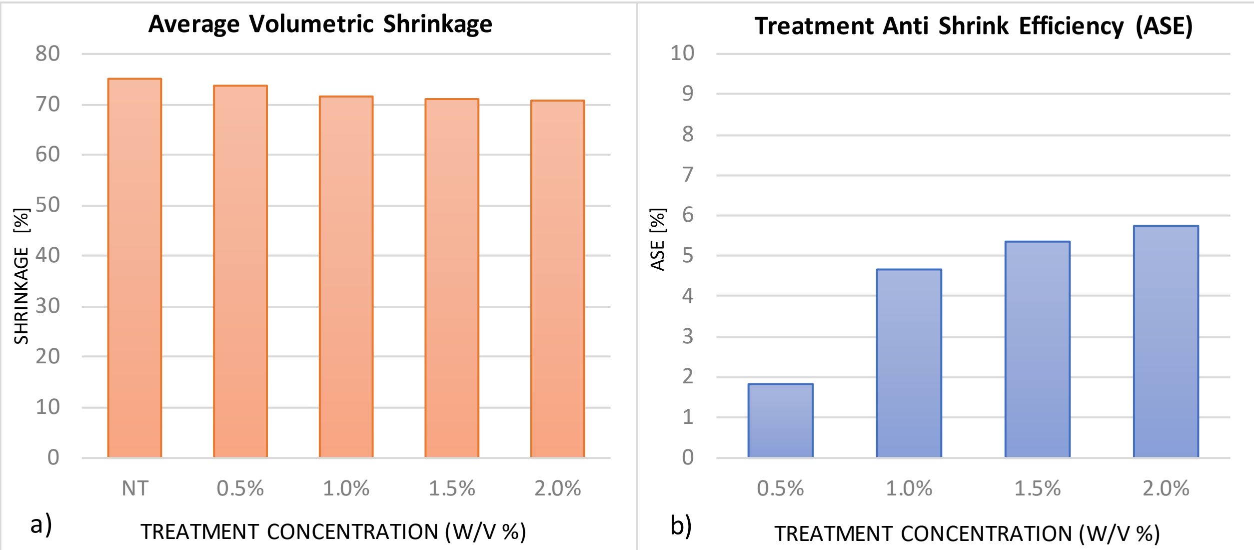

Fig. 2 displays bar charts of the average volumetric shrinkage calculated for untreated and treated wood (2a) and the ASE of the applied treatment (2b).

Considering the measurements made in all three anatomical directions of treated and untreated samples, the highest shrinkage was observed in the tangential direction (as visible from the pictures in Fig.3), which is characteristic of wood subjected to drying.

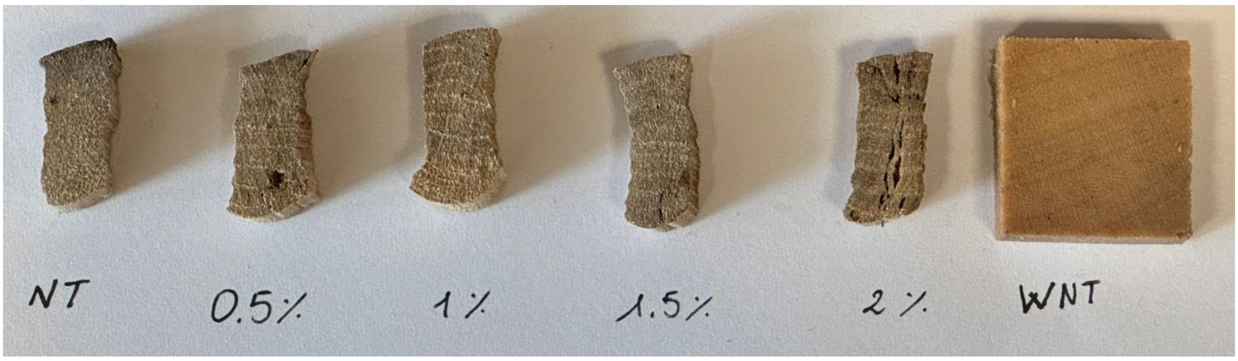

Fig. 3 displays the change in dimension between waterlogged untreated wood (WNT) and both untreated (NT) and treated samples (0.5% - 1% - 1.5% - 2%) after 3 days of air-drying.

Although the literature reports about using alginate as a wood consolidant seemed promising [10], the wood dimensional stabilization obtained in our study is not satisfactory from the conservation perspective. This prompts us to test if chemical modifications of sodium alginate can improve its dimensional stabilization efficiency.

1. Caruso, M.R.; D'Agostino, G.; Milioto, S.; Cavallaro, G.; Lazzara, G. A Review on Biopolymer-Based Treatments for Consolidation and Surface Protection of Cultural Heritage Materials. *J Mater Sci* **2023**, *58*, 12954–12975, doi:10.1007/s10853-023-08833-5.

2. Broda, M.; Hill, C.A.S. Conservation of Waterlogged Wood—Past, Present and Future Perspectives. *Forests* 2021, *12*, 2–55.

3. Christensen, M.; Kutzke, H.; Hansen, F.K. New Materials Used for the Consolidation of Archaeological Wood-Past Attempts, Present Struggles, and Future Requirements. *J Cult Herit* **2012**, *13*, doi:10.1016/j.culher.2012.02.013.

4. Gregory, D.J.; Shashoua, Y.; Hansen, N.B.; Jensen, P. The Use of Bacterial Cellulose for Conservation of Waterlogged Archaeological Wood. In Proceedings of the ICOM-CC 18th Triennial Conference Preprints; 2017.

5. Antonelli, F.; Galotta, G.; Sidoti, G.; Zikeli, F.; Nisi, R.; Davidde Petriaggi, B.; Romagnoli, M. Cellulose and Lignin Nano-Scale Consolidants for Waterlogged Archaeological Wood. *Front Chem* **2020**, *8*.

6. Zhang, J.; Li, Y.; Ke, D.; Wang, C.; Pan, H.; Chen, K.; Zhang, H. Modified Lignin Nanoparticles as Potential Conservation Materials for Waterlogged Archaeological Wood. *ACS Appl Nano Mater* **2023**, *6*, 12351–12363, doi:10.1021/acsanm.3c01998.

7. Song, E.-H.; Shang, J.; Ratner, D.M. Polysaccharides. In *Polymer Science: A Comprehensive Reference*; Elsevier, 2012; pp. 137–155.

8. Abka-Khajouei, R.; Tounsi, L.; Shahabi, N.; Patel, A.K.; Abdelkafi, S.; Michaud, P. Structures, Properties and Applications of Alginates. *Mar Drugs* **2022**, *20*, 364, doi:10.3390/md20060364.

9. Walsh-Korb, Z.; Stelzner, I.; Gabriel, J.D.S.; Eggert, G.; Avérous, L. Morphological Study of Bio-Based Polymers in the Consolidation of Waterlogged Wooden Objects. *Materials* **2022**, *15*, doi:10.3390/ma15020681.

10. Walsh, Z.; Janeček, E.-R.; Jones, M.; Scherman, O.A. Natural Polymers as Alternative Consolidants for the Preservation of Waterlogged Archaeological Wood. *Studies in Conservation* **2017**, *62*, 173–183, doi:10.1179/2047058414Y.0000000149.

3D Digitization and Archaeoastronomical Exploration: Preserving Megalithic Heritage in the Maltese Archipelago

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Abstract – **The Maltese archipelago is home to ancient megalithic structures of extraordinary interest to archaeologists. These massive prehistoric complexes have revealed important architectural and topographical features that suggest the ancient builders knew celestial bodies and astronomical phenomena. These structures demonstrate the complexity of the societies that lived in Malta during prehistoric times. Archaeologists have used techniques to understand better these prehistoric remains, such as terrestrial laser scanning, aerial and terrestrial digital photogrammetry, and 3D modeling. This working method has designed a protocol to improve the defense and valorization of archaeological heritage.**

I. INTRODUCTION

Maltese prehistoric archeology is characterized by megalithic structures, which, despite being very imposing, are fragile. Unfortunately, these historic assets risk permanent damage due to natural and atmospheric phenomena. Digital documentation represents the most effective approach to ensuring their preservation. This article will present some case studies, such as the megalithic complexes of Borġ in-Nadur [1][2] (fig. 1), Ta'Ħammut, Wied Moqbol, and Ta' Ċenċ.

Fig. 1. Borġ in-Nadur Neolithic complex

II. MULTIMODAL 3D DIGITIZATION

In the spring of 2019, a survey was conducted on the islands of Malta and Gozo to assess the condition of surviving Dolmen monuments. The study aimed to propose updated documentation based on the list created by J. Evans in 1971[3]. The study involved surveying GPS coordinates, dimensional and structural data, and the monuments' location [4]. 3D models were created in digital photogrammetry for the best-conserved structures at Ta' Ħammut, Wied Żnuber, and Ta' Ċenċ on the North and South coast of the island of Malta. An example of the Ta' Ċenċ dolmen cluster on the southern side of the island of Gozo was also included. The project's main objective was to conduct a comprehensive topographical and digital archaeological survey of the site. This was achieved through the use of technology such as terrestrial laser scanning (using Faro Focus M70) and aerial and terrestrial digital photogrammetry (using UAV Phantom DJI Pro V2.0 and DSLR camera Canon EOS 2000D). The entire process was thoroughly documented through photographic images and videos, as well as recorded using drones and digital video cameras. The aim was to create future content for public outreach purposes.

Fig. 2. Phases of the remote sensing survey.

Furthermore, in October 2022, a multimodal remote sensing survey was carried out at the prehistoric megalithic structure of Borġ in-Nadur, located in Birzebbuġa (Malta). Certain monuments require specific measures to ensure their preservation in their original conditions. The Maltese government has initiated various efforts to safeguard these monuments, such as constructing shelter structures. Nonetheless, it is essential to monitor their conditions consistently to intervene promptly, if required, before it is too late.

A. Terrestrial laserscanning

A technical survey was carried out in the area, followed by 3D data collection. The focus was on the entire perimeter of the archaeological remains and parts of their interior. The 3D digitization was done using Faro Focus M70, which captured 26 scans with high resolution (43.7 meters per point, 10240 x 4267 points, 6.1 millimeters per 10 meters) (Fig. 3). The raw data was processed using Autodesk Recap Pro 2023, resulting in a 3D point cloud model of 465.315.304 points (Fig. 4).

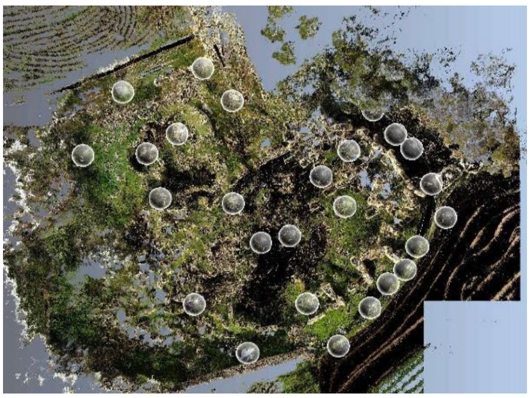

Fig. 3. 3D point cloud with indication of the 3D scanning stations.

Fig. 4. 3D point cloud model of the Neolithic remains.

B. Aerial digital photogrammetry

Regarding aerial digital photogrammetry, a dataset was created using the UAV Phantom DJI Pro V2.0. The dataset had 500 photos taken at a height of 8 meters and a resolution of 4864 x 3648 pixels. The size of each pixel was 8.8 mm and 2.61 x 2.61 µm. This dataset created a 3D model with a dense cloud of 70,159,405 points using Agisoft Metashape and 3DF Zephyr. The 3D model was georeferenced via GPS, and orthophotos of the site were generated. These orthophotos were imported into QGIS to create an updated topographic plan of the entire site. The reference system EPSG:23033 - ED50/UTM zone 33N - Projected was used for georeferencing and positioning the topographic plan. From the 3D aerial photogrammetry model, a digital elevation model (DEM) was extrapolated with a resolution of 2.15 cm/pixel and a point density of 0.217 points/cm² (Fig. 7).

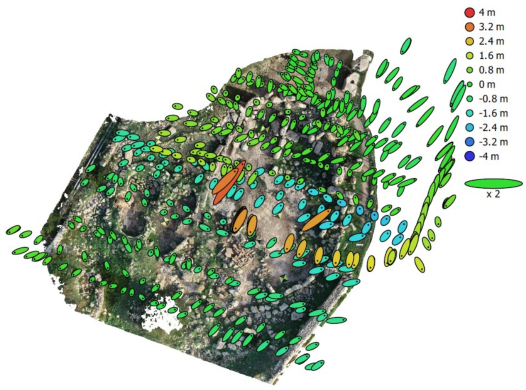

Fig. 5. Drone camera locations and error estimates, Z error is represented by ellipse color. X,Y errors are represented by ellipse shape. Estimated camera locations are marked with a black dot.

C. Terrestrial digital photogrammetry

The survey of the whole area was carried out using a Canon EOS 2000D DSLR camera. A total of 27 archaeological features, megaliths, and other points of interest were captured in 3D, as shown in Figure 8. For

this purpose, 1150 images were taken with a resolution of 6000x4000 pixels, 24-bit sRGB, and a density of 72 dpi. The processing was performed using Agisoft Metashape. The resulting 3D models were made available through the University of South Florida's Institute for Digital Exploration - IDEx Sketchfab account, where a dedicated collection was created. *https://sketchfab.com/usfidex/collections/borg-in-nadur-2022-02b71c7eeb994603a94ad3fbb39083f6*
Additionally, an annotated 3D model of the site with hyperlinks to the individual 3D representations of the 27 architectural features was produced to be used an analysis tool: *https://skfb.ly/oHEoD*.

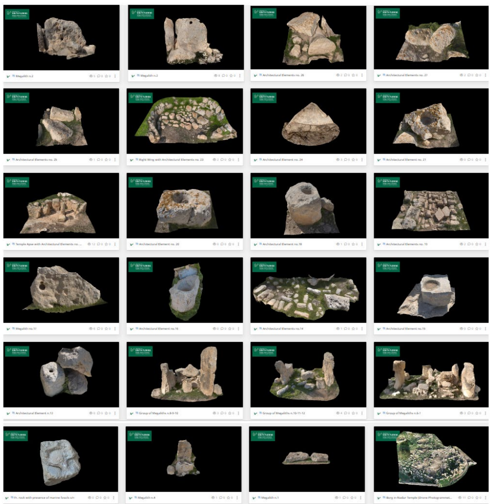

Fig. 8 Sketchfab collection with 3D models of the individual megaliths

The same method was used to digitize the three megalithic structures of Ta'Ħammut (fig. 9) (https://skfb.ly/oDPtt), Wied Moqbol (fig. 10) (https://skfb.ly/oDPtA), and Ta' Ċenċ (fig. 11) (https://skfb.ly/oDPtG), Located respectively on the North and South coast of Malta island and the south of Gozo island.

Fig. 9 Sketchfab model with 3D reprodaction of the Ta'Ħammut dolmen.

Fig. 10 Sketchfab model with 3D reproduction of the Wied Moqbol dolmen.

Fig. 11 Sketchfab model with 3D reprodaction of the Ta' Ċenċ Dolmen.

III. VIRTUAL SIMULATION

To compare the arrangement, characteristics, and position of certain unusual megaliths with the projection of sunrays over a complete cycle and test hypothetical connections, a simplified and retextured 3D model of the structure was placed in a 3D-modeled environment (as shown in Figure 12). This "visualscape" [5] was created by generating a digital elevation model (DEM) of the structure's terrain from layered plans including information on topography and high-resolution aerial photographs of the Marsaxlokk Bay area [6].

Fig. 12. Virtual interactive model of the Borġ in-Nadur structure

The study of sunlight sources was carried out using the radiation raytracer, which simulates a complete cycle of the sun on a mid-summer day (http://radsite.lbl.gov/radiance).

IV DISCUSSION

Thanks to advancements in 3D technology, it is now possible to create accurate replicas of archaeological finds. These digital copies can be used for a variety of purposes. Firstly, they provide a detailed analysis of the condition of the asset. Scholars and restoration experts can plan interventions by examining the 3D models to identify problems or damages that may not be visible to the naked eye. Moreover, 3D models help preserve the archaeological remains' memory, protecting the original artifact's shape and characteristics from the risk of damage. By making 3D reconstructions available to scholars, tourists, and enthusiasts, the archaeological asset can be further appreciated and studied, even remotely. The 3D digital resources have allowed further insights into archaeoastronomy in Borġ a Nadur [7]. To test various potential alignments for critical dates such as the winter and summer solstice, the Sky Safari 6 Pro software was used by setting the location (latitude: 35° 49' 49.0" N, longitude: 14° 31' 45.0" E) and the elevation (56 meters) of Borġ in-Nadur. The results showed that during the winter solstice (December 21, 2,500 BC at sunset (5:01:30 pm)), the constellation Orion appears above the horizon at about 125° from true north. This is the azimuth of the central axis of the apsidal structure, indicating that the entrance to this structure could have served as a potential visibility window for these stars, including the stars of Orion's belt (Fig. 13).

Fig. 13. Winter solstice alignment of the Constellation of Orion at sunset determined by Sky Safari 6 Pro, incorporating the 3D Model of the Neolithic complex.

V. FUTURE WORKS

This study has showcased the significant advancements in digital preservation and visualization technologies applied to the megalithic heritage of the Maltese Archipelago. Through the application of terrestrial laser scanning, aerial and terrestrial digital photogrammetry, we have successfully documented and analyzed the intricate details and complex structures of sites such as the Borġ in-Nadur megalithic complex. The digital replicas produced not only serve as a tool for conservation but also facilitate deeper analytical studies, particularly in understanding the archaeoastronomical alignments and significance of these ancient edifices.

The integration of 3D digitization with traditional archaeological methods has proven essential in uncovering new data about the construction techniques and cultural practices of the prehistoric inhabitants of Malta. Furthermore, this approach has opened new avenues for public engagement and scholarly study, allowing virtual access to these sites, which is invaluable for educational purposes and for the global dissemination of Maltese megalithic heritage.

Looking ahead, our research aims to harness advancements in digital preservation to enhance the resolution and accuracy of 3D models for Malta's megalithic sites. Expanding our digital documentation to more locations across the archipelago will create a comprehensive archive of the region's ancient structures. We also plan to develop dynamic simulation models to visualize changes over time, aiding in conservation efforts and understanding environmental impacts. The integration of augmented and virtual reality could transform public engagement, providing immersive educational experiences.

REFERENCES

[1] D. Tanasi, N.C. Vella (eds), The late prehistory of Malta: essays on Borġ in-Nadur and other sites: Oxford: Archaeopress.

[2] D. Tanasi, N.C. Vella (eds), Site, artefacts, landscape: prehistoric Borġ in-Nadur, Malta: Oxford: Archaeopress.

[3] J.D. Evans J.D., The Prehistoric Antiquities of the Maltese Islands: A Survey, London, 1971.

[4] VECA C., MAGRÌ A., Four stones make a tomb. Funerary models between Malta and Sicily during the Early Bronze Age, in MILITELLO P., NICOLETTI F., PANVINI R., eds. - *La Sicilia Preistorica. Dinamiche interne e relazioni esterne*, Convegno Internazionale di Studi, Catania (ex Monastero dei Benedettini) - Siracusa (Museo Archeologico Regionale Paolo Orsi), 7-9 ottobre 2021. Palermo: 531-534.

[5] M. Llobera, Extending GIS-based visual analysis: the concept of visualscapes, International Journal of Geographical Information Science 17.1, 2003, 25-48.

[6] F. Stanco, D. Tanasi, Beyond virtual replicas. 3D modeling and Maltese prehistoric architecture, Journal of Electronic Computer Engineering, 2003, 1-7. https://doi.org/10.1155/2013/430905

A. Orlando, D. Tanasi, The first archaeoastronomical study of the Maltese temple of Borg in-Nadur, in A. Orlando (ed), The Light, The Stones and The Sacred, Proceedings of the XV Italian Society of Archaeoastronomy Congress, Springer 2017, 47-62.

Application of XRF and EXAFS to the characterization and study of ink on manuscript fragments found in the Santi Quattro Coronati complex (Rome, Italy).

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Figure 1 – *Photo of multiple handwritten fragments of similar size.*

This study focuses on handwritten paper artifacts discovered during an excavation in the 1990s at the Santi Quattro Coronati complex in Rome. The excavation site consisted of a section of the tower that was used as a disposal pit between the 15th and 16th centuries [1-2], where fragments of hand-written paper were found among the archaeological remains. These fragments vary in size and shape from approximately 3 cm to 15 cm and are highly fragmented, complicating the understanding of their content and the assembly of the pieces. The fragments belong to two main archaeological units. The aim of this study is to determine the composition of the ink and find a method to associate the fragments. Utilizing techniques such as X-ray fluorescence (XRF) and Extended X-ray Absorption Fine Structure (EXAFS), performed using synchrotron radiation at the Diamond Light Source in Oxford, we characterized the inks on the fragments. Scanning XRF maps of different sizes were acquired. Depending on the fragments, we performed single or multiple maps using an incident photon beam with an energy fixed at 16.50 keV. Additionally, the acquisition of EXAFS spectra at the Fe K-edge (6.9 – 7.4 keV) provided valuable information on the ink composition. These non-destructive methods allow for detailed chemical analysis. Based on the historical period of the archaeological units and literature[3], the composition of the ink as iron gall ink was confirmed through the conducted analyses. The study identified various metallic elements, primarily Fe, along with other elements such as Cu and Pb, as the main components of the ink. The relative ratio of these elements, along with other elements, served as fingerprints for the inks.

This analysis allowed us to study the composition of the samples and identify potential groupings, which helped in associating the fragments based on their origin (same document, same ink recipe). This study has enabled us to investigate previously unstudied artifacts, providing valuable assistance to the archaeologists by offering new insights into the materials and methods used in historical manuscripts.

[1] L. Barelli., *The monumental complex of Santi Quattro Coronati in Rome. Translation by Christopher McDowall,* viella (2009).
[2] Moricca, Claudia, Francesca Alhaique, Lia Barelli, Alessia Masi, Simona Morretta, Raffaele Pugliese, and Laura Sadori. "Early arrival of New World species enriching the biological assemblage of the Santi Quattro Coronati Complex (Rome, Italy)." *INTERDISCIPLINARIA ARCHAEOLOGICA* 9 (2018): 83-93.
[3] Kolar, Jana, Andrej Štolfa, Matija Strlič, Matevž Pompe, Boris Pihlar, Miloš Budnar, Jure Simčič, and Birgit Reissland. "Historical iron gall ink containing documents—properties affecting their condition." *Analytica chimica acta* 555, no. 1 (2006): 167-174.

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Terahertz time domain spectroscopy (THz-TDS): dataset development and applications for the discrimination of painting materials

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Terahertz radiation (0.1–10 THz) has started to be efficiently employed in a variety of industrial and scientific disciplines, including gas detection, building and construction, agriculture, food science, and medical diagnostics. Moreover, new technological advancements in the THz research field have led to the creation of portable, compact, and high-resolution systems. In fact, in the last decades, terahertz radiation has gained increasing interest in Heritage sciences due to the properties of these frequencies. In particular, Cultural Heritage materials can be investigated non-invasively and in a non-ionizing way by employing THz-based techniques [1–4].

Moreover, a large number of materials that constitute an artifact can be considered almost transparent in this spectral region (e.g., parchment, paper, binders, and varnishes [1]); for this reason, they have no significant contribution to pigments' spectral response. However, despite efforts to apply THz techniques to build a database of pure materials, most of them have not yet been characterized at these frequencies, and there are still some limitations in practical applications. In particular, the application of THz spectroscopy for material characterization in reflection geometry is filled with challenges, including weak signal intensity and losses associated with scattering effects [5].

Therefore, in this work, we implemented a commercially available setup for the spectral mapping of pigment on several supports (i.e., canvas, paper, parchment, etc.). The samples under investigation are mock-ups prepared employing commercially available pigments.

The selected pigments were preliminarily investigated in their pure powder form in transmission configuration to obtain a spectral dataset to be compared with the mockups.

The system exploited is a terahertz time-domain spectrometer (THz-TDS) which covers the range 0.1-7 THz. The THz electric field of the sample and the reference were recorded in the time domain in a time window of 200 ps, which corresponds to a resolution of 5 GHz. The spectra in frequency were obtained via Fourier transforming the time waveform after a filtering procedure to remove the unwanted oscillations. Specifically, raw absorbance spectra were analysed with an approach based on the Savitzky-Golay filter to remove unwanted oscillations without compromising the goodness of the data.

The materials investigated revealed specific spectral features that represent their fingerprints in the THz region. Subsequently, the mock-up samples were prepared. In the context of the present study, we dealt with a thin paint layer created using pigments dispersed in the binder, which means that the transmitted and reflected signals were attenuated. For this reason, in reflection geometry, we employed a practical approach based on the use of a reflective surface behind the mock-up to enhance the signal, in the so-called single reflection configuration [5]. The transfer function of the sample was evaluated according to:

$$\mathscr{H}(\nu) = Ae^{j\phi} = \frac{E_{sample}}{E_{reference}} \tag{1}$$

where E_{sample} represents the signal of interest and $E_{reference}$ corresponds to the reflection signal obtained from a silver-coated mirror, which is considered close to 100 % reflective in this frequency region [5]. The mirror is positioned at the plane of reference and reflects the wave into the photoconductive antenna that acts as the receiver [4–6].

The proposed approach was tested also on binary mixtures of pigments on support, to highlight THz-TDS spectroscopy's ability to discriminate and retrieve the spectrum of a single component in a heterogeneous system.

The preliminary results obtained allowed to gain insights into the potential of THz reflection spectroscopy to identify pigments on pictorial materials (i.e., manuscripts, paintings, painted metals, etc.). Moreover, a laboratory-designed approach to perform spectroscopic THz mapping was proposed to explore the potential advantages and limitations for pictorial materials.

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[1] K. Fukunaga, *THz technology applied to cultural heritage in practice*. Springer, 2016.
[2] C. Moffa, C. Merola, E. Chiadroni, L. Giuliani, A. Curcio, L. Palumbo, A. C. Felici, M. Petrarca *et al.*, "Pigments, minerals, and copper-corrosion products: Terahertz continuous wave (thz-cw) spectroscopic characterization of antlerite and atacamite," *Journal of Cultural Heritage*, vol. 66, pp. 483–490, 2024.
[3] C. Moffa, A. Curcio, C. Merola, M. Migliorati, L. Palumbo, A. C. Felici, and M. Petrarca, "Discrimination of natural and synthetic forms of azurite: an innovative approach based on high-resolution terahertz continuous wave (thz-cw) spectroscopy for cultural heritage."
[4] A. Artesani, R. Lamuraglia, F. Menegazzo, S. Bonetti, and A. Traviglia, "Terahertz time-domain spectroscopy in reflection configuration for inorganic and mineral pigment identification," *Applied Spectroscopy*, vol. 77, no. 1, pp. 74–87, 2023.
[5] M. Naftaly, *Terahertz metrology*. Artech House, 2015.
[6] A. Artesani, R. Lamuraglia, F. Menegazzo, S. Bonetti, and A. Traviglia, "Terahertz time-domain spectroscopy in reflection configuration for inorganic and mineral pigment identification," *Applied Spectroscopy*, vol. 77, no. 1, pp. 74–87, 2023.

HBIM methodology for a constructive critical survey: the romanesque composite pillar of San Michele Maggiore in Pavia

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Introduction

This contribution is part of a research project aimed at the implementation of the Historic Building Modelling (HBIM) methodology for the knowledge and management of the church of San Michele Maggiore in Pavia. The general aim is to know the genesis of the church through the evolutionary phases and construction techniques used, through the creation of an HBIM model consisting of objects that keep track of the geometric, historical and technological information associated with the building.
The basilica of San Michele Maggiore was built in Pavia between the eleventh and twelfth centuries. In the nineteenth century it was the subject of important restorations and reliefs [1]. The contribution, which we want to implement, is the definition of the construction system of the technological units that make up the church of San Michele Maggiore. The method used will be the study of existing literature [2], archival sources, survey made and digitalization.
In the preliminary knowledge phase, a combination of critical survey (including geometric survey, study of materials and construction techniques and classification of the buckling and cracking model), stratigraphic analysis and study of the building typology is optimal. This study finds its purpose of application in the structural recovery of historic buildings, which takes the form of their consolidation. It is therefore essential to have as in-depth a knowledge as possible of the construction phases, the executive techniques, the materials, the transformations and the ancient differences in height now historicized [3].

Figure 1 - View from the side aisle of the central nave pillars.
San Michele Maggiore , Pavia, Italy

According to the Italian NTC [4], "in order to correctly identify the existing structural system and its state of stress, it is important to reconstruct the construction process and the subsequent changes undergone over time by the building, as well as the events that affected it." Historical-critical analysis through the HBIM methodology is of paramount importance in the broader context of structural safety assessment. As Aveta et al. [5] write, the design of historical architecture is not a mere graphic restitution of a pre-existence, but acquires a decisive hermeneutical role. Using the survey surveys and the HBIM model, we will try to reconstruct the as-built elements of the historic building.

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Related works

From a state-of-the-art review of the HBIM methodology, HBIM contributions working in the field of built archaeology were selected. The built archaeology is in fact a method of studying existing architecture, with which the information for history is drawn directly from the materials, techniques and conformation of buildings. The following case studies dealt with the geometric and material composition of the elements that make up a historic building. A significant example from the contribution in HBIM of the church of Collemaggio in L'Aquila [6]. Through the diagnostic investigation conducted, the authors derived the exact geometry of a column, modeling the individual stones, but it was not possible to investigate its core. The thickness of the pillar has been hypothesized. Martinelli L. et al. [7] show an HBIM workflow to support the conservation and maintenance of historic buildings, with a focus on the simulation of building construction systems. Delpozzo et al. [8] propose a conceptual HBIM model of the Aosta arch by modeling each parametric ashlar in view of a conservation intervention.
All these HBIM models have integrated the stratigraphic and material knowledge, the various historical and evolutionary phases of the building with different processes and tools.

Methodology

This research aims to study the construction techniques of existing historic buildings, with the method of historical-critical analysis. Through the use of the HBIM methodology, the information collected will be digitized. To test this workflow, it was decided to use a Romanesque composite pillar of the church of San Michele Maggiore in Pavia (fig.1) as a case study, as its material stratigraphy is not currently known. This methodology lends itself to being usable for the study of any existing building.
The proposed workflow includes an initial phase of information collection through documents, sources and architectural treaties useful for knowledge. This phase makes it possible to critically and scientifically trace the most probable stratigraphic configuration of the element under study.
Subsequently, it is necessary to develop a geometric and photogrammetric survey in order to achieve an accurate digitization of the building.
Through the integrated use of the data previously collected, it will be possible to define the configuration closest to the real of the architectural element in the HBIM environment. The model made with the HBIM methodology, like any restitution, will never be an exact replica of the real building, but will always constitute an approximate model. It will form the basis of study for infinite types of analysis (historical, architectural, energetic, structural), the strength of the HBIM method. In the future, the model created will be used for subsequent structural assessments, adopting appropriate simplifications in the digitalization of the building.
The method presented is part of an ongoing research, which will concern the implementation of a historical BIM system for the church of San Michele Maggiore in Pavia, aimed at its knowledge, maintenance and conservation.

Expected results

From the integration of the use of the HBIM methodology for the study of a historical-critical survey, we want to propose an approach that can be a support to professionals in the AEC sector. The HBIM method proves to be a valuable tool for the knowledge and management of historic buildings. Architects and structural engineers can investigate all the construction stages within a digital model, visualize the stratigraphic components of an architectural and structural element, and obtain technical information on the materials present. Specifically, the structural engineer can find in the adoption of an HBIM model, a support of deep knowledge of the building in the various construction evolutions and stratigraphic investigations in order to be able to design consolidation and structural improvement interventions.
In the future, the interoperability of a structural HBIM model with this type of information with a calculation software will be investigated.

[1] De Dartein F., *Étude sur l' architecture lombarde et sur les origines de l'architecture romano-bizantine*. Dunod, Parigi, 1865-82
[2] Peroni A., *San Michele di Pavia*, Cariplo, Milan, 1967
[3] Matteuzzi E., *San Biagio di Cerbara in Città di Castello – miglioramento sismico e restauro strutturale*, Tesi di Laurea Magistrale 29 maggio 2017.
[4] Italian standards *NTC 2018* https://www.gazzettaufficiale.it/eli/id/2018/2/20/18A00716/sg
[5] Aveta C., Salvatori M., *Il rilievo del costruito storico tra rappresentazione della "materia" e "intelligendi vis" (conoscenza) dell'opera*, Il disegno delle trasformazioni, Naples 1-2 December 2011

[6] Brumana R., Della Torre S., Previtali M., Barazzetti L., Cantini L.,Oreni D., Banfi F., *Generative HBIM modelling to embody complexity (LOD, LOG, LOA, LOI): surveying, preservation, site intervention—the Basilica di Collemaggio (L'Aquila)*, Applied Geomatics (2018)
[7] Martinelli L., Calcerano F., Gigliarelli E., *Methodology for an HBIM workflow focused on the representation of construction systems of built heritage,* Journal of Cultural Heritage 55 (2022) 277–289

[8] Delpozzo D., Appolonia L., Scala B., Adami A., *Federated HBIM models for cultural heritage: survey model and conceptual model*, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLVI-2/W1-2022 9th Intl. Workshop 3D-ARCH "3D Virtual Reconstruction and Visualization of Complex Architectures", 2–4 March 2022, Mantua, Italy

Statistical processing of IR data for the definition of an integrated protocol in the analysis of geomaterials

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The characterization of geomaterials in archaeological and architectural contexts plays a crucial role in understanding their origin, composition, degradation processes, and conservation strategies. Infrared (IR) spectroscopy is a widely employed technique for the analysis of geomaterials, providing preliminary information about the composing mineralogical phases [1]. However, the heterogeneous nature of the geomaterials used in the field of cultural heritage sometimes negatively affects the interpretation of spectroscopic data, resulting in numerous and broad peaks (often overlapped) and shoulders, which are very difficult to be resolved.

In addition, portable IR instrumentation should be preferred in the analysis of cultural heritage as it shows numerous advantages due to its non-destructiveness and non-invasiveness and the possibility to acquire data on site. However, there are significant drawbacks in the spectral interpretation as the reflectance spectra differ from those obtained by attenuated total reflection (ATR) or in transmission mode due to the distortions present [2,3]. Consequently, the interpretation of vibrational profiles is difficult, and the absence of a large database have determined its limited application in the field.

A chemometric approach is here proposed in the elaboration of IR spectra of various geomaterials analyzed. Indeed, the chemometric approach, by highlighting even minimal spectral variations (caused by a different mineralogical-petrographic and chemical composition), can provide useful information on the nature of the raw materials, provenance, and variations over time, allowing the monitoring of degradation.

The present work aims at evaluating the statistical processing of IR spectra of archaeological ceramics, mortars and marbles (from different archaeological contexts), acquired in transmission mode, macro-ATR and external reflectance to assess their potential use in defining the origin of raw materials, production techniques and conservation state. In addition, the comparison among spectra acquired in different modes will allow to create a comprehensive database of reference reflectance spectra for different geomaterials with known composition.

The final step will be the possibility to establish standardized protocols which will ensure consistency and reproducibility across different studies, facilitating data comparison and collaboration between researchers. Finally, the possibility to adapt the developed approach in other fields, such as geology and material science, could broaden the impact of the research and contribute to advancements in various discipline.

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[1] M. Manfredi, E. Barberis, A. Rava, E. Robotti, F. Gosetti, and E. Marengo, "Portable diffuse reflectance infrared Fourier transform (DRIFT) technique for the non-invasive identification of canvas ground: IR spectra reference collection", *Analytical methods*, pp. 2313- 2322, 2015.
[2] L. Nodari, and P. Ricciardi, "Non-invasive identification of paint binders in illuminated manuscripts by ER-FTIR spectroscopy: a systematic study of the influence of different pigments on the binders' characteristic spectral features", *Heritage Science*, pp. 1-13, 2019.
[3] C. Miliani, F. Rosi, A. Daveri, and B.G. Brunetti, "Reflection infrared spectroscopy for the non-invasive in situ study of artists' pigments". *Applied Physics A*, pp. 295-307, 2012.

Digital analysis and protection of mountain archaeological heritage: a case study of the Byzantine church of St. George of Pietra Cappa (San Luca, RC).

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Abstract

This paper focuses on the potential of an integrated approach using aerial and terrestrial photogrammetry, terrestrial laser scanning, and archaeological survey to acquire in-depth documentation for the Byzantine St George church, located in Calabria (San Luca municipality, RC), on the eastern slopes of Aspromonte's mountain. The building is situated in an extraordinary historical and naturalistic context: surrounded by dense vegetation, near the UNESCO site of Pietra Cappa, and not far from other important archaeological sites. The church, partially excavated in the middle of 30' by the Superintendence of Reggio Calabria, is dated to the Byzantine period but probably the spectacular *sectilia* floor has Norman origin. The St George church, unfortunately now in ruins, was chosen as a case-study because no updated and modern archaeological documentation exist for the building and the integration of all data represents a useful dataset for the knowledge and protection of the remains.

1- Introduction

Technological development in Remote Sensing techniques has provided several pivotal advances in landscape archaeology for the analyses, protection, and conservation of cultural heritage. This science has demonstrated to be particularly useful, especially for archaeologists working in difficult-to-access areas where archaeological investigation is challenging (Gennaro 2018; Abate et al. *ii* 2023).
This study presents results coming from the integration of non-invasive close-range terrestrial LiDAR techniques. It aims to demonstrate a virtuous methodological approach: 1) data acquisition from the use of terrestrial laser scanner and archaeological studies for the identification of the remains 2) data validation 3) creation of detailed 2D and 3D documentation 4) GIS information database 5) monitoring the site. The case study is the Byzantine church of St George, at San Luca, in the Aspromonte National Park. This site was the perfect scenario because archaeological and historical interpretations of the remains are still not based on archaeological observations, since the structures were never documented or systematically studied, except for a short excavation and some pictures by Pesce in 1935.

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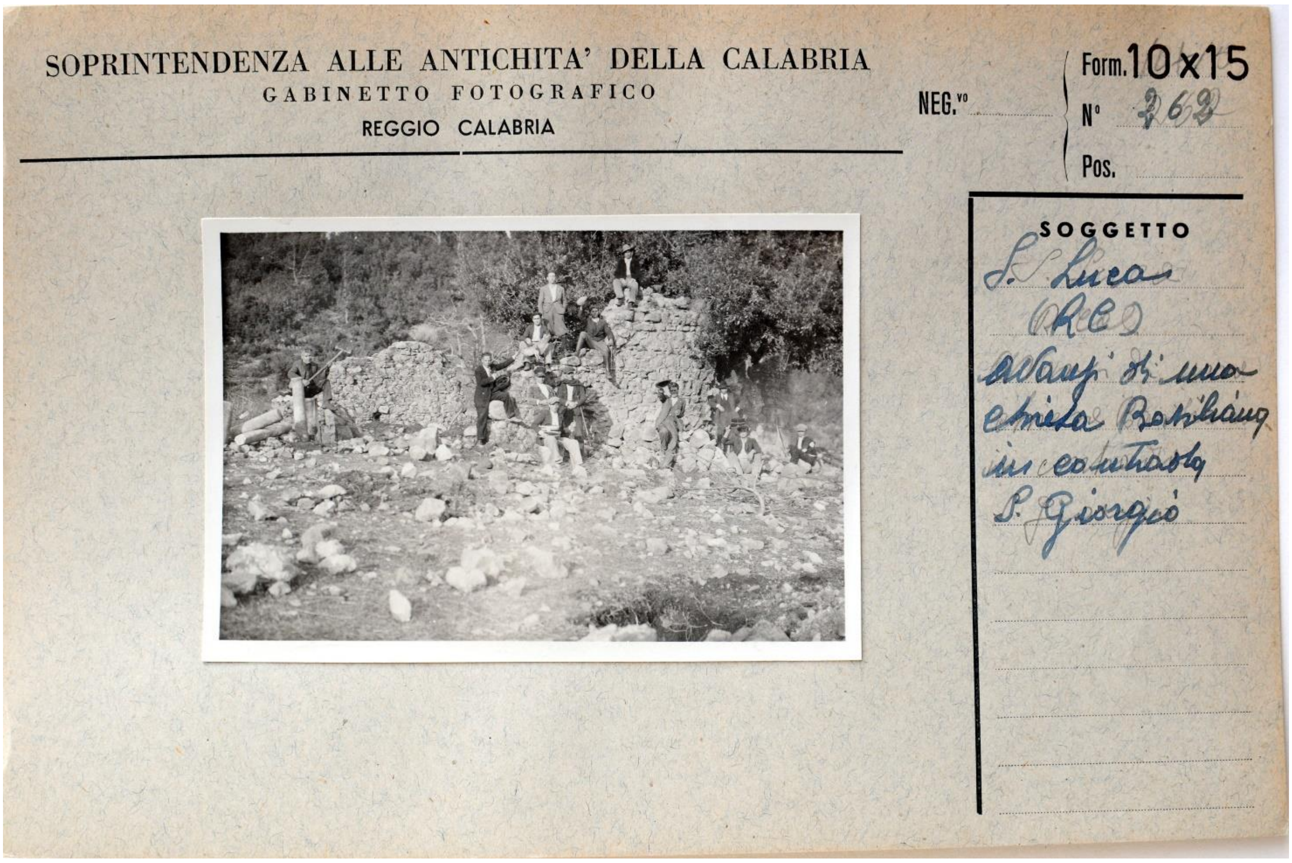

Fig. 1 – Archaeological excavations carried out by Pesce in 1936 (Archive of the Superintendence of Reggio Calabria).

In addition, another key-factor is the church's state of conservation; building's integrity has been affected by several factors as lack of proper management, monitoring and evaluation due to lack of funds, low level of community concern, vandalism and illicit trafficking. For this reason, the final outcome will enable policy makers to take correct and appropriate decisions in order to the conservation of the entire building.

2- *Study area*

The archaeological area stands on the top on the mountain in San Luca municipality (RC), few kilometres far from Pietra Cappa, the famous monolith and UNESCO geo-site. San Luca is a very small town in the province of Reggio Calabria, it's the birthplace of the most famous Calabrian writer, Corrado Alvaro and is also considered one of the best gateways to the Aspromonte National Park. Despite all archaeological work in the area has focused on lowland areas and especially the coastal strip, and few sites are known from amateur finds in the high mountains, the new systematic archaeological exploration of the mountain zone carried out by the Superintendence of Reggio Calabria is drawing a new scenario. Focusing on San Luca, characterized by thickly forested and steeply mountainous landscape, the archaeological record demonstrates that the entire area was intensively frequented since prehistoric times, at least from Neolithic, as demonstrated by the recent discovery of an axe.hammer. In addition, in the same "*Valle delle Grandi Pietre*" (literally Big Stones Valley) but on another mountainous platform lies an important Medieval castle. The fortress, built around a peak, served as a refuge for the surrounding populations and can be considered as the demonstration of the real control of the *elite* over the rural people seeking protection from the Muslim raids during IX and X century [Noyè 2021].
The Aspromonte National Park in modern scholar minds is primary a sacred and religious landscape, the main and distinctive place where the actions of monks and saints occur. In spite of the fact that we cannot understand or measure the perception of the people of Byzantium, however written sources describe Aspromonte and its woodland at the same time as a site of pilgrimage and venerations due to the presence of several ascetic monks, hermits and saints, living in areas now mostly inaccessible to us, but also as trans-regional organized area with church, monasteries, roads and cultivated lands.
Keeping in mind this picture, the church of St George represents the other important monumental evidence and one of the most important Byzantine building in the entire Calabria. The building, about 750 m over the sea level, was excavated

only in 1936 by Gennaro Pesce and it was never been the object of archaeological project until now. Scholars considered it as a Byzantine foundation, clearly dating back to X century, for its architectural style and especially for the masonry walls. However, the building's integrity has been compromised by several factors and now the planimetric lecture of the ruins challenges scholars. Probably, as a hypothesis of reconstruction, we can assume that the church of St George belongs to the typology of the cross-in-square plan with five domes, as other famous Byzantine churches in Calabria: the Cattolica of Stilo, St. Mark at Rossano and St. Gregory "degli Ottimati" at Reggio Calabria. The presence of a narthex and a central dome have been postulated but never demonstrated.

A remarkable element is the re-use of Greek-Roman columns, capitals, bricks and bases, a phenomenon that characterize many Calabrian monuments built during Norman era from eleventh century [Morrone 1998]. Unfortunately, at the moment, only four columns are visible (grey granite and *breccia*), while the other were lost or used in modern buildings. In addition, the important *opus sectile* floor, a clear clue to the existence of a rich patronage (royal?), is no longer visible, despite several scattered fragments were recovered during our project all over around the church. This remarkable floor shows many elements in common with the church of St. Gregory "degli Ottimati" at Reggio Calabria [Malacrino, Todesco 2011] and it uses several polychrome marbles: porphyry, serpentine, yellow, red/green.

Some scholars have attributed a first monastic function to St George [Minuto 1977], who is linked with Count Roger, but the question remains open.

3- Mapping the building

The remains of the church are situated deep within a dense forest, which makes traditional surveying challenging due to the abundance of plants. Additionally, accessing the archaeological site requires navigating a long dirt road, making equipment transportation difficult. Therefore, we used a Faro Focus S70 terrestrial laser scanner in the initial phase. This tool enabled us to quickly generate a 3D model of the entire structure and its surroundings by combining 15 scans. Using the point cloud, we can create a new survey of the building and analyze the characteristics of the walls in detail. This allows us to clearly define the construction techniques and identify any differences in the chronology.

Fig. 2 – Laser scanner measurements.

By combining traditional research methods with the analysis of 3D models, using the so-called Archaeology of Archaeology analysis technique [Lercari et alii 2024], conducting a more in-depth study of archaeological remains and understanding their state of preservation is possible. These remains are often subject to various challenges, such as fires, extreme heat, heavy rain, and snow during the winter. Therefore, it is essential to thoroughly assess the conditions in which the archaeological assets are located to carefully plan the studies and the activities aimed at their protection.

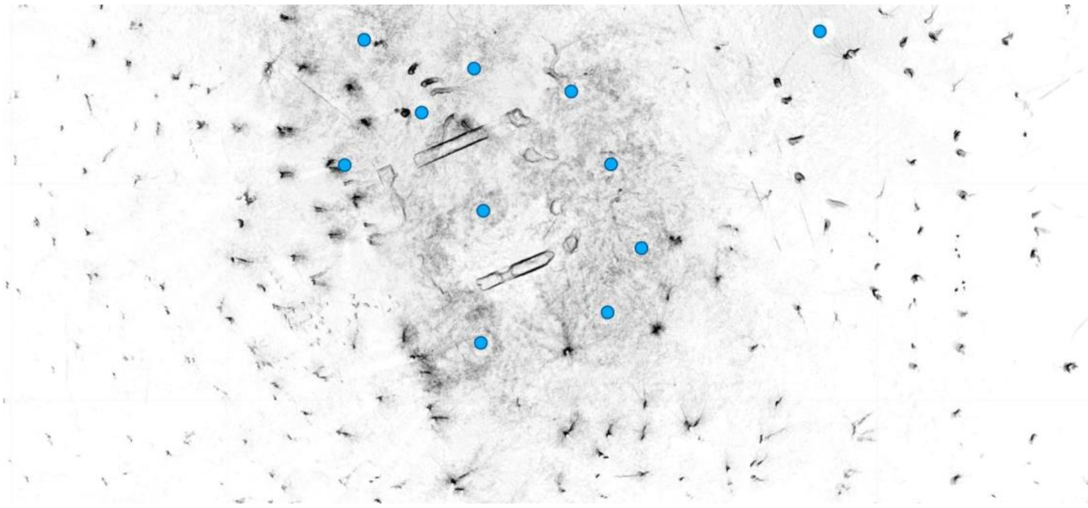

Fig. 3 - The image shows the archaeological remains surrounded by dense forest. The blue points are the laser scanning registration places.

Fig. 4 - Detail of the point cloud showing the archaeological remains of the church.

4- Result and discussion

The preliminary results here presented can contribute in different ways to archaeological science. The challenges offered by a such complex context require continuous advances in these fields and a constant interaction between scientist working on archaeological landscape studies. The documentation produced is just a part of a larger project that will develop through future campaigns of archaeogeophysical acquisition, chemical studies and archaeological excavations.

As a result of this approach, several new data have been acquired at the site, and despite Pesce's work was remarkable for that time (1936) our study provides pivotal data from several perspectives. We were able not only to detect and to document the condition of the structure, located in such a peculiar environment, but the study was also useful in order to determine for the first time the exact position and dimension of the terracing wall on which the church was built, making the reading of the site completer and more organic. The results clearly demonstrate that the church is located substantially in the center of this elevated space; in light of this, it’s quite reasonable to assume that the church and the terrace wall are contemporary and are part of the same architectural idea. The terrace wall was probably erected primarily for static reasons, creating a suitable platform for the church’s construction; moreover, another effect is undeniable: the elevation made the appearance of the church more majestic, isolating the building and creating a clear break with the surrounding environment.

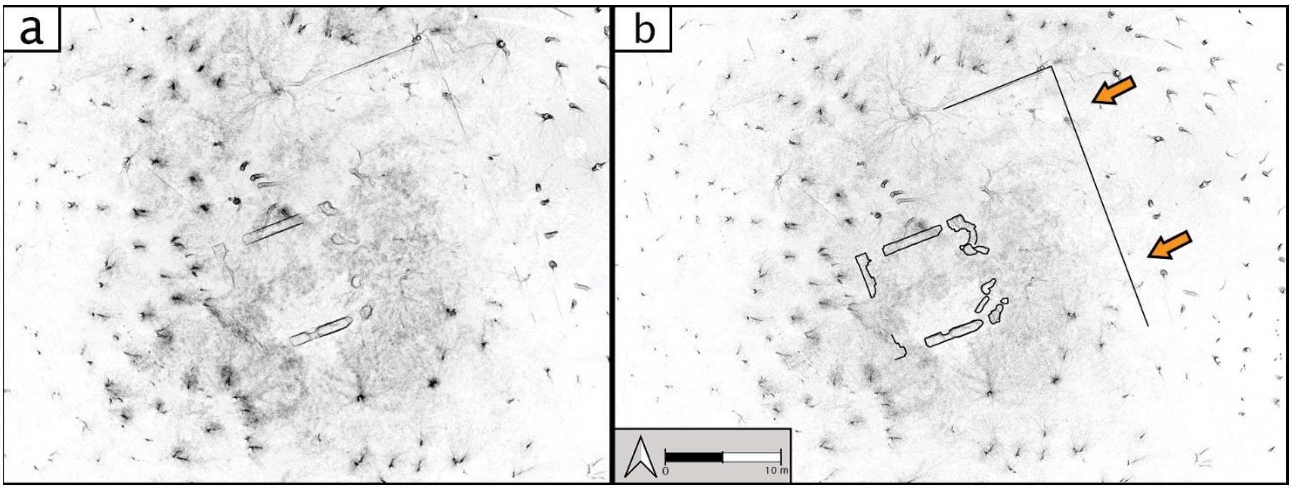

Fig. 5 – On the left image a) displays the plan extracted from the point cloud. In image b) the orange arrows highlight the rectangular structure on which the church rests.

Unfortunately, no dating pottery was found inside the wall, so the chronological debate remains still open.
Finally, the final output constitutes the first valuable help in the next years for the protection activities conducted by the Superintendence on Reggio Calabria. The church is affected by several risks, among which stands out the grazing of wild boars and wild pigs capable of severely damaging the building’s wall. For this reason, a sturdy fence will be positioned around the terracing wall with the aim of not allowing the transit of wild animals.

REFERENCES:

Gennaro, A. M., Candiano, A., Fargione, G., Mangiameli, M., Mussumeci, G.: Multispectral remote sensing for post-dictive analysis of archaeological remains. A case study from Bronte (Sicily). In: Archaeological Prospection, 1-13 (2019).

Abate, N., Rochi, D., Vitale, V., Masini, N., Angelini, A., Giuri, F., Minervino Amodio, A., Gennaro, A.M., Ferdani D.: Integrated close range remote sensing techniques for detectin, documenting and interpreting lost medieval settlements under canopy: the case of Altanum (RC, Italy). In: Land, 12, 310 (2023).

Lercari, N., Tanasi, D., Sonnemann, T., Hassam, S., Calderone, D., Trapani, P., Ruider, L., Lanteri, R.: Archaeology of archaeology at Heloros: Re-interpreting the urban layout of a complex Greek settlement in Sicily using proximal sensing and data fusion. In: Digital Applications in Archaeology and Cultural Heritage 33 (2024).

Malacrino, C., F. Todesco, F.; I marmi del pavimento medievale della chiesa di Santa Maria Annunziata (c.d. degli Ottimati) a Reggio Calabria. In: Marmora, 7, 55-92 (2011).

Minuto, M.: Catalogo dei monasteri e dei luoghi di culto tra Reggio e Locri, Roma (1977).

Pesce, G.: S. Luca d’Aspromonte. Chiesa bizantina in contrada S. Giorgio. In: Notizie degli scavi di Antichità, 360-365 (1936).

Morrone, M.; L’antico nella Calabria medievale fra architettura di prestigio e necessità. In: Mélanges de l’Ecole francaise de Rome, 110 (1), 341-357 (1998).

Noyè, G.: Byzantine Calabria. In: Cosentino, S. (eds): A companio to Byzantine Italy, Leiden, 434-452 (2021).

The multidisciplinary studies of the Megalithic Temples of Malta leading to their sheltering, and beyond

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Figure 1 - The sheltered megalithic complex of Mnajdra

Protecting the Megalithic Temples of Malta

The Megalithic Temples of Malta, a group of Neolithic complexes constructed on the Maltese Islands during the 4th and 3rd millennia BC, represent the development of a unique and sophisticated architecture reflecting a good knowledge - and a clever use - of available resources, utilising similar layouts across different buildings, dictating physical and visual access and how people experience the sites.

These complexes are important symbols of national identity: their distinctiveness makes them recognizable as a Maltese creation, with some of their features represented in various art forms, depicted in coats of arms of some municipalities where they are located (Mġarr, Paola, and Xagħra) as well as on national coinage whilst also becoming sought-after tourist attractions and contributing significantly to cultural tourism and also to the Islands' economy.

These sites' outstanding universal value has been recognized by UNESCO, with six of them (Ġgantija, Ħaġar Qim, Mnajdra, Tarxien, Ta' Ħaġrat, and Skorba) inscribed on the World Heritage List [1] as "outstanding examples of an architectural ensemble that illustrates a significant stage in human history" (criterion iv). Apart from attesting to the sites' universal importance, inscription on the World Heritage List also requires state parties to ensure suitable management of the sites so that they survive to be enjoyed by future generations. Research and actions that lead to their preservation, therefore, can be viewed as part of Malta's obligation towards the international community.

Studying these internationally significant sites

The first interest in studying these sites started from archaeologists and explorers with purely archaeological studies and activities in the first decades of the 20th century [2]. These researches were later complemented by the first scientific research - started in 1985- focused on studies to elucidate their construction technology and their conservation, the latter increasingly becoming a priority for researchers [3,4]. Increasingly multidisciplinary studies focused on topics ranging from the direct study of deterioration processes, to the causes including that of suspended particles and pollution [5,6], and geophysical investigations [7], and also management issues such as the impact of the pandemic closures on the Megalithic sites [8]. Multidisciplinarity now guides research, emphasising the use of non-invasive approaches [9,10].

The conservation and the management of such important sites is a great challenge. We know - from some construction evidence and unique “models” found in the Temples themselves - that these structures were originally roofed over [11]; their original purpose is unknown, but they definitely also protected the internal, softstone (Globigerina Limestone) megaliths from the action of the surrounding aggressive marine environment; interestingly, the exterior walls of this Temple complex are built of the harder, more durable Coralline Limestone. The loss of roofing in ancient times therefore resulted in the continuous exposure of even the internal megaliths to the salt-laden environment, as well as to solar radiation, winds and rain.

The continuous action of the environmental parameters has led to the progressive deterioration of the megaliths, causing an alarming loss of material over the last 30 years [10]. Deterioration has also generated structural problems, partially due to the weakening of the megaliths, and creating cracks and great loss of thickness on occasions; when coupled with extreme events, like heavy prolonged rain or even vandalism, these have evolved into structural failures and collapses, as witnessed in 1994 and in 1998 at Mnajdra and Ħaġar Qim respectively [11]. Hence the need for a multidisciplinary Scientific Committee for the Conservation of Megalithic Temples (2000-2018) with the aim of providing recommendations to preserve these unique sites [12].

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Informing and executing the sheltering decision

Years of studies and debates led to the strategic decision to temporarily protect the site of Mnajdra - and the nearby site of Ħaġar Qim (and also later that of the Tarxien Temples) - with reversible, open-sided shelters [13]. The form was chosen through an international design competition in 2003. The sheltering decision was accompanied by a strong recommendation by experts to carry out continuous and long-term monitoring of the sites [14]. A detailed one-year campaign of analysis [15] gave a good picture of the pre-sheltering situation, providing a baseline with which to compare in the future. In addition, periodic condition assessments and continuous monitoring, also following the erection of the shelters, were considered essential to help identify any potential consequences of the sheltering but also to provide data for any necessary adaptation and improvement of the original (temporary) sheltering solution [14,15,16]. The monitoring has continued since the erection of the shelters, with the ongoing intense project for the evaluation of their performance starting in 2019.

Current approaches looking to the future

The analysis of such important heritage sites has utilised the combination of the most advanced, multidisciplinary techniques especially non-invasive analyses - generally limiting the study to the stone surfaces and making it difficult to understand complex cause-effect relationships. This current research ably integrates materials science with environmental numerical modelling, not only to assess the microclimatic conditions within the shelters but also their impact on ongoing weathering processes, which are also being intensely studied.

Periodical non-invasive on-site stone surface analyses, dust deposit characterisation, and seasonal thermal surveys are being performed to monitor changes on the surface of the megaliths [10]. Computational Fluid Dynamics (CFD) modelling is used to simulate environmental impact (with particular attention to wind) around and within the shelters, providing insights for optimising design and safeguarding the megaliths [9]. CFD can provide the information solving fluid motion equations (Navier-Stokes equations) along with energy conservation and species transport equations. This method has been used in the past in several conservation studies, particularly for indoor environments, and rarely for external conditions, and certainly none for such complex architectures. Thus, for complex outdoor cases, studies so far have not been with the aim of understanding environmental physics for scientific heritage conservation purposes.

While site measurements provide valuable information on the environmental conditions that prevail in and around the Temples, these data are usually limited to point measurements with little to no information on multi-scale physical effects. The latter are important because degradation processes are dependent on these complex physical and chemical processes that cannot be solely understood with point measurements or with limited datasets. Using simulation techniques, validated with measurements taken on site, one can obtain a more complete picture of the physics that is prevalent on site. Environmental factors such as wind flow, turbulence intensity, temperatures and relative humidity distribution are key in attaining this complete understanding, and thus feeding into our understanding of the prevailing deterioration processes.

The study of the physics that characterises stone surfaces requires the use of a multiscale approach due to the wide range of length scales to be modelled, which goes from km to sub-centimeter scale, in proximity to the surfaces. This approach can therefore provide general information by identifying wind behaviour in different areas of the archaeological site, whilst also operating in more detail through micro simulations of identified critical areas. The great revolution of this approach is that the availability of a variety of data from campaigns carried out in the pre-sheltering period makes it possible to validate and simulate both sheltered and unsheltered cases, to evaluate the current impact of the shelters, to understand environmental impacts in the pre-sheltering period, as well as to predict future scenarios, providing simulations to support the development of long-term conservation plan.

Looking at current issues, the final frontier in this ongoing quest for conservation lies in incorporating future climate scenarios into a realistic conservation plan [17]. How will a changing climate impact these irreplaceable structures? By collaboration across disciplines and embracing innovative methodologies, researchers are seeking the best solution to address this challenge, looking at the possibility of simulating extreme events, anticipating further strategies of sustainable heritage management to protect these invaluable World Heritage sites and ensure their preservation for future generations.

[1] UNESCO World Heritage Convention, Megalithic Temples of Malta. unesco.org/en/list/132/ (accessed June 2024).

[2] T. Ashby, R.N. Bradley, T.E. Peet, and N. Tagliaferro, “Excavations in 1908–11 in various Megalithic Buildings in Malta and Gozo”, Papers of the British School at Rome 6(1), pp. 1–126, 1913.

[3] J. Cassar, “Research activities by Ing. Gennaro Tampone on the Megalithic Temples of Malta – An insider’s view”. In Bollettino Ingegneri della Toscana 1–2, pp.3–13, 2019.

[4] J. Cassar, G. Tampone, and S. Vannucci, “Conservazione e restauro dei Templi Megalitici Preistorici Maltesi: il progetto bilaterale di ricerca e risultanze delle prime missioni di studio” In *The Conservation of Monuments in the Mediterranean Basin: The Influence of Coastal Environment and Salt Spray on Limestone and Marble*, Proceedings of the 1st International Symposium, Bari, 7–10 June 1989, eds. V. Fassina, H. Ott, and F. Zezza, pp. 139–156,1990.

[5] M. Galea, R. DeBattista; M. Grima, L. Maccarelli, R. Borg, and C. Zerafa, “Pollution Monitoring for Sea Salt Aerosols and Other Anionic Species at Hagar Qim Temples, Malta: A Pilot Study”, *Conservation and management of archaeological sites*, Vol.17 (4), pp.315-326, 2015.

[6] T. Grøntoft, and J. Cassar, “An assessment of the contribution of air pollution to the weathering of limestone heritage in Malta”, *Environmental earth sciences*, 2020-06, Vol.79 (12), Article 288, 2020.

[7] S. D'Amico, R.P. P. Galea, and Zammit, M.E., “Geophysical investigations at the Mnajdra Temples UNESCO World Heritage Site (Malta)”, European Seismological Commission: 26th General Assembly, 2018.

[8] J. Caruana, E. Debono, K.Stroud, and M.E. Zammit, “The impact of COVID-19 closures on the Megalithic Temples of Malta UNESCO world

heritage site", *Journal of Cultural Heritage Management and Sustainable Development*, Vol.13 (1), pp.15-27, 2023.

[9] M. Valantinavičius, D. Micallef, J. Cassar, J. Caruana, and C. Ciantelli, "Sheltering megalithic temples in Malta – Evaluation the process through data collection and modelling", *IOP Conference Series: Materials Science and Engineering* 949: 012035, 2020.

[10] R. Faieta, J. Cassar, M. Valantinavicius, D. Micallef, and J. Caruana "The impact of protective shelters on the megalithic structures of Malta: Looking at the past through non-invasive approaches", in *Working Towards a Sustainable Past*. ICOM-CC 20th Triennial Conference Preprints, Valencia, 18-22 September 2023, ed. J. Bridgland. Paris: International Council of Museums, 2023.

[11] A. Torpiano, "The engineering of Malta's megalithic prehistoric temples", presentation, 2011.

[12] A. Pace and R. Grima, "The conservation of Malta's megalithic temple sites: A technical experts' meeting convened by the Ministry of Education, Malta", *Conservation and management of archaeological sites*, Vol.4 (2), pp.119-124, 2000.

[13] J. Cassar, M. Galea, R. Grima, K. Stroud, and A. Torpiano, "Shelters over the Megalithic Temples of Malta: debate, design and implementation", *Environmental earth sciences*, Vol.63 (7-8), pp.1849-1860, 2011.

[14] J. Cassar, S. Cefai, R. Grima, and K. Stroud, "Sheltering archaeological sites in Malta: lessons learnt", *Heritage Science*, 6:36, 2018.

[15] P. Mandrioli, P. De Nuntiis, C. Guaraldi, A. Bernardi, C. Sabbioni, A. Bonazza, N. Ghedini, L. Girotto, and A. Folli. "Environmental monitoring at Ħaġar Qim and Mnajdra Temples: Results and recommendations on the micro-environmental impact of the shelters for the Temples", Istituto di Scienze dell'Atmosfera e del Clima, Consiglio Nazionale delle Ricerche, Italy, 2006, (unpublished).

[16] F. Becherini, J. Cassar, M. Galea, and A. Bernardi, "Evaluation of the shelters over the prehistoric Megalithic Temples of Malta: environmental considerations". *Environ Earth Sc*, 75(14): 1–13, 2016.

[17] J. Cassar, "Climate change and archaeological sites: adaptation strategies". In R.A. Lefèvre, & C. Sabbioni (Eds.), *Cultural heritage from pollution to climate change*, pp. 119-127, Santo Spirito (Bari), Edipuglia, 2016.

Pigments, minerals, and copper-corrosion products: Terahertz continuous wave (THz-CW) spectroscopic characterization of antlerite and atacamite

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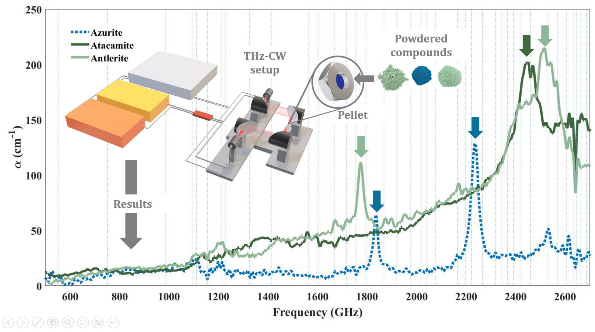

Figure 1: Visual Abstract: THz-CW setup and the retrieved absorption coefficients for azurite, atacamite, and antlerite, with highlighted features.

Terahertz (THz) radiation lies in a relatively uncharted region of the electromagnetic spectrum, bridging the gap between microwaves and infrared radiation. Recently, this spectral region has gained increasing interest due to its unique properties, valuable across a broad range of research areas. THz technologies are non-destructive and non-invasive, with photon energies as low as 4.2 meV at 1 THz, rendering them non-ionizing and safe for operators [1, 2]. The transparency of many dielectric materials at THz frequencies is particularly advantageous for Cultural Heritage applications, such as in the analysis of paper, parchment, and various binders. This transparency facilitates the precise identification of painting materials, mineral compounds, and alteration products in Cultural Heritage objects. [3]

Terahertz continuous wave (THz-CW) spectrometers represent a promising complementary technique for cutting-edge applications in the Cultural Heritage field [4, 5]. Unlike the more commonly employed Terahertz Time-Domain Spectroscopy (THz-TDS) systems, THz-CW spectrometers offer higher spectral resolution combined with compact and portable designs. These spectrometers generate signals via two frequency-modulated Distributed Feedback Infrared lasers with offset wavelengths, converted into a monochromatic terahertz wave by a photomixer. The capability to emit signals at both fixed frequencies and in sweeping mode, where frequencies dynamically vary during measurements, enables a wide array of applications within a single instrument [2]. Characterization studies, such as the present one, are essential in the early stages of THz applications in Cultural Heritage science. They reveal each compound's unique spectroscopic fingerprint, allowing for precise identification across various substrates and environments, even with differing analytical setups. Beyond Cultural Heritage, these studies have extensive applications in materials science, security, gas detection, pharmaceuticals, and other fields [1, 2]. The ability to differentiate between various compounds facilitates significant advancements across these areas.

This study focuses on characterizing some of the most important and noteworthy copper compounds in the field of Cultural Heritage studies: azurite, atacamite, and antlerite. These compounds, found in nature in their mineral form, have historically been used as pigments (with azurite being one of the most renowned blue hues [5]) and are of crucial importance in the study of corrosion in copper alloys and bronze artifacts.

Atacamite and antlerite, copper trihydroxy chloride and copper sulfate respectively, are characterized here for the first time; their optical properties in this frequency range were previously unknown. Additionally, azurite (basic copper carbonate) has been characterized for the first time using a THz-CW spectrometer instead of a THz-TDS, providing detailed information about its features with advanced resolution. Unlike previous research, these copper compounds have been analyzed in their pure, unmixed forms. Atacamite, antlerite, and azurite were acquired in ground form and pressed into

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pure pellets with thicknesses ranging between 200-600 μm.

A transmission configuration was selected for this study (set-up is reported in Fig. 1). Using four off-axis parabolic mirrors, the compounds were analyzed with a highly focused THz beam, ensuring precise results. Spectra were obtained in sweeping mode, covering frequencies from 500 GHz to 2700 GHz, with an integration time of 30 ms per point and a frequency resolution of 100 MHz. Data processing and interpretation were conducted using the Hilbert Transform method via a MATLAB algorithm developed by the authors. The optical properties were successfully retrieved for each compound.

THz-CW investigations of atacamite and antlerite have revealed significant spectral features in both compounds [4] (see Fig. 1). Atacamite exhibits increasing absorption across the investigated frequency range and a distinct peak centered at 2.45 THz with a full-width half maximum (FWHM) of 77 GHz. The calculated refractive index, averaged over the entire spectral range studied, is approximately 1.14 ± 0.01.

Antlerite shows two distinct absorption peaks: one centered at 1.77 THz with an FWHM of 24 GHz, and another at 2.52 THz with a bandwidth of 60 GHz. The average refractive index is approximately 1.23 ± 0.01.

Regarding azurite, it displays two sharp peaks centered around 1.83 and 2.23 THz, known from previous literature [6] but presented here with significantly improved resolution (at least 10 times better than THz-TDS systems). These features have FWHMs of 37 GHz and 23 GHz, respectively. The average refractive index in the relevant frequency range is approximately 1.65 $\pm$0.01.

In addition to defining the unique spectral features and optical properties of each compound, this study underscores the ability to identify and quantify these compounds in binary mixtures. Various mixtures prepared with different weight ratios were examined, and THz-CW spectroscopy effectively recovered the spectral features of the mixed compounds according to their distinct concentrations.

Concentration retrieval was achieved through a linear combination fitting procedure, assuming no interaction between the compounds, in a tailored MATLAB environment. This process quantified the compound percentages in the mixtures and generated expected absorbance spectra, allowing fit results to be evaluated by both statistical and visual analyses. The linear combination routine involved an iterative definition of three coefficients: two parameters multiplied by the absorbance of pure compounds, and a third one for background corrections. This method allows to calculate percentage weights with a relative error of 1%. The study primarily analyzed two types of mixtures. The first type mixed azurite and atacamite, a combination frequently observed on altered bronze patinas. The second type of mixture combined atacamite and antlerite. The resulting spectra consistently displayed the characteristic features of both compounds and weight percentages were accurately retrieved across a wide range of weight ratios. Successful analysis of these mixtures confirmed sample homogeneity and indicated that losses due to scattering processes are negligible.

It is important to note that minor shifts in spectral features may occur, largely due to the influence of water vapour on THz absorption. Ongoing and future work aims to identify and correct these shifts, incorporating this variable into the data analysis protocol.

Furthermore, Energy Dispersive X-Ray Fluorescence (ED-XRF) and Fiber Optics Reflectance Spectroscopy (FORS) were employed to assess the results of the THz-CW analysis. This integrated approach underscored the relevance of THz spectroscopy as a non-invasive diagnostic tool in Cultural Heritage studies, providing interesting and complementary insights for material identification and detecting potential forms of degradation.

Additionally, copper-based compounds have been characterized using ED-XRF and FORS spectroscopies. This combined approach underscores THz spectroscopy's relevance as a non-invasive method for diagnostic investigations in Cultural Heritage, providing crucial and complementary information about materials and their degradation forms [4].

In conclusion, this pioneering characterization of pure copper compounds and binary mixtures demonstrates the versatility and precision of THz-CW systems in analyzing Cultural Heritage materials, encompassing pigments, minerals, and corrosion products. The insights gained from this study not only enhance the diagnostic capabilities for Cultural Heritage conservation but also pave the way for broader applications of THz spectroscopy.

[1] S. Dhillon, M. Vitiello, E. Linfield, A. Davies, M. C. Hoffmann, J. Booske, C. Paoloni, M. Gensch, P. Weightman, G. Williams *et al.*, "The 2017 terahertz science and technology roadmap," *Journal of Physics D: Applied Physics*, vol. 50, p. 043001, 2017.

[2] A. D'Arco, D. Rocco, F. P. Magboo, C. Moffa, G. D. Ventura, A. Marcelli, L. Palumbo, L. Mattiello, S. Lupi, and M. Petrarca, "Terahertz continuous wave spectroscopy: a portable advanced method for atmospheric gas sensing," *Optica express*, vol. 30, 2022.

[3] K. Fukunaga, *THz Technology Applied to Cultural Heritage in Practice*, ser. Cultural Heritage Science, 2016.

[4] C. Moffa, C. Merola, E. Chiadroni, L. Giuliani, A. Curcio, L. Palumbo, A. C. Felici, M. Petrarca *et al.*, "Pigments, minerals, and copper-corrosion products: Terahertz continuous wave (thz-cw) spectroscopic characterization of antlerite and atacamite," *Journal of Cultural Heritage*, vol. 66, pp. 483–490, 2024.

[5] C. Moffa, A. Curcio, C. Merola, M. Migliorati, L. Palumbo, A. C. Felici, and M. Petrarca, "Discrimination of natural and synthetic forms of azurite: An innovative approach based on high-resolution terahertz continuous wave (thz-cw) spectroscopy for cultural heritage," *Dyes and Pigments*, vol. 229, 2024.

[6] E. M. Kleist, C. L. Koch Dandolo, J.-P. Guillet, P. Mounaix, and T. M. Korter, "Terahertz spectroscopy and quantum mechanical simulations of crystalline copper-containing historical pigments," *The Journal of Physical Chemistry A*, vol. 123, pp. 1225–1232, 2019.

As above, so below: painting an integrated LiDAR legacy

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Figure 1 – Valletta Underground: WWII shelters and Knights of Saint John Water Cisterns 2021.

Scanning for legacy requires transforming the real world into a digital format. This process, known as digitalisation, involves converting analogue information to digital, then to virtual, to create a digital twin of reality. This digital twin is enriched by integrating insights from various fields. Equipped with this data and knowledge, policymakers and decision-makers can now prepare for a new research and analytical paradigm [1], [2]. Preservation and conservation is vital to Cultural heritage where the authors sought to capture as many artefacts as possible, such as the Valletta subterranean WWII shelters and ancient water cisterns (Figure 1).

In recent years, the authors have pursued excellence by creatively transforming data into information and acquiring knowledge for future actions. [3]. The projects incorporated aerial LiDAR scanning, bathymetric LiDAR scanning, terrestrial and mobile scanning, as well as photogrammetric capture. Initially, these digitalisation technologies were primarily used for GIS mapping [4], but they have increasingly become essential in a variety of scientific fields, including archaeology [5], [6] and cultural heritage [7], [8].

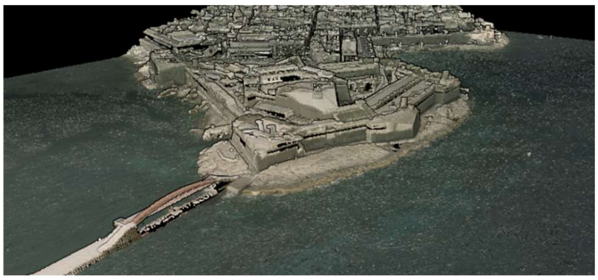

Figure 2 – Aerial LiDAR scanning – Valletta 2018.

The Maltese approach to the digitisation process was hands-on, resulting in the development of various projects such as the 3D CloudIsle (www.cloudisle.org) spatial information system, the SIntegraM geoportal, and the MAKS Immersion Lab VR-AR-MR interactivities [9]. To facilitate visually realistic scenes for decision-making, an extensive examination of the entire data lifecycle was undertaken. This led to the establishment of a continuous data capture system designed for near-real-time data collection and dissemination. Landscape mapping through photogrammetry, laser-mapping, and GPR was performed in 2012 and 2018 (Figure 2) with the aim of creating highly detailed models that could be explored in a 3D environment, providing access to otherwise unavailable landscapes [10]. The application of these outputs to other domains, such as inaccessible space analysis [11], erosion studies, and heritage preservation, demonstrated the effectiveness of these processes [12].

Figure 3 – Terrestrial LiDAR scanning – G'Mangia 2020.

Laser-scanned areas were also captured using Riegl's VZi400 and a mobile laser scanner for street-level drive-through scanning. Riscanpro and Riprocess facilitated the generation of point clouds and simple meshes for further visualisation outputs. Data visualisation in immersive environments was achieved through rendering the 3D models in Unity 3D for the 7-panel CAVE (Computer Automated Virtual Environment), Oculus Rift, and Magic Leap [13], [14]. Exporting these models to interactive applications has enhanced the outputs, allowing users to revisit scenes that integrate terrestrial and subterranean data from a desktop or mobile device (Figure 3).

The application of technology to achieve increasingly precise resolutions is enhanced by advanced analytical and visualisation tools, propelling spatial information to the next phase in urban planning. This is especially crucial for visualising and capturing hard-to-reach areas, such as deep underwater arte facts, using aerial bathymetric scanning (Figure 4), which is set to be updated in 2024.

The application of visualisation tools across environmental, social, psychological, and other multidisciplinary domains has recently been challenged by AI art renderers that replicate, mimic, or create outputs resembling reality. In the coming years, researchers will need to empower the spatial domain by integrating these tools to gain deeper insights of data and intricate dynamics embedded in physical, social, and natural environments. This integration aims to harness the power of AI for empirical research and operational tasks by identifying elements that may be overlooked by human inspection.

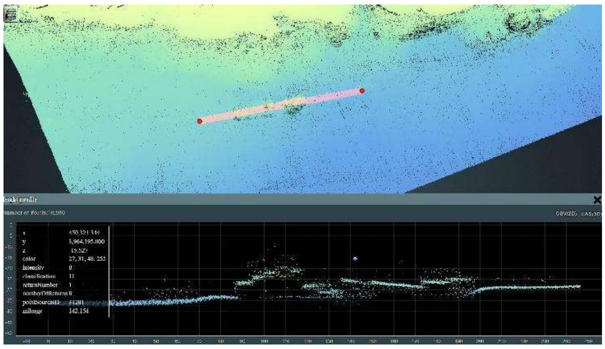

Figure 4 – Aerial Bathymetric LiDAR– Zurrieq 2012.

[1] L.L. Lachvajderova, and J. Kadarova (2021), “Digitization, Digitalization and Digital Transformation In Industry - A Systematic Literature Review.” *In Proceedings of 17th International Conference for Ph.D students and Young Researchers*, 298-309. 10.7441/dokbat.2021.25.
[2] J.J. Vrana and R. Singh (2021), “Digitization, Digitalization, and Digital Transformation”. *Handbook of Nondestructive Evaluation* 4.0, 1-17. 10.1007/978-3-030-73206-6_39
[3] J. Bloomberg (2018), “Digitization, Digitalization, And Digital Transformation: Confuse Them At Your Peril. Enterprise & Cloud, Forbes”, Apr 29, 2018, accessed on 06 November 2022. Retrieved from: https://www.forbes.com/sites/jasonbloomberg/2018/04/29/digitization-digitalization-and-digital-transformation-confuse-them-at-your-peril/
[4] G. Konecny (2014), *Geoinformation: Remote Sensing, Photogrammetry and Geographic Information Systems, Second Edition*. CRC Press.
[5] P. Drap, and D. Merad and B. Hijazi, and L. Gaoua and M.M. Nawaf and M. Saccone … and F. Castro, (2015), “Underwater Photogrammetry and Object Modeling: A Case Study of Xlendi Wreck in Malta”. *Sensors*, 15(12), 30351–30384. https://doi.org/10.3390/s151229802
[6] K. Kingsland (2020), “Comparative analysis of digital photogrammetry software for cultural heritage”. *Digital Applications in Archaeology and Cultural Heritage*, 18, e00157. https://doi.org/10.1016/j.daach.2020.e00157
[8] F. Remondino (2011), “Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning”. *Remote Sensing*, 3(6), 1104–1138. https://doi.org/10.3390/rs3061104
[9] S. Formosa and J. Formosa Pace and E. Sciberras (Eds). (2022), *Virtualis: Social, Spatial and Technological Spaces in Real and Virtual Domains - SpatialTrain III,* Planning Authority
[10] A. Lovett and K. Appleton and B. Warren-Kretzschmar and C. Von Haaren (2015), “Using 3D visualization methods in landscape planning: An evaluation of options and practical issues”. *Landscape and Urban Planning,* Volume 142: 85-94
[11]H. Obanawa and Y. Hakawa and C. Gomez (2014), “ 3D Modelling of Inaccessible Areas using UAV-based Aerial Photography and Structure from Motion”. *Transactions of the Japanese Geomorphological Union*, 35.
[12] A. Bustillo and M. Alaguero and I. Miguel and J.M. Saiz and L.S. Iglesias (2015), “A flexible platform for the creation of 3D semi-immersive environments to teach Cultural Heritage”. *Digital Applications in Archaeology and Cultural Heritage*, Volume 2, Issue 4
[13] T.T.N. Nguyen and S. Formosa (2022), “Reconstructing Humans Using Photogrammetry in S., Formosa, J., Formosa Pace, & E., Sciberras, (Eds)”. *Virtualis: Social, Spatial and Technological Spaces in Real and Virtual Domains - SpatialTrain III*, Planning Authority, ISBN 978-9918-23-097-6
[14] F. Cali (2022), “An Immersion Lab Presenter’s Perspective” in S., Formosa, J., Formosa Pace, & E., Sciberras, (Eds). *Virtualis: Social, Spatial and Technological Spaces in Real and Virtual Domains - SpatialTrain III*, Planning Authority, ISBN 978-9918-23-097-6

The use of pseudo-noise pulse compression thermography for inspecting of masonry wall

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Introduction

A widely used technique for the non-destructive evaluation (NDE) is Active thermography (AT), which is used in several applications, e.g. inspecting composite materials. In recent years, the use of AT has attracted the interest of heritage science as it allows the analysis of a large area of an object to be performed in a relatively short time, which is fundamental for the inspection of painted surfaces, including that within historical buildings. These paintings are typically made of a brick wall, and the accurate identification of defects that are not visible to the naked eye is pivotal for their maintenance and restoration. A common technique employed in AT is pulsed thermography (PT), which uses a flash lamp to heat the inspected sample within a time duration that is significantly shorter than the typical cooling time of the sample itself. The impulse response $h(t)$ is thus retrieved for each pixel of the acquired image by just collecting a series of thermograms, from which features of interest can be extracted, such as thermal signatures of detachments or defects[1]. While PT offers a multitude of advantages, it also presents a series of challenges when applied to artworks. In fact, these are unique items, which can be damaged by the high energy delivered in a short time. A recently developed technique is the Pulse Compression Thermography (PuCT). This method was originally developed for RADAR aiming at increasing the range resolution and the final SNR. The principal advantages of the combined use of PuC and coded signals for estimating the $h(t)$ are that an SNR enhancement can be achieved by simply increasing the time duration T of the excitation [2]. This work focuses on the analysis of a mock-up of a masonry wall consisting of different layers, including a plaster, and with an artificial defect inside in the form of a cross made by an insulating foam [3] using Pseudo-noise Pulse Compression Thermography (PN - PuCT).

Experimental setup and Results

The PN-PuCT setup is composed of a portable TiePie HS5 Handyscope for generating the coded waveform. In particular, the pseudonoise code modulates the ON/OFF state of two halogens lamp with a nominal power of 1kW each. The thermal camera used is a FLIR XC6990.
The measurements was conducted on the specimen shown in Figure 2. Defects buried within the brick wall of different nature and placed at a range of depths were artificially realized in the inspected sample. A wooden cross was here of interest, with its arms placed at 12 mm from the inspected surface, while the cross center was at 8 mm from the front side surface. All measurementes were conducted by inspecting the front side, see Figure 1(a).

a) 

 b)

Figure 1 – Back side (a) and front side (b) of the mock-up of masonry wall used for measurement

To perform correctly the PN-PuC, the DC component resulting from the use of the PN sequences as the modulating waveform for the heat source must be removed by performing a polynomial fitting, as shown in Figure 2.a. The

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reconstruction of the impulse response is depicted in Figure 2.b, which is obtained after PuC. The presence of a defect results in a different decay of the reconstructed impulse response.

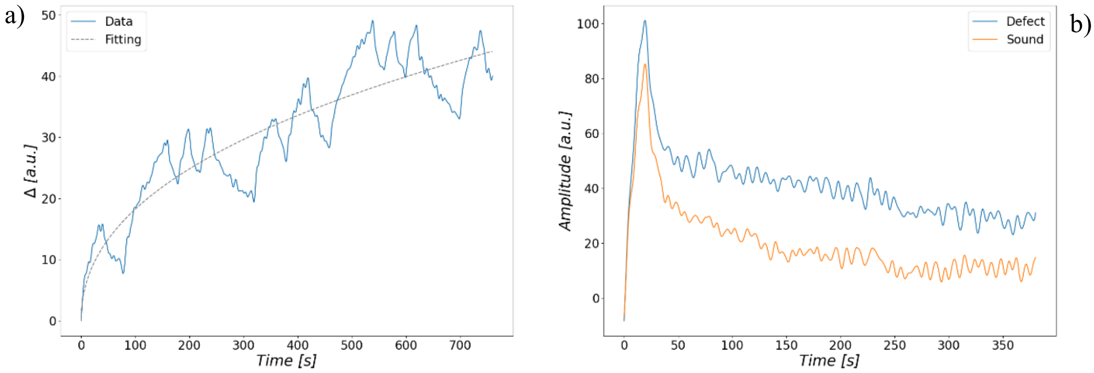

Figure 2 - (a) Acquired thermograms frame by frame for a generic pixel (after removing the background value) and polynomial fitting function. b) Reconstructed impulse response in two different areas of the specimen, one with the presence of a defect and one without the presence of a defect (b)

The application of the PuCT algorithm to each pixel of the thermograms acquired outputs a series of images, some of which are depicted in Figure 3. As expected, the cross centre defect, which is the shallowest, appears earlier in time, after 50 seconds approximately. The presence of the cross arms can also be observed later, i.e. at 100 s c.a. Finally, a clear presence of the cross defect is observed.

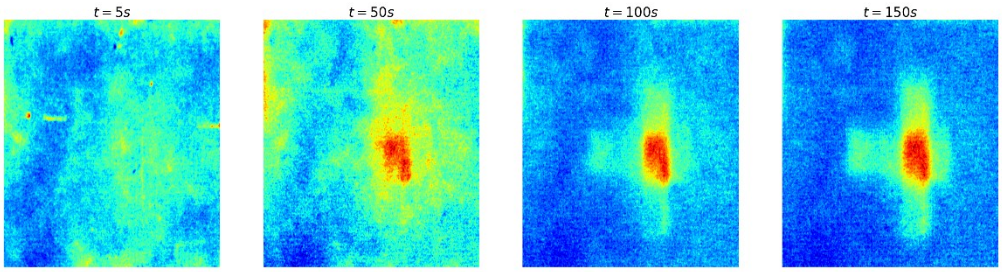

Figure 3 – Results obtained at different time after applying PuC algorithm to each pixel.

Conclusions

PN-PuCT has been here use to investigate the presence of a defect inside a masonry wall, reasonably mimicking an environment where the risk to damage artworks might take place. It is shown that this method is a good alternative to the PT when unique heritage items are to be inspected.

Acknowledgements

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References

[1] Theodorakeas, P., Sfarra, S., Ibarra-Castanedo, C., Avdelidis, N. P., Koui, M., Maldague, X. P. V., ... & Paoletti, D. (2013, May). The use of Pulsed Thermography for the investigation of art and cultural heritage objects. In Proceedings of the 5th International Conference on NDT of HSNT-IC MINDT (pp. 2-5).
[2] Ricci, M., Zito, R., & Laureti, S. (2024). Pseudo-noise pulse-compression thermography: a powerful tool for time-domain thermography analysis. arXiv preprint arXiv:2405.00598.
[3] Ferrarini, G., et al. "Calibration of thermal nondestructive testing methods on mock-up historic masonry." Thermosense: Thermal Infrared Applications XL. Vol. 10661. SPIE, 2018.

"Manuscripts don't burn."
Optical techniques to acquire information from hidden layers

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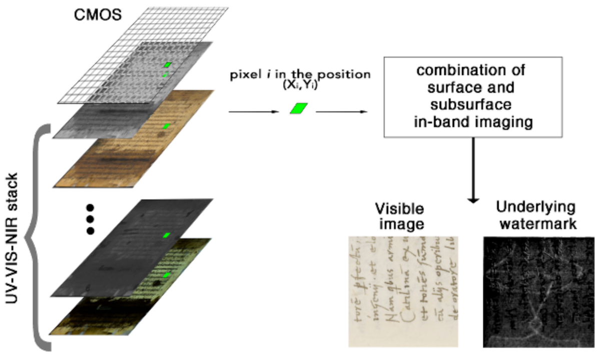

Figure 1: Sketch of the concept.

"Manuscripts don't burn" is one of the most famous phrases in Mikhail Bulgakov's The Master and Margarita (1967): a pained echo of the very destiny of Bulgakov's work itself, it is an ideal hymn to the immortality of art. In objective reality, however: even if they are not destroyed - the word is eternal - ancient manuscripts can sometimes be damaged.

Manuscripts are layered objects in which tangible and intangible (text) dimensions are interlaced: original text is not legible due to material degradation, it is erased and overwritten as in the case of palimpsests. Optical image-based methods are powerful in book heritage documentation providing non-invasive measurements and legible results [1, 2]. This activates cross-disciplinary synergies with philologists, allowing to tailor methodologies to specific needs.

Nowadays, high-performance multispectral imaging platforms are available. A CMOS high-performance camera allows to acquire the manuscript in reflectance and luminescence mode and to probe the manuscript layers thanks to the different penetration depth of the UV-VIS-IR wavelengths. UV-based imaging detects surface features (faded ink and erased text), IR imaging detects subsurface features (underwriting, carbon-based inks on blackened parchment); narrow-band imaging allows smaller spectral features to be discriminated to tailor materials response [3, 4].

The idea underpinning this short paper is to exploit the optical transparencies of the materials and to analyze the image stack (acquired both in transmission and reflection setup) on a physical basis, i.e., by combining the signals according to the surface or the subsurface character of the in-band imaging modality. This allows in principle a manuscript "delayering" to enhance the hidden features.

To this aim, an optimized setup and acquisition pipeline is necessary to obtain a high-quality, radiometric spectral stack suitable for further data processing.

Multispectral imaging data were acquired with the Phase One RAINBOW system including an iXG 100MP Wide Spectrum camera (CMOS sensor, 350 nm to 1050 nm), multiple sources for controlled narrowband stimulus in the UV-VIS-NIR (Rainbow LED lights system and Dedo DLED7 UV), a filter wheel and a Schneider Kreuznach RS 72mm lens mounted on a reprographic column. Reference standards were placed in-scene and the images were calibrated using Capture ONE 20 by PhaseONE and Rainbow MSI software.

Case study

Figure 1 depicts the concept on a 15th century code watermark.

Manuscripts contain hidden features, e.g., watermarks, laid lines, and chain lines. By identifying and classifying the subtle differences on laid papers, their similarity and potential identical nature may be determined, allowing historians to gain insight into the date and location of a sheet's origin. For instance, the finding of identical watermarks on two different artworks lets us presume that both were created within a short period of time, since the corresponding sheets of paper were undoubtedly produced with the same mold. Experts refer to these matches as "moldmates".

We follow the data pipeline described in [5] with VIS image, using as data the multispectral image stack. Starting from a multilayer modeling of the document (the back side (V), the watermark (W), and the front side (R)), an image in transmission-mode $T(x,y)$ is acquired. The attenuation induced by the three physical layers can be modeled with a multiplicative model, pixel-wise, $T(x,y) = R(x,y) \cdot W(x,y) \cdot V(x,y)$. By knowing $R(x,y)$ and $V(x,y)$, we could easily

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Figure 2: Transmission-mode image T, reflection-mode image (front side) R, and the watermark W signal. (top) 15th century, code CCLVII (229). (bottom) notarial deed (1864).

calculate the corresponding watermark signal $W(x,y)$. The layers R and V can be obtained (approximation) from the transmission image T, by acquiring and combining the images of the front and the back side, this time taken in reflection modality, $\tilde{R}$ and $\tilde{V}$. The reflection-mode images $\tilde{R}$ are convolved with Gaussian filter to add scattering, then spatially registered.

We carried out the procedure for the detection of watermarks on a paper epistle written in Latin drafted in the 15th century, code CCLVII (229) and on a notarial deed (1864), ink on paper, preserved in the Archivio di Stato di Verona (Figure 2).

The potential of the test underlines the need for further study regarding the knowledge of the response of the manuscript materials (spectral data) and the use of advanced data processing algorithms.

Acknowledgments

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[1] A. Tonazzini, E. Salerno, Z. A. Abdel-Salam, M. A. Harith, L. Marras, A. Botto, B. Campanella, S. Legnaioli, S. Pagnotta, F. Poggialini, and V. Palleschi, "Analytical and mathematical methods for revealing hidden details in ancient manuscripts and paintings: A review," *Journal of Advanced Research*, vol. 17, pp. 31–42, 2019.

[2] M. Perino, L. Pronti, C. Moffa, M. Rosellini, and A. C. Felici, "New frontiers in the digital restoration of hidden texts in manuscripts: A review of the technical approaches," *Heritage*, vol. 7, no. 2, pp. 683–696, 2024.

[3] K. T. Knox, "Enhancement of overwritten text in the archimedes palimpsest," *Proc. SPIE*, vol. 6810, p. 681004, 2008.

[4] K. Bloechl, H. Hamlin, and R. L. Easton Jr, "Text recovery from the ultraviolet-fluorescent spectrum for treatises of the archimedes palimpsest," *Proc. SPIE*, vol. 7531, p. 753109, 2010.

[5] P. Ruiz, O. Dill, G. Raju, O. Cossairt, M. Walton, and A. Katsaggelos, "Visible transmission imaging of watermarks by suppression of occluding text or drawings," *Digital Applications in Archaeology and Cultural Heritage*, vol. 15, 2019.

PUTTING THE PEACES TOGETHER. A STUDY OF BRONZE FRAGMENTS FROM THE NECROPOLIS OF TREBENISHTE

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Keywords: bronze objects, EDX analysis, ICP-LA-MS, optical metallography

The objects from the VI century BC Necropolis of Trebenishte have a unique story starting from their excavation and finishing with the restoration which is still ongoing process- a hundred years after the first discovery. Belonging to tree different countries – Bulgaria, Serbia and Republic of North Macedonia, they are for the first time a subject of study as a direct consequence of a series of big mutual exhibition.

The discovery was made by the Bulgarian military unit during the World War I while repairing the road between Skopje and Ohrid. The first seven greaves were excavated and afterwords documented and published. The second phase of research took place in the period from 1930 to 1939 and was founded by National Museum in Belgrade. During 1960`s third phase of excavations were organized by Socialistic Republic of Macedonia.

here are some reports that the information though is not entirely accurate and some fragments where mistakenly attributed to objects they do not belong. In the process of trying to identify which fragments belong where it was necessary a study to be undertaken in order to organize the information in clusters and interpret it. The first approach was to obtain qualitative and quantitative results for the major elements of the composition of the alloy such as copper, tin and lead etc. using XRF spectrometer. In order to be more precise, it was still necessary to acquire accurate data about the trace elements which would have given a possibility for better knowing and understanding the composition of the different alloys used for making the different objects which was possible applying the ICP-LA-MS method. As a final step in the process of getting to know better the production technology were prepared cross sections of samples from the vessels for optical metallography.

As a result of the study, it was finally possible to have better knowledge for the elemental composition of the bronze vessels form the Necropolis of Trebenishte respectively for the composition of the alloy of every analyzed fragment. The process of the interpretation of the data gave an opportunity to put every individual fragment in the context of the others and to find eventually where it belonged.

Multi-scale diagnostic observation for buildings of conservation: a project idea

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Figure 1 – Archival material affected by biodeterioration problems due to poor storage conditions.

This work presents a research approach related to the Integrated and Sustainable Conservation of the Cultural Heritage of the State Archive of Cagliari, deriving both from the successful experiences in the national and international framework, and from the multiple technical-scientific results obtained, and also for the concrete applications implemented by the partners of the collaboration. This background allows o operate in a systemic way and intends to structure a sequence of Knowledge-Protection-Conservation-Enhancement of the Heritage. The methodologies and technologies presented are contextualized by a design that treats the complex system with a global point of view, considering important variables deriving from the action and characteristics of the environment, from the micro- and macro-climatic and structural static control of the monument and from the behavior of the materials constituting the assets to be preserved contained in it. Thus, individual applications in the diagnostic field converge to address the problems and strategies of conservation, with the aim of defining an integral and complex plan for understanding and intervening the effects of damage and its causes, to develop an interoperability platform, and to properly root efforts towards treatment and prevention.

The State Archive of Cagliari is one of the foremost archival preservation institutions in Sardinia. The documentation preserved here, spanning from the early 14th century to the 20th century, is notable for its variety of materials, their conditions, and their specific conservation needs. As a historical entity responsible for the preservation of cultural heritage, one of its missions is to safeguard the items it houses through the implementation of both direct and indirect practices aimed at creating a suitable environment. Among the various forms of preservation in the cultural sphere, the preventive approach is certainly the most effective, as it reduces, over time, the need to act directly on the items through costly and invasive operations, which are impractical given the enormous volumes characterizing archival materials. Generally, this is pursued through indirect interventions, of either structural or anthropogenic nature, often oriented towards controlling environmental parameters to counteract the causes of accelerated degradation affecting all artistic artifacts.

Despite being a legislatively mandated activity in Italy, fundamental for the preservation of cultural heritage, and considered indispensable according to the Code of Cultural Heritage and Landscape, preservation sites, especially monumental ones, often lack adequate storage environments and suitable structures.

Specifically, the State Archive of Cagliari is a historical building dating back to the 1920s, constructed from Lecce stone, a calcareous lithotype known primarily for its ease of working at the expense of its durability. Despite its decent functional qualities, it is a stone that, by its very nature, is highly susceptible to the mechanical action of atmospheric agents, rising ground moisture, and water and smog stagnation. Over time, the building has gradually deteriorated structurally, showing significant consequences in the loss of thermal maintenance capacity, favouring the occurrence of further effects on the rapid fluctuation of internal thermo-hygrometric values in the short and long term.

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The storage areas themselves, differently located within the structure's layout, exhibit problems of excessive humidity, rising damp, or thermal fluctuations, with potential or observable compromise of stability, leading to the direct manifestation of chemical-physical damage to the documents stored within.

Diagnostic observations and monitoring at the scale of a site or individual monument are fully completed in the analysis of the composition and state of conservation of the materials constituting the assets.
Thanks to the ability to capture high-resolution images of the Earth's surface, satellite monitoring offers a global and detailed view of the changes taking place on the monumental building and facilitates the understanding of ongoing structural and geotechnical phenomena.

COSMO-SkyMed is the ASI SAR constellation, the only one in the world to be made up of 5 satellites operational (3 first generation and 2 second generation) in the X band, capable of providing very high spatial resolution images (up to 1m per civil use), very high acquisition frequency, in any meteorological and light conditions. The use of satellite SAR interferometry technique applied to COSMO-SkyMed images is combined with the advantage of being able to use the archives of radar images that allow us to deduce, in an extensive manner, the evolution in time of more than fifteen years of deformation processes. Interferometric techniques generate not only ground deformation maps measured along the sensor's line of sight, but by taking advantage of a series of images (instead of just two) acquired over time, they allow the temporal evolution of the deformation itself to be followed. The results obtained are to be considered a support of a data in situ collected [1-2].

On the scale of the monument, the structural monitoring based on satellite technologies and advanced techniques for the use of the results of the measurements carried out outside the premises is interconnected with the measurements of the parameters inside the building and specifically with the control of the microclimate and biological contaminants. This aspect of the study is strongly correlated with the analysis of the composition and state of the art of the materials constituting the assets preserved in the rooms of the archive.

Since the composite and poly-material nature that characterizes the artifacts preserved, in particular, in the archives, the necessary in depth step of the described approach remains the applying of different investigation techniques aimed at characterizing their composition, state of conservation and the deterioration processes in progress, through the definition of a dedicated diagnostic investigation protocol. The ultimate goal, therefore, considers the evaluation of the single artifact in its conservation environment, in its macroscopic dimensions up to the microscopic ones.

In relation to the treatment strategy for the cure and removal of biodegradation, the radiation sterilization technique is evaluated as a particularly effective and sustainable method. The applications in the field of recovery of goods in paper, parchment and leather, typical book supports, demonstrate the complete safety of the method and the phenomenology guarantees its use in series on large volumes [3-7].

The work is conducted at the Archive of Cagliari in collaboration with the Italian Space Agency and the University of Rome Tor Vergata.

[1] Virelli M., et al. (2020), COSMO-SkyMed: uno strumento satellitare per il monitoraggio dei beni culturali. In: Monitoraggio e Manutenzione delle Aree Archeologiche. Cambiamenti climatici, dissesto idrogeologico, degrado chimico-ambientale / Atti del Convegno Internazionale di Studi, Roma, Curia Iulia, 20-21 Marzo 2019 / Alfonsina Russo e Irma Della Giovampaola - (a cura di) - «L'ERMA» di BRETSCHNEIDER, 2020 - (Collana Bibliotheca Archaeologica, 65) 278 p.; ill., pp. 103-112.

[2] Tapete D., Coletta A. (2022) ASI's roadmap towards scientific downstream applications of satellite data, EGU General Assembly 2022, Vienna, Austria, 23–27 May 2022, EGU22-5643.

[3] M. Vadrucci, F. Borgognoni, C. Cicero, N. Perini, L. Migliore, F. Mercuri, N. Orazi, A. Rubechini, "Parchment processing and analysis: Ionizing radiation treatment by the REX source and multidisciplinary approach characterization", *Appl. Radiat. Isot*., vol. 149, 159–164, 2019.

[4] M. Vadrucci, G. De Bellis, C. Mazzuca, F. Mercuri, F. Borgognoni, E. Schifano, D. Uccelletti, C. Cicero, "Effects of the Ionizing Radiation Disinfection Treatment on Historical Leather", *Front. Mater.*, vol. 7, 21, 2020.

[5] M. Vadrucci, C. Cicero, C. Mazzuca, F. Mercuri, M. Missori, N. Orazi, L. Severini, U. Zammit, "Effect of X-ray and artificial aging on parchment", *Eur. Phys. J. Plus*, vol. 136, 873, 2021.

[6] M. Vadrucci, C. Cicero, C. Mazzuca, L. Severini, D. Uccelletti, E. Schifano, F. Mercuri, U. Zammit, N. Orazi, F. D'Amico, P. Parisse, "Evaluation of the Irradiation Treatment Effects on Ancient Parchment Samples", *Herit.*, vol. 6, 1308-1324, 2023.

[7] F. Mercuri, C. Cicero, S. Paoloni, U. Zammit, N. Orazi, M. Vadrucci, L. Severini, C. Mazzuca, "Deterioration effects of X-ray irradiation in artificially aged parchment", *Eur. Phys. J. Plus*, vol 138, 993, 2023

Tales of Colours – Latest Results of the Archaeometrical Examinations Carried out on Murals in Syrian Crusader Castles

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Fig. 1: Crac des Chevaliers and a part of the wall paintings

The extended research program of the Syro-Hungarian Archaeological Mission comprises the documentation and research of the medieval wall paintings in three Syrian Crusader castles: Margat (Qal'at al-Marqab) [1-2] and the UNESCO World Heritage Sites of Saone (Qal'at Saladin) and Crac des Chevaliers (Qal'at al-Husn). Wall paintings of these three castles were made in various locations and sometimes in different periods, which resulted in significant variations both in style and in the painting techniques employed. The execution of the paintings spans roughly 100 years, from the end of the 12th century to the end of the 13th century. After the castles fell into the hands of the Mamluks, they underwent a major transformation. As the castle chapels were converted into mosques, a significant part of the paintings was destroyed or covered with undecorated Muslim plaster. Due to this fact, the paintings were preserved in different states. A notable part of them were uncovered *in situ*, but hundreds of detached painted fragments were also unearthed by excavations. Some reused Crusader ashlars with their painted surfaces were discovered in later Muslim masonry and some murals had been previously detached and are stored in museums. Both Margat and the Crac were inhabited until the beginning of the 20th century and underwent countless interventions and transformations during the nearly 800 years. In addition to the Crusader murals, Muslim paintings have also been preserved on the sites, which can be mainly dated to the late Ottoman period.

The main objective of the research on murals is to learn about the painting techniques and material usage characteristics, which in many cases also play a significant role in understanding the depictions. The investigations can also help to precise certain issues of the periodization of the paintings. During the on-site research, surveys, phototechnical investigations, and digital reconstructions were made, which were followed by on-site measurements using a handheld energy-dispersive X-ray fluorescence spectrometer (ED-XRF). Based on the results of more than a thousand XRF measurements, the scopes and objectives of further required

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archaeometrical examinations were mapped. The examinations were carried out with an optical microscope, a plasma-focused ion beam scanning electron microscope equipped with energy dispersive X-ray spectrometer (PFIB SEM + EDS) and a Fourier transform infrared spectroscope (FTIR) in the laboratories of the Faculty of Materials and Chemical Engineerings at the University of Miskolc. During the research, the aim was to gain as much information as possible with the least sampling.

As part of the research and restoration program funded by the Hungarian State through the Hungary Helps Agency in the war-damaged Crac des Chevaliers, research and conservation of the *in situ* wall paintings of the castle chapel has been started in 2022. During the restoration works significant medieval painted surfaces became visible compared to those previously known.

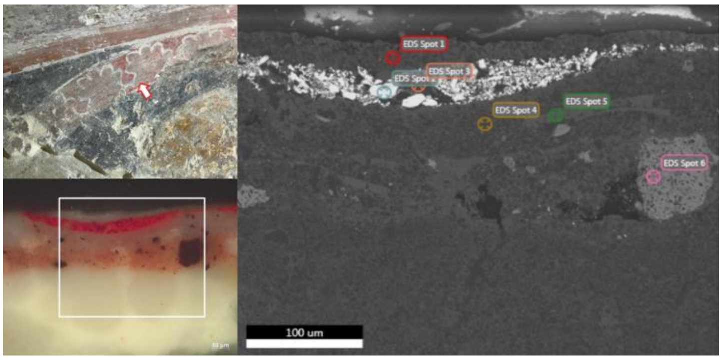

Fig. 2: OM and PFIB SEM images of a sample of the wall paintings of Crac des Chevaliers

The large fragments found during the conservation works of 2022-2023 in Crac des Chevaliers also form the base for the research on the painting techniques and the use of materials. In addition to identifying the raw material of each shade, it was possible in several cases to draw conclusions on the changes in the original colours and to find traces of the painting technology. Our presentation intends to present the rich iconographic and technical diversity of these murals and the results of the archaeometrical research and the conclusions that can be drawn on the production of medieval murals in these important meeting points of civilisations between the medieval East and West.

[1] B. Major and É. Galambos, “Archaeological and Fresco Research in the Castle Chapel of al-Marqab: A Preliminary Report on the First Results of the First Seasons” in *The Military Orders 5: Politics and Power*, ed. P. Edbury, pp. 23–47, 2012.
[2] Zs. Márk, “Mural Painting in Margat Castle” in *Bridge of Civilizations, The Near East and Europe c. 1100-1300,* eds. P. Edbury, D. Pringle and B. Major, pp. 246-259, 2020.

Hydraulic hardening of low T fired bricks with dolomite addition: sustainability while preserving the built heritage in humid areas

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Figure 1 - Current clay quarries in Vale Coimbra area (above) and some of the testing probes prepared for the flexural strength determination (below).

Clays have been used as building material since ancient times and fired bricks build up constructions that are symbols of cultural identities. The built heritage is increasingly at risk largely due to climate changes, pointing the Disaster Risk Reduction (DRR) methodologies towards competences such as knowledge and prevention. In this context, the production technologies of ancient bricks provide significant data to consider in order to strength the resistance over time of historical buildings and structures. Moreover, as traditional materials, fired bricks are meaningfully linked with socio-cultural values of peoples and, in turn, represent an eco-innovative and sustainable solution for restoration and new construction purposes.

Carbonate-rich clays support a wide range of firing temperatures and result in fired products with exceptional porosity, mechanical behaviour and weather resistance [1]. The high resistance over time of Roman bricks made out of calcium/magnesium-rich calcareous clays and fired at high temperatures (> 900 ºC) was largely due to the noteworthy formation and development both of a calcium-rich amorphous phase and specific firing phases, that provided an important binder action and a significant strength to the ceramic bodies, respectively [2]. In addition, high humidity conditions have enhanced the conservation of such amorphous binding phase, fostering the better preservation of Roman bricks [3].

However, carbonate content must be controlled as lime blowing may arise if free lime and/or magnesia are still available after firing [4]. For their complete reaction during firing, high temperatures (> 900 ºC) must be reached, but lower ones (850-900 ºC) are required by current ceramic industry to save energy and reduce costs. Several studies stated that when dolomite-rich clays are fired at low temperature (< 900 °C), results a permeable and semi-hydraulic structure composed of the pristine carbonates and the newly-formed phases [5]. This semi-hydraulic material is able to achieve a hydraulic hardening under water or humid environs, increasing the mechanical strength of the ceramic products [6].

The work-in-progress here presented aims to produce durable bricks made out of clay materials from the Portuguese Western central area, enriched in dolomite and fired up to 900 °C, able to achieve self-improving hydraulic properties under water and high humidity conditions. This area is characterized by the occurrence of important clayey deposits and by its European leadership ceramic industry, being the CICECO-Aveiro Institute of Materials a research centre focused on the innovative ceramics production towards sustainable development. Even more, clays are synergistically entangled with the culture and traditions of the territory and the Aveiro lagoon is one of the highest humid areas of Portugal.

Two types of non-calcareous clays outcropping nearby the city of Coimbra were sampled, yellowish clays from Vale Coimbra (VC, Figure 1, above) and red clays from Taveiro (TV), and micronized dolomite has been used as the additive. A total of 20 different compositions were considered (Table 1), comprising the two types of the base clays and their mixtures (in three different proportions) -both without and with dolomite addition (using three clays:dolomite ratios)-, that were fired at 750, 850 and 900 °C. Firstly, the raw materials (the two types of base clays and micronized dolomite) were characterized by chemical, mineralogical and granulometric analysis. Then, specific testing probes with the 20 considered compositions were prepared (Figure 1, below), in order to measure the colorimetric parameters, to identify the mineral phases and to determine the water absorption and flexural strength, before and after firing as well as after water immersion and high humidity exposure. In addition, the shrinkage upon drying, after firing and after water immersion/high humidity exposure was likewise measured.

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Table 1 - The 20 compositions considered, comprising the two types of the base clays and their mixtures.

BASE CLAYS AND MIXTURES																			
UNMIXED CLAYS								MIXED CLAYS (CLAYEY PASTES)											
VALE COIMBRA				TAVEIRO				$VC_{50} : TV_{50}$				$VC_{75} : TV_{25}$				$VC_{25} : TV_{75}$			
Base clay	With dolomite			Base clay	With dolomite			Blank	With dolomite			Blank	With dolomite			Blank	With dolomite		
	95:5	9:1	8:2		95:5	9:1	8:2		95:5	9:1	8:2		95:5	9:1	8:2		95:5	9:1	8:2

From a chemical point of view, the base clays are highly rich in silica, have significant contents of alumina, are moderately rich in iron and potassium oxides and very poor in calcium and magnesium oxides. Mineralogically, the two clay-based bodies correspond to quartz-rich kaolinitic and illitic clays, being detected in those from Taveiro the iron oxide wustite and a higher content of feldspars. The clay-size fraction of both clayey materials is chiefly composed of kaolinite, illite and smectites, and the main difference was just found in such < 2 mm fraction, since higher illite and kaolinite amounts were noted in Taveiro clays. The granulometric curves show that the silt and clay content (< 63 microns) is higher in the Vale Coimbra clays, whereas the very fine sand size (63 - 125 microns) is rather significative in the Taveiro clays. The micronized dolomite corresponds mineralogically with dolomite and calcite or magnesium-rich calcite (the slight presence of the iron oxide maghemite was also detected).

With the data achieved from the analysis of the 20 different compositions, two main challenges are pursuit: i) to state the relation of the mineralogical and colour changes with the mechanical/hydric behaviour of the ceramic products with increasing temperature (750, 850 and 900 °C), as well as the influence of dolomite addition in such changes and behaviour, and ii) to confirm if the semi-hydraulic material has developed after one year of water immersion and high humidity exposure of the ceramic products and, if so, to analyse if the mechanical/hydric performance has improved (considering likewise the mineralogical and colour changes).

In turn, this points towards two new perspectives: i) the achievement of high-quality building bricks made out of non-calcareous clays enriched with dolomite and fired at low temperatures (fired up to 900 °C) is completely aligned with current industry challenges, such as the sustainable raw materials supply (the use of local clays reduces transport costs and promotes circular economy) and the eco-efficient production (the low firing temperatures reduce CO_2 emissions and energy consumption), and ii) the addressing of the production of fired brick for restoration purposes as a DRR preventive measure for the conservation of heritage constructions placed under water and/or in high humid environments.

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[1] W.D. Kingery, “Introduction to ceramics”, John Wiley & Sons, Inc., New York, 1960.

[2] E.M. Pérez-Monserrat, L. Maritan and G. Cultrone, “Firing and post-firing dynamics of Mg- and Ca-rich bricks used in the built heritage of the city of Padua (north-eastern Italy),” *Eur. J. Mineral*, vol. 34, pp. 301–319, 2022.

[3] E.M. Pérez-Monserrat, M.A. Causarano, L. Maritan, A. Chavarría, G.P. Brogiolo, and G. Cultrone G, “Roman brick production technologies in Padua (Northern Italy) along the Late Antiquity and Medieval Times: durable bricks on high humid environs,” *J. Cult. Herit*, vol. 54, pp: 12–20, 2022.

[4] N. Saenz, E. Sebastián and G. Cultrone, “Analysis of tempered bricks: from raw materials and additives to fired bricks for use in construction and heritage conservation,” *Eur. J. Mineral*, vol. 31, pp. 301–312, 2019.

[5] L. Lindina, L. Krage, L. Bidermanis, I. Vitina, G. Gaidukova, V. Hodireva, and J. Kreilis, “Formation of calcium containing minerals in the low temperature dolomite ceramics,” *IOP Conf. Ser.: Mater. Sci. Eng*, vol. 25, pp. 012006, 2011.

[6] H.H.M. Darweesh, “Building materials from siliceous clay and low-grade dolomite rocks,” Ceram. Int, vol. 27, pp. 45–50, 2001.

Non-invasive integrated diagnostics for the conservation of wall paintings at the Complex of Santa Maria la Nova in Naples

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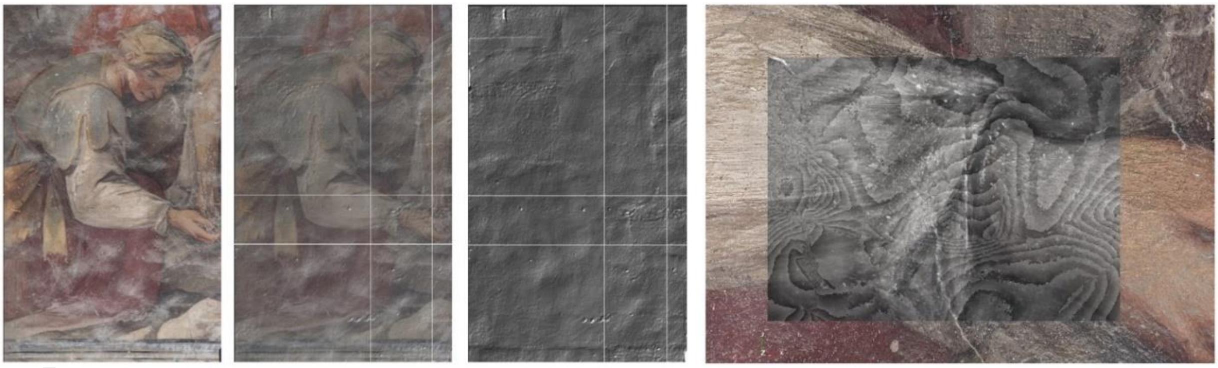

Figure 1 – TLS and Digital Photogrammetry 3D reconstruction of the wall painting representing "the Deposition of Christ" counter façade: comparison between DHSPI and DP ortophoto on a detail of the artwork.

Nowadays the use of a multidisciplinary diagnostic approach can be of crucial importance to an effective intervention of restauration and conservation of artifacts. Diagnostic can be a difficult task: the different results of the analysis testifying the effect of decay/damage need to be correlated to the cause or multiple concomitant causes to find the optimal conservation solution. According to these premises, the goal of this research work in progress is the pre, during and post-restoration documentation, evaluation and verification of the state of conservation of the wall paintings located in the entrance area and the small cloister of the Monumental Complex of Santa Maria la Nova in Naples, known as the cloister of San Giacomo della Marca.

This multidisciplinary work originated in the context of a didactic workshop on the restoration of works of art of the qualifying degree course in Conservation and Restoration of Cultural Heritage, active at the Suor Orsola Benincasa University of Naples [1].

The stylistic characteristics fully confirm the traditional attribution to the early 17th-century Neapolitan painter, Simone Papa. His name first emerges in the late 17th-century manuscript by Father Teofilo Testa da Nola and in Carlo Celano's "Notizie del bello." The cycle depicting the stories of the then-blessed Giacomo della Marca was created between 1627 and 1628, initiated by Father Stefano Chiesta from Genoa.

These areas were previously used as a car park. This high-smog environment has exacerbated the damage over time and wall paintings are in a poor state of conservation. The conservation status is outlined below:

- superficial deposits: coherent and less coherent, atmospheric particulate matter and various pollutants, particularly CO2, presumably residues of acrylic resins applied during previous restoration interventions, brown patinas due to oxidation/alteration of organic protectives and retouching and localized biological patinas;
- plaster detachment from the mural support, presumably more localized in correspondence with certain lesions;
- white or gray patinas: attributable to moisture infiltrations and the presence of salts and/or biodeterioration attacks;
- progressive disintegration: progressive disintegration phenomena of the preparatory plasters and the pictorial and finishing layers due to the formation of soluble salts;
- paint layer abrasion and micro gaps: abrasion of the paint layer and micro gaps.

The integrated analysis and diagnostic approach were characterized by a multi-instruments field campaign involving, among others: 3D modelling, Digital Photogrammetry (DP), Terrestrial Laser Scanner (TLS), Digital Holographic Speckle Pattern Interferometry (DHSPI) and Stimulates Infrared Thermography (SIRT), X Ray Fluorescence (Portable XRF), molecular biology technique (meta-barcoding).

The biodeterioration of wall structures with paint layer is a complex phenomenon that involves the physical and chemical degradation of the materials constituting the walls and the frescoes themselves due to the action of various

microorganisms, including bacteria, fungi, algae and lichens. The sampling of the patinas identified on the paintings was carried out in several places, taking care collect from the five areas where the alterations were most evident.
The meta-barcoding analyses carried out thanks to the sequencing of the 16S marker identified three prokaryotic organisms belonging to the Bacteria domain and to the sequencing of the 18S marker identifies three eukaryotic organisms, all belonging to the fungal domain. These microorganisms can deteriorate paint surfaces through various mechanisms, including the production of organic acids, the penetration of fungal hyphae in substrates and the formation of biofilms which can retain moisture and promote further processes degradation.

Portable X-ray fluorescence operates directly on the object without carrying out any sampling to identify the chemical elements and possible pigments present in the different types of samples analyzed, characterized, on average, by the presence of earths on Fe and Mn oxides for the reds and yellows and partly the blacks, smalt blue for the blues and green earths for the green pigments.

3D Modeling from integrated digital survey (i.e., active and passive sensors) provides highly detailed qualitative and quantitative information, such as morphometric and colorimetric documentation and multidisciplinary thematic characterizations. The digital twin of the paintings supports the integration between multisensor techniques, geolocalization and comparison of heterogeneous data acquired in specific areas, reading and restitution of the state of superficial and morphometric material conservation and traces of the specific executive techniques (e.g. engravings, superpositions, stratifications). Digital Photogrammetry (SfM and MVS software) allowed the processing of the reality-based model of the artworks (coloured point cloud, color per vertex high-poly mesh, diffuse and AO_Ambient Occlusion textured mesh, ortho-images, radiometric calibration), guaranteeing conservation of support, recording of variations for different intervention steps and supporting preventive approaches [2, 3, 4, 5]. The acquisition of the entire painting of the Deposition of Christ (fig. 1) was performed using a camera on a tripod (max height 7.5 m) and remote shutter release (GSD = 0.13 mm/pixel ca) [6]. In this work, we set the Terrestrial Laser Scanner [7, 8] sample-to-instrument distance at 6.40 m, and resolution and quality parameters at 1/1 and 5´ and image dimension of 6275*3074 pt. A knowledge of the invisible defects and its morphology can lead to a correct maintenance and assure its durability. The coloured dense cloud (.pts) allows comparison between the dense point clouds processed for the different steps of the intervention. The integration/alignment between digital photogrammetric model and 3D laser scanning is in progress to record any morphometric variations and in reflectance values (colour, material analysis) between the different areas of the frescoes located on the different walls of the architectural-structural system.

Complementary to the traditionally used techniques, an analysis based on the use of a portable Digital Holographic Speckle Pattern Interferometer (DHSPI) especially designed for the structural diagnosis of work of arts was performed [9,10]: the analysis of the evolution of the fringe pattern with time provides information about the below material and the sub superficial condition through its deformation response to thermal excitation [11].

Stimulates Infrared Thermography (SIRT) is based on the measurement of heat propagation in the object when irradiated by heat sources. The recorded photothermal signal depends on physical parameters of conductivity, emissivity, diffusivity, temperature: these parameters can be directly correlated to properties of the observed paintings, its topography, the presence of delamination and cracks, the structural condition of the material, water content and chemical reactions.
The integration of these techniques and related results supports the multidisciplinary approach adopted for this ongoing restoration and conservation activity.

Keywords: interferometry; NDT, restoration; 3D survey; phase-shift technique; SIRT, diagnostics

[1] https://www.unisob.na.it/ateneo/restauro/attivita0.htm?vr=1
This is a compulsory activity required by Ministerial Decree 87/2009 in connection with the training of professional restorers, which in this case was initiated thanks to the support of San Martino Alberghi srl.

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[2] Caroti, G., Piemonte, A., Ulivieri, D., 2023. Historic stone pavement photogrammetric 3D-survey: a way to get a catalogue to pass on ancient crafts. ISPRS, Vol. XLVIII-M-2-2023.
[3] Grifoni, E., Gargano, M., Melada, J., Interlenghi, M., Castiglioni, S Romano Gosetti di Sturmeck, I., Ludwig, N., 2021. Documenting Cultural Heritage in very hostile fruition contexts: the synoptic visualization of Giottesque frescoes by Multispectral and 3D Close-range Imaging. METROARCHAEO 2021. Journal of Physics: Conference Series, 2204 (2022) 012060. IOP Publishing. doi:10.1088/1742-6596/2204/1/012060.
[4] Adami, A., Fregonese, L., Helder, J., Rosignoli, O., Taffurelli, L., Treccani, D., 2022. High-resolution digital survey of floors: a new prototype for efficient photogrammetric acquisition. ISPRS Volume XLIII-B2-2022.
[5] Chiabrando, F., Lingua, A., Noardo, F., Spanò, A., 2014. 3D Modelling of trompe l’oeil decorated vaults using dense Matching techniques. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume II-5, 2014. ISPRS Technical Commission V Symposium, 23 – 25 June 2014, Riva del Garda, Italy
[6] For the DP of the Deposition of Christ, photos were acquired with a Camera Canon EOS R6 mirrorless con sensore FF (1.0x) da 20 Mpx; Manfrotto 269HDBU Super Giant Stand BK_Stativo; tablet for remote shooting control, focal length 50 mm, average distance 1 m, frame size 5472 x 3648 px, sensor (24 x 36) mm, 1/125 sec., ISO-800, f/8, manual shooting mode.

[7] Pulcrano, M.; Scandurra, S.; Minin, G.; Di Luggo, A. 3D CAMERAS ACQUISITIONS FOR THE DOCUMENTATION OF CULTURAL HERITAGE. Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. 2019, XLII-2/W9, 639–646, doi:10.5194/isprs-archives-XLII-2-W9-639-2019.

[8] Media.faro.com. Available online: https://media.faro.com/-/media/Project/FARO/FARO/FARO/Resources/1_BROCHURE/2022/FARO-Sphere/AEC_Focus-Premium/3154_Brochure_FocusPremium_AEC_ITA_A4.pdf?rev=85dfa574707b4100994fff2644294562

[9]. Tornari V. Analytical end Bioanalytical Chemistry Laser interference based techniques and applications in the structural inspection of works of art (2007)

[10] Tornari V., Tsiranidou E., Bernikola E. Interference fringe-patterns association to defect-types in artwork conservation: an experiment and research validation review Appl. Physics A (2012) 106

[11] C. Riminesi, R. Manganelli, Del Fà, S. Brizzi, A. Rocco, R. Fontana, M. Bertasa, E. Grifoni, A. Impallaria, G. Leucci, L. De Giorgi, I. Ferrari, F. Giuri, S. Penoni, A. Felici, Architectural assessment of wall paintings using a multimodal and multi-resolution diagnostic approach: The test site of the Brancacci chapel in Firenze Journal of Cultural Heritage 66(2024) 99-109

Quantitative analysis of mediaeval urban planning: identifying measurement units and plot divisions with *cosine quantogram*

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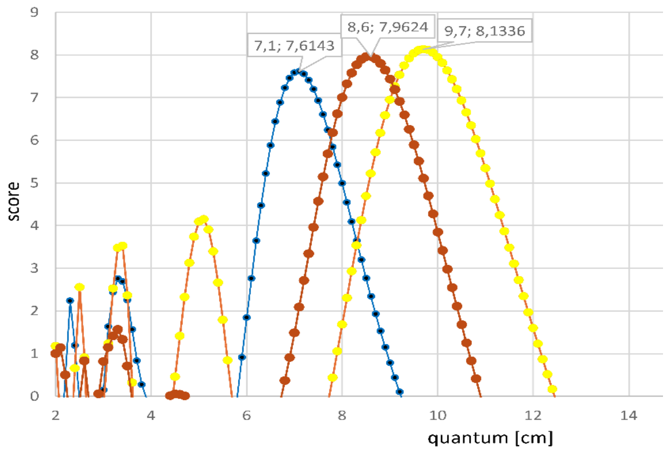

Figure 1 - Results of cosine quantogram for selected group of towns. Blue - plots of 25 feet of 0.288; red - plots of 30 feet of 0.288, yellow - plots of 30 feet of 0.314 m (by A. Kubicka-Sowińska)

The phenomenon of regular towns with diverse structures extends beyond antiquity and the Renaissance, also occurring in the 12th-14th centuries in Western Europe during internal colonisation and on a large scale in the colonisation of Eastern Europe [1]. The reconstruction of the original urban layouts of new towns has been a subject of research since the early 20th century. Methods based on simple geometric relationships or modular analysis were used, albeit with low-accuracy plans.

A key aspect of this research was investigating the measurement systems used in the layout of urban structures [2]. The main challenge in studying historical urban layouts is the transformation of plot divisions, linked to the splitting and merging of plot fragments, as well as the construction of neighbour walls beyond plot boundaries. This led to the distortion of the original layouts. Reconstructing the original plan, therefore, requires access to archival data and, ideally, the results of archaeological research. With the application of statistical methods, modern measurement techniques, such as LiDAR, and GIS tools for georeferencing historical cadastral plans, it has become possible to verify previous concepts.

The reconstruction was conducted using modular analyses and the cosine quantogram method [3]. Measurements of plot widths and block dimensions were collected for 20 regular mediaeval towns in Poland. Additonaly 10 mediaeval new towns and villages in Tuscany and Occitania, where original masonry architecture has been preserved, were used as a reference. These data were compared with historical information and archival cartographic records. Results revealed significant diversity in the design of mediaeval towns. This diversity included the entire urban structure concept, block sizes, and plot dimensions. Systems based on different modules were identified: multiples of the foot, rod, and those resulting from the division of chain/line. Based on the measurements, efforts were made to determine the fundamental unit of measurement used in city planning. The obtained quantum values confirm the hypothesis that at least two different measurement systems based on two foot values of 0.288 m and 0.314 m, were used in the mediaeval period in the region of Poland. Certain chronological trends, such as the tendency for plot sizes to decrease, were also observed.

The presented research offers new insights into the evolution of regular towns in Central Europe. The use of modern methods and the expansion of the analysis to a broader geographical context allow for a more precise understanding of urbanisation processes and the identification of regional specifics.

[1] R. Bartlett, The Making of Europe: Conquest, Colonization, and Cultural Change, 950-1350, Princeton: University Press, 1994

[2] M. Legut-Pintal, A. Kubicka, "Methodological issues of metrological analysis of planned medieval towns and villages", *Acta IMEKO*, Vol. 10 No. 1, pp. 217 - 223, 2021.

[3] D. G. Kendall, "Hunting quanta", *Philosophical Transactions of the Royal Society of London*, Series A, *Mathematical and Physical Science* 276, pp. 231-266, 1974.

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Developing Macro-Raman mapping as a non-invasive method for the analysis of cultural heritage

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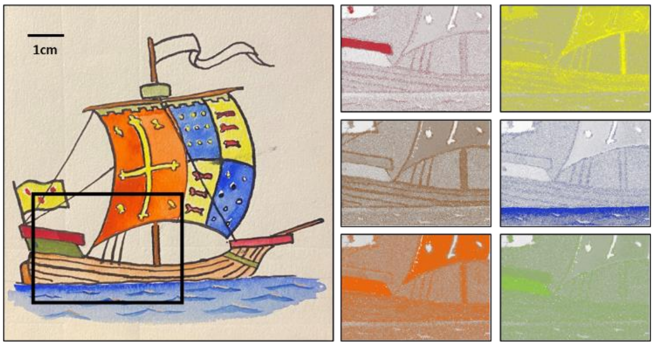

Figure 1 – Example of a watercolour painting of a ship, that was used to evalueate the macro-Raman mapping experiments, with some principal-components based Raman maps corresponding with different coloured zones in the artwork.

Raman spectroscopy has evolved into a highly regarded molecular spectroscopic technique across diverse fields such as geology, semiconductor industry, polymers, pharmacology, forensics, and archaeometry. This technique offers significant advantages in cultural heritage research, including high spatial resolution (down to 1 µm), relatively short measurement time, a non-destructive approach, and the feasibility to analyse various materials – both organic and inorganic. Raman spectra provide detailed information on molecular presence, quantity, and crystallinity, all at high spatial resolution.

This analytical method has proven particularly beneficial in art analysis as it has permitted to study of valuable objects without the need for sampling or posing other forms of physical damage. However, traditional point analysis often fails to provide comprehensive spatial information on the molecular distribution. These constraints are eliminated with Raman mapping experiments, which record an array of spectra to generate detailed molecular distribution maps. Mapping instruments are commercially available, but they are typically benchtop instruments that require mechanical and spectral stability, thus limiting its application to larger objects.

To address this limitation, a macro-mapping system is proposed for recording Raman maps of larger artifacts.[1] This point-by-point mapping approach records full spectra at each position. We introduce an innovative approach for large-scale Raman mapping, particularly useful in conservation science for visualizing artwork composition and distinguishing original from later additions. This method, combining a fiber-optics Raman spectrometer with precise positioning equipment and tailored software, enables detailed molecular imaging of large surfaces.

The first phase of a macro-Raman experiment is the experimental set-up and the recording of thousands of Raman spectra. This is a very time consuming process: not only the accumulation time per spectrum, but also accurate positioning of the probehead in front of the artwork need some time. The number of measurement points (hence the step size of the mapping grid) and the measurement time per spectrum are critical factors. The influence of the step size, as a function of the laser spot size is determined.[2] Moreover, as the Raman sensitivity can be largely different, a strategy is developed to minimise the measurement time, while maintaining sufficient response to yield quality macro-Raman maps.[3]

Moreover, it is possible to develop a sampling strategy that does not require systematic sampling of all the points in the Raman map. By observing the results of a Raman map, it can be understood that not every sampling point has equal information content: there is a distribution over the artwork, and points in rather homogeneous zones might seem less informative. Therefore, these points can be substituted by the interpolated values from neighbouring points. Therefore, the partial derivative towards the two space coordinates of the image plane can be considered as a measure for the importance of the points. However, this is an *a posteriori* approach, once all the spectra of the map are recorded. An *a priori* selection of the most interesting points can be made based on the RGB colour picture of the artwork. In this case, alignment of the artwork is critical. After data processing, the gaps in the map can be filled in by using a suitable interpolation algorithm. Thus, the procedure uses *a priori* information that is avaialble from another technique: in this case the 3 colour channels from a visual image. In a more extended approach, it is possible to use data other imaging techniques to feed the algorithm. The results from hyperspectral imaging or macro-X-ray flurescence, for instance, could be used as the source of *a priori* information.

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The second phase of a macro-Raman mapping experiment consists of the reconstruction of the image. This implies that relevant data need to be extracted from the data cube that is obained. Appropriate scaling and baseline corrections can be useful. Straightforward monovariate approaches can be used[4], such as colour coding the intensities at a specific wavenumber, or plotting the area under a curve. When studying crystalline materials or degradations, colour coding the band position can be informative. However, one can also think on more advanced approaches to colour code the pixels of the map, such as the use of multivariate techniques, including principal components analysis.

In the current paper, examples of the proposed macro-Raman mapping approaches are presented. These include both, the different possibilities to record the spectra, and some alternatives for the extraction of the images from the achieved 3-dimensional datacube. Thus, we aim to unlock the potential of macro-Raman mapping as a highly interesting tool in cultural heritage research.

[1] P. Vandenabeele, A. Rousaki, “Developing Macro-Raman Mapping as a Tool for Studying the Pigment Distribution of Art Objects,” *Anal. Chem.*, vol. 93, pp. 15390–15400, 2021.

[2] P. Vandenabeele, “Evaluating the influence of step size in macro-Raman mapping experiments,” *Eur. Phys. J. Plus*, 2024 (Submitted).

[3] P. Vandenabeele, “An Alternative Macro-Raman Mapping Algorithm, Adapting the Numbers of Accumulations,” *J. Raman Spectrosc.*, 2024 (Submitted).

[4] D. Lauwers, P. Brondeel, L. Moens, and P. Vandenabeele, “In situ Raman mapping of art objects,” *Phil. Trans. R. Soc. A*, vol. 374, 20160039, 2016.

Unveiling the Holy Sepulchre's Past: A Multidisciplinary Approach to Characterise Mortars and Wood Remains

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The Holy Sepulchre in Jerusalem stands as a powerful symbol for Christianity, marking the site of Jesus' crucifixion and burial. Understanding the construction methods and materials employed throughout its history provides valuable insights into past practices and the socio-economic context of its development. The project Cultural Heritage Active Innovation for Sustainable Society (CHANGES) presents a unique opportunity to combine archaeological and scientific expertise for a multidisciplinary investigation of recently discovered charred wood fragments embedded within mortar remains unearthed during excavations at the Basilica of the Holy Sepulchre (IAA license G-20-2022).

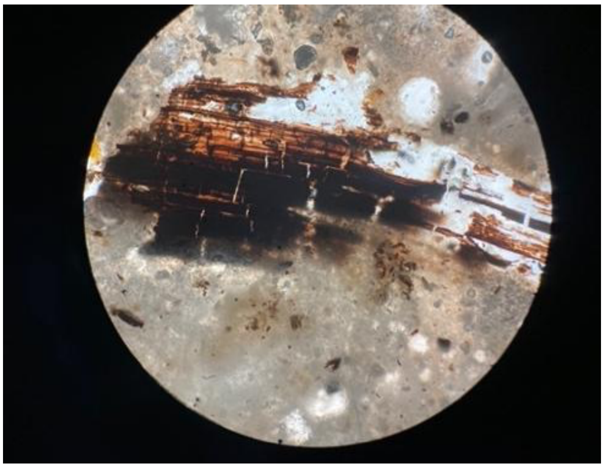

Figure 1 – Section of mortar including a charred wood fragment.

This research brings together the complementary skill sets of archaeobotany and geology. The charred wood fragments have been analysed in order to identify the specific wood species used. The goal is to identify the type of trees employed in the construction and potentially their source location.

Mortar samples from different areas of the archaeological excavation have been characterised by means of Optical Microscopy, and X-ray diffraction (XRD) analysis to identify the mineralogical composition and scanning electron microscopy (SEM) to analyse the chemical composition and the microstructure of the aggregate and the binder. By analysing the size and distribution of the charred wood fragments within the plaster, we can gain valuable insights into the intended function of the wood – whether it served as structural reinforcement, fuel for calcination or another purpose entirely (Fig. 1).

The data obtained from this multidisciplinary study will be integrated with existing archaeobotanical information from the Holy Sepulchre site. This will allow us to create a more comprehensive picture of wood utilisation in the area throughout its history. By comparing the type of wood used in the mortars with other identified plant remains, we can potentially establish patterns of wood selection and availability during the construction period. The archaeobotanical data obtained so far shows that charcoal, with 271 fragments, are the most abundant remains recovered in the excavation showing the dominance of deciduous oaks. Seeds and fruits are recovered as well and represent both cultivated and spontaneous plants.

This project represents a novel approach to investigating the Holy Sepulchre. Never before has such a combined archaeobotanical and geological approach been employed to analyse these specific materials. The findings have the potential to shed light on past construction techniques, resource management practices, and the broader environmental context surrounding the Holy Sepulchre's development. The knowledge gained will contribute to a more nuanced understanding of this sacred site's history and enhance its cultural heritage value.

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Portable X-ray CT system for on-site Cultural Heritage analysis: the case study of the *cornetto*

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X-ray Computed Tomography (CT) has emerged as a pivotal non-destructive technique in the field of Cultural Heritage diagnostics, offering 3D insights into the internal structures of a wide variety of historical and archaeological objects. The primary goal of our research is to enhance the preservation and restoration of cultural heritage by developing and implementing advanced CT systems specifically tailored to address the diverse characteristics of cultural artifacts. Our X-ray imaging group has successfully developed two compact and transportable CT setups designed for both on-site and laboratory analysis of artworks and archaeological artifacts, each operating at different resolutions to suit varying diagnostic needs.

Both CT systems are equipped with a VARIAN PS2520D flat panel detector (active area of 19.5x24.4 cm), which features a pixel size of 127µm, ensuring high-resolution imaging capabilities. The former utilizes a KEVEX PXS10 microfocus X-ray tube, which is particularly effective for the assessment of medium-sized objects. This system achieves a voxel size ranging from about 50 to 100µm, making it ideal for capturing detailed internal features of artifacts that require meticulous examination. The second configuration, on the other hand, is designed for inspecting larger objects. It employs a YXLON SMART EVO 200D X-ray tube with a 1 mm focal spot, providing a typical resolution in the range of 200 to 300µm. In both setups, the detector is placed on a X-Y stage, allowing the field of view to be extended up to 50x50 cm for the former and 150x150 cm for the latter [1].

These transportable CT systems have demonstrated their versatility and efficacy through their application to a wide range of cultural heritage objects, varying significantly in nature, shape, and size. Their compact and portable design enables on-site diagnostics, which is particularly beneficial for artifacts that cannot be easily transported due to their size, fragility, or historical value.

For instance, the medium-sized objects CT system has been employed in the detailed analysis of a curved woodwind musical instrument, dating back to the late 16th or early 17th century and preserved in the *Musei Civici di Reggio Emilia* (Fig.1a).

Cornetto is the Italian name for a European woodwind instrument from the late Renaissance and early Baroque period; it can be considered a hybrid between a woodwind (it's provided with fingerholes) and a lip-driven musical instrument (like a trumpet, it was played with a cup-shaped mouthpiece). Among the woodwinds of the period, it was the most versatile and expressive, able to imitate many features of the human voice with great agility. It existed in different forms: straight ("mute", if the mouthpiece was a part of the body of the instrument), or curved. The treble size of the curved cornetto was the most common [2].

The *cornetto* conserved in the *Musei Civici di Reggio Emilia* was probably made in the workshop of the Bassano family, the most renowned woodwind instruments makers in Europe between the 16th and 17th century. The brandmark, a pair of small, stylized silk moths, is clearly visible. The manufacturing technique of the *cornetto* was very peculiar: instead of making the bore and the body on a lathe and then curving it, it was made in two halves

Figure 1- CT scan of a woodwind musical instrument. (a) Picture of the *cornetto* (L=580 mm; D= 7.5÷26.5 mm). (b) 3D rendering of the whole object. Virtual cut along the vertical direction.

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by longitudinally cutting a single piece of wood. The inner bore was carved in the two parts along a curved profile, then the two halves were glued together and shaped with a typical octagonal section. At the end of the process, the fingerholes were drilled and the external wooden surface was covered with black-dyed leather or parchment [3-4].

No historical source describes the manufacturing process, leaving many details (e.g. tools, materials, surface treatments) unknown; however, it is possible to gain hints and clues by means of physical and chemical techniques. For this very reason, a tomographic measurement campaign has been carried out directly at the place where the instrument is stored, using our custom CT system.

To optimize performance, several technical specifications were addressed. The CT system for medium-sized objects featuring the micro-focus X-ray tube was chosen as it is the most appropriate to obtain high-resolution images [5].

Achieving a voxel size of 63.5µm required a two-step tomographic acquisition process. Initially, the first half of the instrument was scanned from its base. Subsequently, flipping the object upside down, the second half was acquired taking a few cm overlapping into account, in order to ensure a seamless virtual reconstruction during 3D rendering.

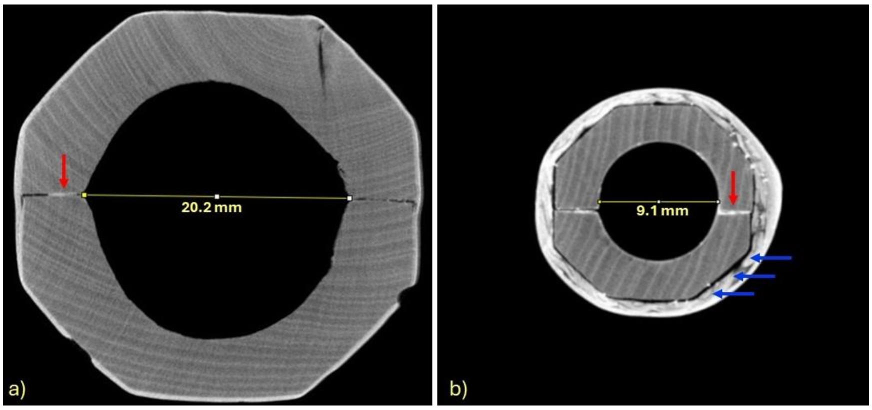

Figure 2- Axial sections of the *cornetto*, where the glue between the two wooden pieces (red arrows) and the continuity of the growth rings is clearly visible. a) Section at the base, showing an irregular shape of the inner cavity and a small crack . b) Section at the top, showing an almost circular shape and the rope used for tying the two wooden halves (blue arrows).

The capability to view the object from different angles, select specific materials to display, and make virtual cuts along different spatial planes (Fig.1b) underscores the crucial role of the tomographic technique. Furthermore, the high-quality images obtained - two-dimensional representations of the internal sections of the object - showcase the system's remarkable ability to capture fine details at various depths.

Analysing the axial sections, the continuity of the wood grain is clearly evident, confirming that the two carved parts originate from the same piece of wood. The glue used to join them is also overtly visible (Fig.2). The bore shape is irregular throughout the instrument, as it is the diameter, which is more than 2 cm at the base (Fig.2a) and decreases to less than 1 cm at the other end (Fig.2b). Figure 2b also shows the presence of the rope with which the two halves were tied together before being coated. In addition, CT scans allow for measuring the thickness of the wood at any height, which would otherwise only be possible near the base and tip of the object using a gauge. As can be seen from the horizontal sections, it also comes in different thicknesses, even within the same slice, as does the outer leather upholstery. Finally, in alignment with the visual inspection, the object exhibits signs of degradation such as wear damage, abrasions and cracks, likely resulting from inadequate storage conditions.

This study provides an in-depth examination of the practical benefits and successes of an advanced diagnostic tool used to delve into the ancient and peculiar construction techniques of a musical instrument, demonstrating through still ongoing data analysis process that this non-invasive method is indispensable for enhancing preservation and restoration strategies, as well as for creating accurate replicas for museal, musical, and scientific purposes.

[1] F. Albertin, M. Bettuzzi, R. Brancaccio, M.P. Morigi, F. Casali, "X-Ray Computed Tomography in Situ: An Opportunity for Museums and Restoration Laboratories", *Heritage 2,* 2028-2038, 2019.

[2] C.F. Gouse, "The Cornett: Its History, Literature and Performance Praxis Including a Practical Tutor for Developing Performance Skills.", Ph.D. diss., Boston University School of Fine and Applied Arts, ch.1, 1974.

[3] C. Canevari, P. Ferrari, C. Merlo, P. Modesti, "Il cornetto "africano" dei Musei Civici di Reggio Emilia. Un progetto di studio, restauro, conservazione e valorizzazione", *Lo stato dell'arte 21 – Atti del XXI Congresso Nazionale IGIIC*, 2023

[4] C. Canevari, P. Ferrari, C. Merlo, P. Modesti, "The case of the Abyssinian cornett of the Musei Civici di Reggio Emilia", *Cornetto Conference 2023 - Studientage Zink,* Schola Cantorum Basiliensis FHNW, 2023.

[5] F. Albertin, L.E. Baumer, M. Bettuzzi *et al., "* X-ray computed tomography to study archaeological clay and wood artefacts at Lilybaeum", *Eur. Phys. J. Plus 136*, 2021.

Structural Health Monitoring: A Kriging Convolutional Network Approach for Time Series Imputation

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The Structural Health Monitoring (SHM) and Non-Destructive Testing (NDT) are strategic experimental approaches for the conservation and safeguarding of historical architectonic heritage with complex soil conditions like the "Sassi" region of the Matera city in Italy. The presence of numerous underground structures and subterranean sites with aboveground masonry structures, even on multiple levels, affected by a set of "cavities" below floor level, because of strong and continuous, deep, and frenzied transformations of this part of the city, makes it indispensable to apply a monitoring and control system for the area [1]. The presence of these cavities poses a serious risk to the safety of the structures and the population of the city due to the potential collapse of buildings and structures. Nonetheless, today we increasingly see the implementation of Digital Twins (DT) [2], which, combined with the use of the Internet of Things (IoT), have determined a connection between the physical world and the digital one becoming increasingly mature and advanced, allowing much more comprehensive control over SHM systems [3, 4]. In this regard, "Data augmentation" is fundamental, since it arises from the concept of integration of the IoT and artificial intelligence (AI) paradigms, which, combined and integrated within systems and processes, can determine intelligent systems in order to use digital data much more efficiently and effectively. However, the spread of innovative 3D modelling techniques in Geographic Information System (GIS) environments, structured also on multiscale approaches for various Levels of Detail (LoD), or 3D GIS development environments that facilitate the management of multipath entities and point clouds, adopting evolved OGC standards or CityGML, is not accompanied by equally fast growth of IoT infrastructure. The basic idea is to make digital processes less dependent on human influence, which is often a limiting factor for the correct execution of processes, systematically applying AI and machine learning techniques to data acquired from IoT platforms, with the aim of "increasing" the informational power of these digital systems, including developing systems capable of anticipating or predicting certain phenomena. The ambition is to implement DT capable of updating in real time, adapting to data coming from geospatial sensors. Geospatial sensors, however, encompass a vast variety of devices that need to be able to detect numerous geographical and "non-geographical" information and characteristics of the real world.

In a SHM approaches, the sensors are installed on some area of the investigated structure in order to measure the static and dynamic structural characteristics. Environmental conditions very often can influence the experimental data acquired by the sensor, generating the noise. So, it is important to involve a "Data cleaning" activity to eliminate the anomalies in the digitally acquired data. The important challenge is often having to face the lack of correct and sufficient information to determine, with a good degree of reliability, the conditions of civil structures [5]. In this context, the aim of our research is to define an effective "Data augmentation" strategy and realize a digital process integrable into a SHM system capable of detecting and knowing how to process any anomalous trends or missing values [6] in the acquire signals. For the case study, the data related to an eight-month campaign of static monitoring of the Church of San Domenico in the Matera city (Figure 1), (from February 2019 to October 2019), were analysed [7].

Figure 1 - 3D Model of the Church of San Domenico in Matera (available at the link: https://sketchfab.com/3d-models/rilievo-chiesa-san-domenico-matera-02a6a376f50746b897f7b9720074430c)

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The research activities focused on analysing signals acquired from biaxial inclinometers and associated temperature and humidity sensors. Specifically, time series acquired from five MEMS-type biaxial inclinometers were analysed, four of which were positioned on the columns of the central nave of the church and one on the main facade of the church. After verifying the completeness and the continuity in the data, missing data were found in the time series, referring to the temporal period from May 2019 to June 2019. Another specificity recorded in the data is the presence of "out-of-range" anomalous values, which strongly deviate from the average trend of the values registered by the sensors within the acquisition period of February 14 - February 22, 2019. The removal of these anomalous data further negatively altered the quality of the time series, preventing to complete the structural monitoring with inclinometer sensors and evaluating a possible substantial variation in the static scheme of the structure. To solve this problem, it was developed an innovative process for imputing the missing data time series based on AI techniques ("Data augmentation"). Traditionally, approaches to input time series data are based on statistical methodologies, such as mean imputation, interpolation techniques (Inverse Distance Weighted – IDW [8], Kriging [9], etc.), or regression models [10].

However, these methods often fail to capture complex spatial-temporal dependencies or determine nonlinear relationships within time series. The emergence of Graph Neural Networks (GNN) [11,12] has introduced new potentials and possibilities for time series imputation [13]. The proposed method takes advantage of the topology of IoT sensors and combines the benefits of GNN [14-16] with those of the Kriging interpolation method [17,18]. The GNN is trained on samples, namely on subgraphs generated randomly and extracted from the time series data. The GNN is able to capture the complex relationships and interdependencies within sensor networks, thus determining the missing values in the time series provided. Currently, the Authors are engaged in training the GNN network and implementing the algorithm.

[1] A. Lerario, A. Varasano, "An IoT Smart Infrastructure for S. Domenico Church in Matera's "Sassi'': A Multiscale Perspective to Built Heritage Conservation" *Sustainability*, 12(16):6553, 2020. https://doi.org/10.3390/su12166553

[2] H. X. Nguyen, R. Trestian, D. To, M. Tatipamula, "Digital Twin per 5G e oltre", in *IEEE Communications Magazine*, vol. 59, n. 2, pp. 10-15, 2021. https://doi.org/10.1109/MCOM.001.2000343

[3] H. V. Dang, M. Tatipamula, H. X. Nguyen, "Cloud-Based Digital Twinning for Structural Health Monitoring Using Deep Learning", in *IEEE Transactions on Industrial Informatics*, vol. 18, n. 6, pp. 3820-3830, 2022. https://doi.org/10.1109/TII.2021.3115119

[4] D. A. T. Burgos, R. C. G. Vargas, C. Pedraza, D. Agis, and F. Pozo, "Damage Identification in Structural Health Monitoring: A Brief Review from its Implementation to the Use of Data-Driven Applications" *Sensors*, 2020. https://doi.org/10.3390/s20030733

[5] J. Zhang, M. Huang, N. Wan, Z. Deng, Z. He, J. Luo, "Missing measurement data recovery methods in structural health monitoring: The state, challenges and case study", Measurement, 2024.

[6] M. Jin, H. Y. Koh, Q. Wen, D. Zambon, C. Alippi, G. I. Webb, I. King, S. Pan, "A survey on graph neural networks for time series: Forecasting, classification, imputation, and anomaly detection" *arXiv preprint* arXiv:2307.03759, 2023.

[7] A. Varasano, A. Fraddosio, M. D. Piccioni and G. Andria, "Development and characterization of an IoT cloud platform operating in 5G network for structural health monitoring of civil constructions," 2023 IEEE International Workshop on Metrology for Living Environment (MetroLivEnv), Milano, Italy, pp. 269-275, 2023. https://doi.org/10.1109/MetroLivEnv56897.2023.10164062

[8] S. Nittel, Q. Liang, J. C. Whittier, J.C., S. de Bruin, "Real- time inverse distance weighting interpolation for streaming sensor data" *Transactions in GIS*, 2018. https://doi.org/10.1111/tgis.12458

[9] G. M. Laslett, "Kriging and splines: an empirical comparison of their predictive performance in some applications" *Journal of the American Statistical Association*, 89(426):391-400, 1994.

[10] M. Saad, M. Chaudhary, F. Karray, and V. Gaudet, "Machine learning based approaches for imputation in time series data and their impact on forecasting," *2020 IEEE International Conference on Systems, Man, and Cybernetics (SMC)*, Toronto, ON, Canada, pp. 2621-2627, 2020. https://doi.org/10.1109/SMC42975.2020.9283191.

[11] E. Šabanovič, P. Kojis, Š. Šukevičius, B. Shyrokau, V. Ivanov, M. Dhaens, V. Skrickij, "Feasibility of a Neural Network-Based Virtual Sensor for Vehicle Unsprung Mass Relative Velocity Estimation" *Sensors*, 21(21):7139, 2021. https://doi.org/10.3390/s21217139

[12] V. H. Dang, H. X. Nguyen, "Multi-task Framework for Vibration-Based Structural Damage Detection of Spatial Truss Structure Using Graph Learning" *J. Vib. Eng. Technol*, 2024. https://doi.org/10.1007/s42417-024-01325-z

[13] A. Cini, I. Marisca, C. Alippi, "Filling the g_ap_s: Multivariate time series imputation by graph neural networks" *arXiv preprint* arXiv:2108.00298, 2021.

[14] G. Dong, M. Tang, Z. Wang, J. Gao, S. Guo, L. Cai, R. Gutierrez, B. Campbel, L. E. Barnes, M. Boukhechba, "Graph neural networks in IoT: A survey" ACM Transactions on Sensor Networks, 5;19(2):1-50, 2023.

[15] G. Tsialiamanis, C. Mylonas, E. N. Chatzi, D. J. Wagg, N. Dervilis, K. Worden, "On an application of Graph Neural Networks in population-based SHM" In Data Science in Engineering, Volume 9: Proceedings of the 39th IMAC, A Conference and Exposition on Structural Dynamics 2021 2022 (pp. 47-63). Springer International Publishing.

[16] G. De Felice, A. Cini, D. Zambon, V. V. Gusev, C. Alippi, "Graph-based Virtual Sensing from Sparse and Partial Multivariate Observations" *arXiv preprint* arXiv:2402.12598, 2024.

[17] Y. Wu, D. Zhuang, A. Labbe, L. Sun, "Inductive graph neural networks for spatiotemporal kriging". In Proceedings of the AAAI Conference on Artificial Intelligence, vol. 35, pp. 4478-4485, 2021.

[18] F.M. de Souza Mello, J. L. Pereira, G. F. Gomes, "Multi-objective sensor placement optimization in SHM systems with Kriging-based mode shape interpolation" Journal of Sound and Vibration, 568:118050, 2024.

A Spectral library to support the Cultural Heritage conservation processes.

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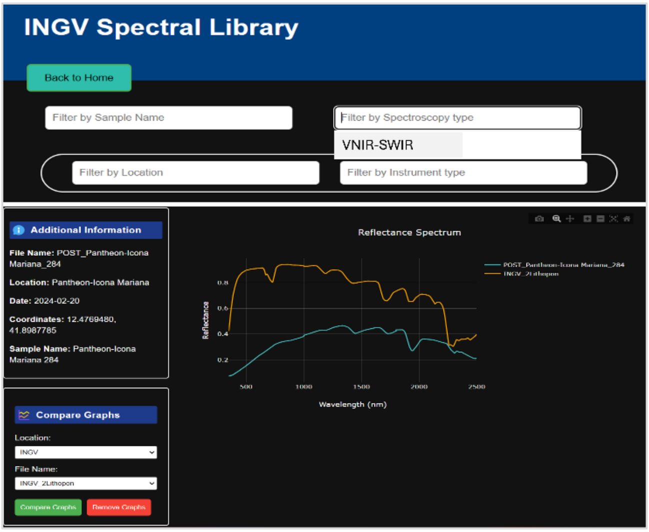

Figure 1.First steps design for DB interrogation.

Conservation of cultural heritage usually requires a multidisciplinary approach involving a variety of specialist skills and techniques. Historical and archaeological sites, painted surfaces such as frescoes and paintings are among the most common artworks to be preserved; to assess the state of conservation and to plan specific interventions, the use of non-destructive and contactless techniques is extremely relevant as allow to preserve the historical, cultural, artistic and religious significance as well as unique environmental features and cultural knowledge. Nowadays cultural heritage sites are under increasing pressure from environmental pollution and climate change, infrastructure development, mass tourism, and other threats. With the aim to preserve the cultural heritage (CH), the International Centre for the Study of the Preservation and Restoration of Cultural Property promotes the approach of "preventive conservation", defined as: "all measures and actions aimed at avoiding and minimising future deterioration or loss. These measures and actions are indirect – they do not interfere with the materials and structures of the items. They do not modify their appearance". We explored various state-of-the-art level methodologies used in Earth Sciences that could be applied to the conservation and restoration of CH, for addressing multidisciplinary environmental services to the protection, enhancement and non-invasive investigations, in the key to fostering Cultural Ecosystem Services though scientific and technical developments and leading a new level of cooperation between cultural heritage, science of life and chemistry top scientists and operators. The huge amount of data collected could represent the backbone for planning future restoration actions to preserve the CH from aging.

The digital construction of the cultural asset represents a suitable and effective method for preserving memory as well as the context in which an asset is inserted for more complete information. The Authors propose a reflectance spectral library of different artwork materials such as standard of pigments and binders, but also spectra recorded *in-situ* on frescoes and paintings enabling the possibility of identifying the relation between the absorption features and the composition of the colour used. The archived measures have been collected by means of a portable spectroradiometer acquiring reflectance values between 0.4 and 2.5 µm and are paired with additional measurements acquired by different instrumentation and by notes and metadata. Reflectance-based technique relies on the capability of pairs absorption features to specific mineral/material used to produce, in that case, the pigment composing the colour or the colour itself.

[1], [2] and [3], described the role of non-invasive spectroscopic techniques in studying and characterizing artwork materials. Indeed, the use of VNIR-SWIR surface reflectance spectroscopy is one of the most powerful tools for the identification of pigments and painted surfaces.

In this paper we present the preliminary design of a DB containing the spectral library and its main functions. The database will contain the reflectance spectra (raw and processed), sample photographs, main absorption features and the most relevant information for the knowledge of the investigated material.

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[1] Anselmi, C., Vagnini, M., Seccaroni, C., Azzarelli, M., Frizzi, T., Alberti, R., Falcioni M., Sgamellotti, (2020) A. Imaging the antique: unexpected Egyptian blue in Raphael's Galatea by non-invasive mapping. Rend. Fis. Acc. Lincei 31, 913–917 https://doi.org/10.1007/s12210-020-00960-. Doe, "My," *Jour. Immat. Sci,* vol. 6, pp. 4568–4575, 2022.

[2] A. Costanzo A, Ebolese D, Ruffolo SA, Falcone S, la Piana C, La Russa MF, Musacchio M, Buongiorno MF. Detection of the TiO2 Concentration in the Protective Coatings for the Cultural Heritage by Means of Hyperspectral Data. Sustainability. 2021; 13(1):92. https://doi.org/10.3390/su13010092Presenter, B. Collaborator, C. Collaborator, and D. Supervisor, "Long," *Jour. Immat. Sci*, vol. 45, pp. 1234–1240, 1993.

[3] Daveri A., Vagnini, M., Nucera F., Azzarelli M., Romani A., Clementi C. (2015) Visible-induced luminescence imaging: A user-friendlymethod based on a system of interchangeable and tunable LED light sources. Micro chemical Journal Volume 125,2016,Pages 130-141,ISSN 0026-265X, https://doi.org/10.1016/j.microc.2015.11.019. (https://www.sciencedirect.com/science/article/pii/S0026265X15002891)Presenter and D. Supervisor, "List," *Jour. Immat. Sci*, vol. 314, pp. 15926–15930, 1992.

Digital Iconometry: Utilising Autodesk AutoCAD and LiDAR Technology to Investigate the Badami Chalukyan and Hoysala Sculptural Art

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Iconometry, in the Indian context, refers to the study of the measurements of the sculptures and was mentioned as the *Talamana* system in the ancient scriptures (Rao 1977, Venkatraman 2011). These scriptures prescribed the guidelines to construct the sculptures in stone, and the sculptures from the temples reflect their applicability. This study aims to digitally examine the iconometry of two dynasties from India, which undertook extensive sculpture-building activity in the same region at different periods. Badami Chalukyan sculptures, carved in the cave temples around the 6th century CE - 8th century CE and Hoysala sculptures, positioned in the structural temples from the 10th century CE - 13th century CE, form the sample set of this study (Figure 1). It was noted during the literature review that the existence of research in the field of Indian iconometry is limited (Bagavandas 1980, Siromoney et al. 1980, Govindaraju 1982, Mosteller 1988, Venkatraman 2011). These studies fail to integrate digital technologies to record the measurements of the sculptures in their research since they chiefly rely on manual documentation using anthropometric tools, which increases the chances of error margin in the recording. Only one research paper (Srinivasan et al. 2017) discusses the digital iconometry of Indian sculptural art in Bronze. This brings us to the crucial aspect in the study of iconometry: incorporating digital technologies to minimise the possible margin of error that manual documentation techniques might involve. This research aims to identify the methodology/s that can generate accurate results and/or measurements to study iconometry.

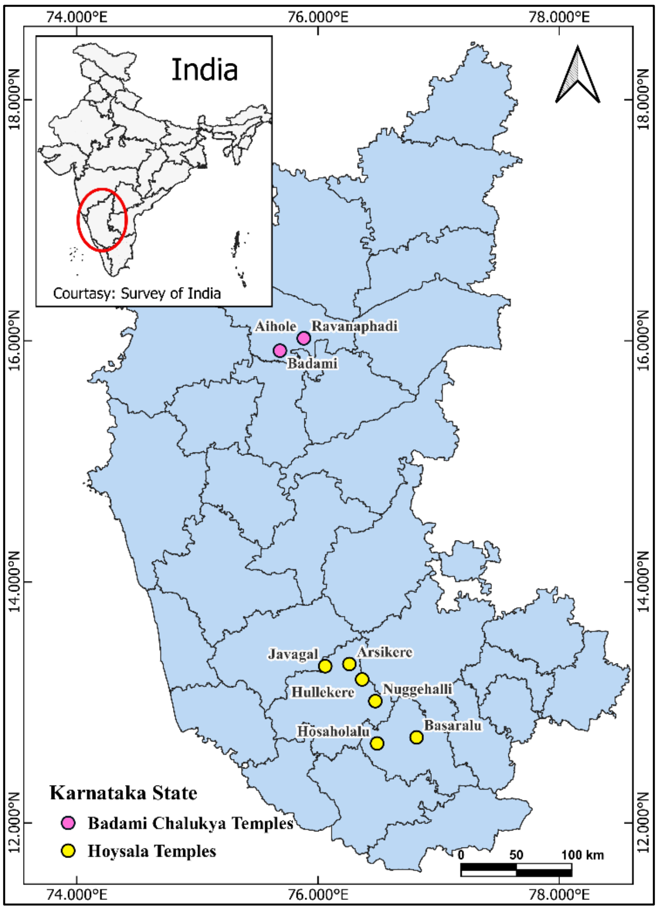

Figure 1 - Study area of the research work indicating the locations of the shortlisted sites

The map here indicates the location of the sites shortlisted for this study. The red circle in the map of India at the top left corner denotes the location of the concerned state, i.e., Karnataka, which is enlarged in blue to show the selected sites distinctly. To study Badami Chalukyan sculptures, three temple sites, namely, Durga Temple, Ravanaphadi Cave Temple, and Badami Cave Temples, were chosen, as they house the sculptures that can safely be considered as the flagship Badami Chalukyan sculptural art. Similarly, in the case of Hoysala sculptures, six temples were selected as follows: Lakshmi Narasimha Temple, Javagal; Ishvara Temple, Arsikere; Chennakeshava Temple, Hullekere; Lakshmi Narasimha Temple, Nuggehalli; Lakshmi Narayana Temple, Hosaholalu; and Mallikarjuna Temple, Basaralu. The dataset consists of a sample of sculptures from the aforementioned temples documented digitally, as it can facilitate the non-destructive recording of the sculptures and reduce the possible harm that the documentation process might unintentionally incur.

To fulfil the objectives of this research work, the following two-pronged approach was undertaken. Firstly, it was understood that the high-resolution, scaled photography could reduce the manual margin of error; hence, Autodesk AutoCAD was employed to process the images, subsequently presenting accurate measurements. Secondly, the LiDAR technology was considered as it can create 3D measurable models of the sculptures with

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minimal to zero margin of error. Both methods, eventually, will be juxtaposed, and the extracted results will be compared to ascertain a better methodology.

Currently, the fieldwork was conducted where the dimensions of the Badami Chalukyan and Hoysala sculptures were recorded using the following methodology. The high-resolution, scaled photography of these sculptures was done using a Sony Alpha ILCE-6400L 24.2 Mp Mirrorless camera, and the images were then processed in the lab using Autodesk AutoCAD software. After recalibrating the images to the appropriate scale, the measurements of the limbs of the sculptures similar to the lengths provided in the scriptures were extracted for further review. In the case of LiDAR technology, the iPhone 12 Pro model was used to record the dimensions of the sample of the sculptures. An open-source software—Scaniverse—was used to document the aforementioned sculptures and their dimensions were extracted using a methodology similar to the one mentioned earlier.

The future direction of this work involves creating a comprehensive database of the measurements extracted from both methods mentioned above. Further, iconometric analysis will be conducted using these measurements to examine any patterns in the proportions of the sculptures. The accuracy and precision of each method will be assessed and compared, and the margin of error will also be calculated to observe the efficacy of each method. The non-destructive nature of both these methods—not touching the sculptures while taking the photographs or LiDAR videos—ensures no harm to the sculptures in question. The integration of digital technology to study iconometry has the potential to transform the domain, as it can effectively reduce the margin of error in the recording, which in turn can provide accuracy in the succeeding iconometric analysis.

References

Bagavandas, M. 1980. 'Statistical Analysis of Iconometric Measurements of South Indian Sculptures'. Doctoral Dissertation, Chennai: University of Madras.

Govindaraju, S. 1982. 'Computer Analysis of Measurements of Pallava Sculptures of South India'. Doctoral Dissertation, Chennai: University of Madras.

Mosteller, John F. 1988. 'The Study of Indian Iconometry in Historical Perspective'. *Journal of the American Oriental Society* 108 (1): 99–110. https://doi.org/10.2307/603249.

Rao, T. A. G. 1977. *Talamana or Iconometry*. Memoirs of the Archaeological Survey of India, No. 3. New Delhi: Indological Book Corporation.

Siromoney, G., M. Bagavandas, and S. Govindaraju. 1980. 'An Application of Component Analysis to the Study of South Indian Sculptures'. *Computers and the Humanities* 14 (1): 29–37.

Srinivasan, Sharada, Rajarshi Sengupta, S. Padhmapriya, Praveen Johnson, Uma Kritika, Srinivasa Ranganathan, and Pallavi Thakur. 2017. 'Vijayanagara Era Narasimha Bronzes and Sculpture: Digital Iconometry'. In *Digital Hampi: Preserving Indian Cultural Heritage*, 173–87. https://doi.org/10.1007/978-981-10-5738-0_11.

Venkatraman, Subashini. 2011. 'The Iconometrical Perspective of the Early Cola Images'. *International Journal of Computer Applications* 22 (7): 8–12. https://doi.org/10.5120/2598-3612.

Various scenarios of measurements using a smartphone with LiDAR sensor in the context of integration with TLS point cloud

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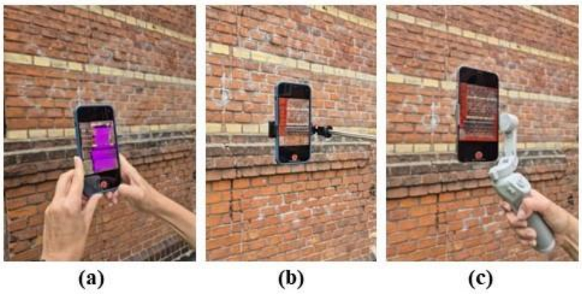

Figure 2 – Scenarios of measuring using smartphone with LiDAR sensor

The use of a smartphone with a Light Detection and Ranging (LiDAR) sensor to measure some building structures or their fragments, especially those rich in carvings and wall decorations, is becoming more and more popular. Due to the fact that a smartphone is not a typical geodetic instrument, performing measurements with this device requires a special approach and caution according to the accuracy and metric nature of the data. In general, the technology of terrestrial laser scanning of buildings is well known and used. However, there are many situations that the use of a large scanner is not possible, or additional measurements need to be performed on small parts of the object, or a point cloud must be obtained at a low cost. Then the best solution is to use a smartphone with a LiDAR sensor. In 2020, Apple launched its first smartphone equipped with a LiDAR sensor. Hence, LiDAR is becoming an increasingly accessible low-cost technology. The possibility of using a smartphone with a LiDAR sensor for various engineering applications has already been tested by scientists. For example, it has been employed in cultural heritage documentations [1], building renovation diagnostics [2] and inventories of building walls [3].

Processing point clouds acquired with a smartphone with a LiDAR sensor requires several steps to prepare full 3D data set. The first step (step 1) is data acquisition. This process generates a point cloud, which consists of individual 3D points (XYZ coordinates) with additional attributes, such as intensity and color information.

The smartphone LiDAR data are stored in a specific file format e.g., LAS, PTS,E57, XYZ, PLY. The data export format may vary depending on the app used for data acquisition. The second step (step 2) is pre-processing which is essential to clean and refine the raw LiDAR data. Common pre-processing step covers first of all removing outliers and noise points to improve data quality (down-sampling [4], optimization [5], cutting). Next, the fundamental stage in LiDAR data processing is registration and georeferencing (step 3).

The approach to registering point clouds from a smartphone with LiDAR is definitely new, because it requires special attention due to: the movement of the smartphone (change of position every second of measurement), distance from the object, high dependence on the structure of the object (flat or complex). Typically, one of two methods is used: Cloud-to-Cloud (C2C) registration or Point-to-Point (P2P) registration to align scans [6]. Whereas georeferencing the data is a process for assigning one coordinates system.

The aim of the study was to compare various scenarios of measuring using smartphone with LiDAR sensor (a smartphone held in hand – Figure 1a, a smartphone on a selfie stick – Figure 1b and a smartphone mounted on a gimbal – Figure 1c) and find the best solution for registering the obtained point cloud with referenced terrestrial laser scanning (TLS) point cloud. Measurements using an iPhone with LiDAR sensor were carried out using additional equipment dedicated to smartphones: selfie stick and gimbal. Equipment used during measurements is presented in Figure 2.It turns out that the way we obtain field data using a smartphone with a LiDAR sensor is important and affects the accuracy of point cloud integration.

[1] L. Teppati Losè, A. Spreafico, F. Chiabrando, F. Giulio Tonolo, Apple LiDAR Sensor for 3D Surveying: Tests and Results in the Cultural Heritage Domain, Remote Sens. 14 (2022) 1–30.
[2] M. Pedro, D. Calvetti, Exploring the Potential of iPad-LiDAR Tech. for Building Renovation Diagnosis : A Case Study, Buildings. 13 (2023) 1–18.
[3] W. Błaszczak-Bąk, C. Suchocki, T. Kozakiewicz, J. Janicka, Measurement methodology for surface defects inventory of building wall using smartphone with light detection and ranging sensor, Measurement. 219 (2023).
[4] C. Suchocki, W. Błaszczak-Bąk, Down-Sampling of Point Clouds for the Technical Diagnostics of Buildings and Structures, Geosciences (2019).
[5] W. Błaszczak-Bąk, Z. Koppanyi, C. Toth, Reduction Method for Mobile Laser Scanning Data, ISPRS Int J Geoinf. 7 (2018) 1–13.
[6] L. Cheng, S. Chen, X. Liu, H. Xu, Y. Wu, M. Li, Y. Chen, Registration of laser scanning point clouds: A review, Sensors. 18 (2018).

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Radiological and structural analysis of materials used in cultural heritage in the Campania region, Southern Italy

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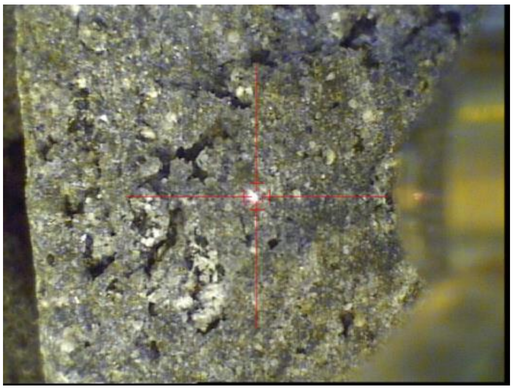

Figure 1 - XRF analysis (elemental chemical composition) view sample

The term cultural heritage encompasses a variety of scientific disciplines and professional expertise, with many interdisciplinary scientists, such as conservators, archaeologists, historians, artists and material scientists, collaborating in one way or another to develop a unified conceptual framework for cultural heritage conservation [1-3]. The development of techniques for the determination of various parameters is essential for the characterisation and measurement of dynamic processes within a material [4]. There are many studies on different techniques and interdisciplinary studies on the protection of cultural heritage in Italy [5-6]. The Campania region in southern Italy, known for its rich cultural heritage and historical buildings, employs a variety of local materials in its construction. These materials not only provide structural integrity but also contribute to the aesthetic and historical significance of the buildings. Understanding the structural composition and radioactivity of building materials used in the Campania region's cultural heritage is essential for preservation and public safety.

These materials, ranging from volcanic rocks like tuff and basalt to sedimentary rocks like limestone, not only define the architectural beauty of southern Italy but also ensure the durability and historical integrity of its structures.

The analyzed samples provide a comprehensive look at various rock and mineral types, revealing insights into their geological and historical significance. The use of advanced techniques, including a CANBERRA standard electrode coaxial detector for radioactivity measurements, and sophisticated methods such as X-Ray Fluorescence spectroscopy (XRF), Fourier Transform Infra-Red spectroscopy (FTIR), X-ray diffraction (XRD), textural analysis by Hg intrusion porosimetry, and scanning electron microscopy (SEM), enabled precise identification of elemental compositions and mineral origins. For all samples, radon emanation and exhalation rates were determined using the RAD7 detector.

These findings are crucial for archaeological studies as they help in understanding the materials used in ancient constructions and artifacts, providing a link between historical usage and modern-day analysis techniques. Understanding the structural composition and radioactivity of these building materials is essential for the preservation and safety of the rich cultural heritage in the Campania region.

[1] K. Curran and N. Zimmermann, "The dynamics of collaboration in heritage science", *Studies in Conservation*, vol. 67(1-2), pp.136-149, 2022.
[2] D. Anglos, "Laser-induced breakdown spectroscopy in heritage science",. *Physical Sciences Reviews*, *4*(7), 20180005, 2019.
[3] M. Magdy, "X-Ray Techniques Dedicated to Materials Characterization in Cultural Heritage", *Chemistry Select*, *8*(33), e202301306, 2023.
[4] L.L. Vergeynst, M. Dierick, J.A. Bogaerts, V. Cnudde, & K. Steppe, "Cavitation: a blessing in disguise? New method to establish vulnerability curves and assess hydraulic capacitance of woody tissues", *Tree Physiology*, vol. *35*(4), pp. 400-409, 2015
[5] S.Akozcan Pehlivanoglu, S. Mancini, N. Todorovic, S. Ozden, & M. Guida, "Assessment of the natural radioactivity content in typical building materials employed in the Italian cultural heritage", IMEKO TC-4 International Conference on Metrology for Archaeology and Cultural Heritage Rome, Italy, October 19-21, 2023.
[6] S. Mancini, N. Todorovic, S. Akozcan Pehlivanoglu, D. Guida, A. Cuomo & M. Guida, "Monitoring of indoor Radon in historical heritage buildings by means of passive and active methods. A case study", IMEKO TC-4 International Conference on Metrology for Archaeology and Cultural Heritage Rome, Italy, October 19-21, 2023.

Effect of UV-A and UV-B radiation on silicate-based paints: fresco and nano-silica-based mock-ups

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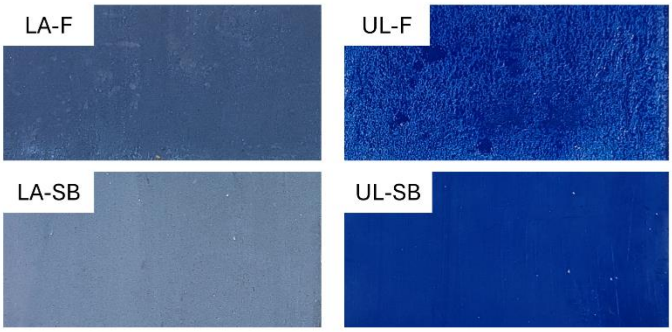

Figure 1 – Paint mock-up before UV accelerated aging. LA (lapis lazuli), UL (blue ultramarine), F (fresco painting) and SB (nano-sized silica chromatic reintegration).

In recent decades, there has been a growing interest in artwork degradation within the archaeological field. Wall paintings are often prone to decay since their durability is markedly influenced by both the intrinsic properties of the materials that compose the paint layer (pigments and/or binder), and the surrounding environment. Wall paintings are sometimes preserved in museums under stable conditions. However, historical wall paintings are generally inseparable from the building in which they are located and, if they are not at risk, they are preserved *in situ* as they are part of the identity of a culture, a country or a population. When outdoor-exposed, their conservation is highly dependent on their surrounding environment and on the action different environmental agents (solar irradiation, humidity, soluble salts, etc.). Among them, one of the primary causes which induce degradation processes is ultraviolet (UV) radiation due to the intensive photons that cause photo-chemical damage through molecular rearrangements of the compounds within the paint layer [1]. Therefore, knowledge of the interaction among paintings and UV radiation is essential for understanding the degradation mechanism [1].

In conservation and restoration of cultural heritage, not only the deterioration processes of historical paintings (e.g. frescoes) is of interest. Knowing how the restoration materials (e.g. binders and pigments used for chromatic reintegration) behave is also important to assess their resistance and stability over time [2]. In this experimental study, two sets of paint mock-ups (Figure 1) were manufactured with i) pigments applied *a fresco* (F hereinafter), following historical recipes, and ii) pigments mixed with a binder for chromatic reintegration (SB hereinafter). The binder used was an aqueous colloidal dispersion of nano-sized silica (Nano Estel®, NE hereinafter), chosen with the purpose of applying a chromatic reintegration not only resistant to photodegradation, but also environmentally friendly and minimally toxic for humans. After evaporation of water (as the solvent for dispersing NE), the silica nanoparticles aggregate to form a silica matrix or xerogel, similarly to that obtained for ethyl silicate consolidants, giving place to a chemically stable surface. Two silicate pigments of similar nature but different origin (natural and synthetic) were selected for this study: lapis lazuli ($3NaAlSiO_4{\cdot}NaS_3$) and blue ultramarine ($Na_7Al_6Si_6O_{24}S_3 + Al_2Si_2O_5(OH)_4$). The colour on both pigments comes from the encapsulation of specific sulphur species (chromophores) [3]. That is S_3^- (blue) and S_2^- (yellow) radical anions, traceable by spectroscopic techniques [3]. Both chromophores are contained in the pigments, but with greater quantity of the blue S_3^-, which was taken into account in this research.

The objective of this study was to investigate how these paintings behave upon accelerated ageing under UV radiation. Thus, paint mock-ups were subjected to artificial UV-A (315-400 nm) and UV-B (280-315 nm) radiations for six months (total exposure 4380 h). Three 300 W OSRAM Ultra Vitalux UV lamps were used for each test: UV-A (13.6 W) and UV-B (1.3 W). The lights were placed vertically, 10 centimetres away from the paint surfaces, so that every mock-up received the same amount of light. On the mock-up surface, the highest temperature that was attained was 40 ± 1 ºC. Colour variations were monitored by spectrophotometry every 30 days and gloss was evaluated before and after exposition. Molecular changes were studied by Attenuated Total Reflectance Fourier Transform Infrared spectroscopy (ATR-FTIR). A study of the surface was performed with stereomicroscopy and Scanning electron microscopy and Energy Dispersive Spectroscopy (SEM-EDS) was applied to find microtextural differences between the reference and the aged samples.

As general results, the painting technique (F or SB) and the origin of the pigment (natural or synthetic) determined the behaviour of the paint mock-ups towards the different UV radiations. On the one hand, lapis lazuli in F paint was more susceptible to UV radiation showing higher colorimetric changes (ΔE_{ab}*: around 11 CIELAB units) than their synthetic analogues; while for the blue ultramarine-based paintings, greater changes were observed in SB mock-up (ΔE_{ab}*:

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around 10 CIELAB units). With regard to the type of radiation (UV-A or UV-B), no major differences were observed throughout the 6-month colour monitorization, except for the case of blue ultramarine SB mock-up where UV-B radiation clearly caused higher colorimetric changes since the first month of exposure. As for the molecular characterization, the presence of silanol (Si–OH) by FTIR analysis around 3500 cm^{-1} (stretching vibration) and 1645 cm^{-1} (bending vibration) might suggest that polymerization of NE was not fully complete [4,5], even though these Si–OH bands can also be related to other mineral phases present in the pigments as impurities (e.g., muscovite in lapis lazuli and kaolinite in blue ultramarine). This broad band showed slightly higher intensity in blue ultramarine SB mock-up after UV-B radiation (Figure 2). Silica gel (SiO_2) bands around 1070 cm^{-1} were generally present with higher intensity after radiation exposure, especially in blue ultramarine SB paints. The chromophore S_3^- molecule bands (540-585 cm^{-1}) did not change in form, regardless of the radiation, painting technique and pigment nature. Finally, no physical changes were observed by SEM-EDS.

Overall, UV-B radiation caused higher colour variations after longer period of UV exposure. Pigment susceptibility depended on the painting technique and on the UV radiation. Results suggest that the high colorimetric changes, especially in LA-F and UL-SB, were due to molecular rearrangements and not related to microtextural changes.

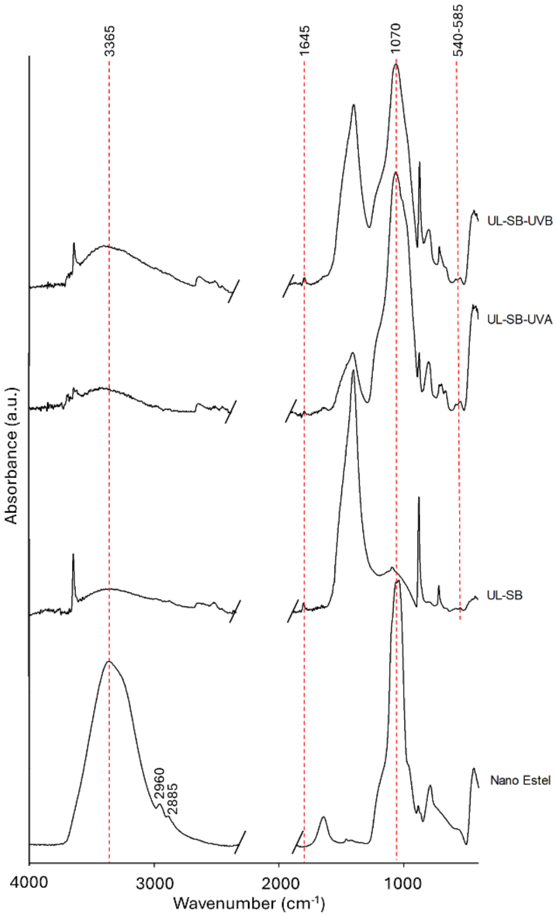

Figure 2 – ATR-FTIR spectra of Nano Estel and blue ultramarine (UL) chromatic reintegration (SB) mock-ups before and after UV radiation.

[1] Magdy, M. “Insights into the Effect of UV Radiation on Paintings: A Mini-Review for the Asset Preservation of Artworks”, *ARCS*, vol. 3(2), pp. 46-54, 2022.

[2] Jiménez-Desmond, D., Pozo-Antonio, J. S., and Arizzi, A. “Present and future of chromatic reintegrations of wall paintings”, *J. Cult. Herit*., vol. 67, pp. 237-247, 2024.

[3] Chukanov, N. V., Sapozhnikov, A. N., Shendrik, R. Y., Vigasina, M. F., and Steudel, R. “Spectroscopic and crystal-chemical features of sodalite-group minerals from gem lazurite deposits”. *Miner*, vol. 10(11), 1042, 2020.

[4] Pozo-Antonio, J. S., Otero, J., Alonso, P., and i Barberà, X. M. “Nanolime-and nanosilica-based consolidants applied on heated granite and limestone: Effectiveness and durability”. *Constr. Build. Mater.*, vol. 201, pp. 852-870, 2019.

[5] Barberena-Fernández, A. M., Carmona-Quiroga, P. M., and Blanco-Varela, M. T. “Interaction of TEOS with cementitious materials: Chemical and physical effects”. *Cem. Concr. Compos*., vol. 55, pp. 145-152, 2015.

Solar loading infrared thermography and signal processing techniques for the non-invasive inspection of precious artifacts

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Figure 1 – Painting on canvas exposed to solar loading

Heat can lead to thermal tensions, moisture reductions, and even chemical reactions within paintings that can damage both the paint layer and the support, sometimes even irreversibly. Excessive heat can damage the support by causing creases, warping, weakening and breaking of the fibers. It can also damage the paint layer by causing cracking, losses and in worse circumstances it can cause paint bubbling and blistering.

When a painting is continually exposed to sunlight, the colors and details of the artwork can fade and the varnish can begin to discolor much more quickly. However, if compared to the thermal shock provoked by flash lamps usually used in active approach of infrared thermography (IRT), the use of solar cycle is highly desirable [1, 2, 3], also because it is not necessary to expose the painting surface directly to the solar rays in order to generate a sufficient ΔT for heat conduction through the material from a primitive radiation. Also, if continuously or routinely heated, some paints can start chalking when exposed to UV light, while the binders and varnishes can embrittle and crack. Indeed, severe sunlight damage can be irreversible. Similar aspects happen in documents, manuscripts, bound materials and ephemera. Common types of chemical and biological damage include fading or darkening/discoloration of pages (due to light damage and acidity). Darkening of pages due to acidity often shows up first on the edges of the textblock, which are more exposed to pollutants and climate fluctuations.

Therefore, a useful balance between indirect lighting and optimal time of thermal exposure is "a way to run" in the thermographic research field dedicated to artworks inspection, in which the defect detection is the goal of the experimental campaign. Defect detection in terms of the shape of the thermal imprints projected on the surface due to conduction and convection mechanisms may be improved thanks to the post-processing phase of thermograms. Considering the authors' experience in ancient and immovable structures recorded into the long-wave infrared spectrum (LWIR) by thermal cameras, however, the results coming from the post-processing phase may be enhanced in case a clever pre-processing is applied to raw thermal images initially [4]. In this sense, Fast Iterative Filtering (FIF) and its derived algorithms, like Multivariate FIF (MvFIF) [5,6], play a fundamental role in pre-processing the collected thermograms to reduce the impact of transient temperature oscillations from the artifact surface due to, for instance, the passage of clouds. These signal processing techniques have been developed in the last ten years with the goal of identifying, extracting and/or removing non-stationary oscillations contained in real-life signals. In this poster, the authors will present the application of these techniques to the analysis of paintings, Fig. 1, and books. The authors will show how it is possible to remove temperature oscillations in time (Fig. 2), to improve the identification of possible defects or anomalies hidden under the surface of these artifacts. Also, the main current activities of the bilateral

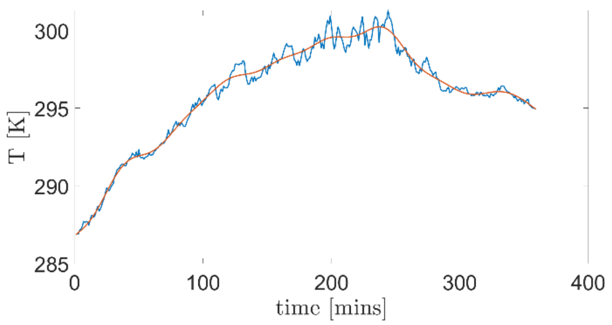

Figure 2 – Example of pre-processing via MvFIF

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Italy-China research project for “science and technology cooperation” (Italian unit: University of L’Aquila, P.I. Prof. S. Sfarra; Chinese unit: Harbin Institute of Technology, P.I. Prof. H. Zhang), titled “sCHans – Solar loading infrared thermography and deep learning teCHniques for the noninvAsive iNSpection of precious artifacts” (promoted by the Italian Ministry of Foreign Affairs and International Cooperation and co-financed by the Ministry of University and Research, grant number PGR02016) will be shown in the poster thanks to a clear block diagram.

[1] S. Klein, . Heib, & H. G. Herrmann “Estimating thermal material properties using step-heating thermography methods in a solar loading thermography setup”. Applied Sciences, 11(16), 7456, 2021.
[2] K. Tu, C. Ibarra-Castanedo, S. Sfarra, Y. Yao, & X. P. Maldague. “Multiscale analysis of solar loading thermographic signals for wall structure inspection”. Sensors, 21(8), 2806, 2021.
[3] G. Washer, R. Fenwick, & N. Bolleni. “Effects of solar loading on infrared imaging of subsurface features in concrete”. Journal of Bridge Engineering, 15(4), 384-390, 2010.
[4] S. Sfarra, A. Cicone, B. Yousefi, C. Ibarra-Castanedo, S. Perilli, X. Maldague. “Improving the detection of thermal bridges in buildings via on-site infrared thermography: the potentialities of innovative mathematical tools”. Energy & Buildings. Volume 182, Pages 159-171, 2019.
[5] S. Sfarra, A. Cicone, B. Yousefi, S. Perilli, L. Robol, X.P.V. Maldague. “Maximizing the detection of thermal imprints in civil engineering composites via numerical and thermographic results pre-processed by a groundbreaking mathematical approach”. International Journal of Thermal Sciences, Volume 177, 107553, 2022.
[6] A. Cicone and E. Pellegrino. Multivariate Fast Iterative Filtering for the decomposition of nonstationary signals. IEEE Transactions on Signal Processing, Volume 70, pages 1521-1531, 2022.

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Comparing the Performance of Expert Paleographers and Capsule Networks in Separating Overlapping Greek Characters in Palimpsests

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The main goal of this work is to compare the performance of expert paleographers and deep learning models in separating overlapping Greek characters. Palimpsests, which are documents where previous text has been erased and overwritten with new text, often contain overlapping text, complicating the task of distinguishing the original under-text from the over-text. For paleographers, the ability to separate these layers is crucial for accurate textual and historical analysis. Previous studies have explored the use of deep learning to automate this separation [1, 2], but it remains unclear whether these models can match or exceed the expertise of human specialists, particularly in complex scenarios involving heavily degraded or intricately layered texts.

In this study, we employ a Capsule Network (CapsNet) [3], a type of neural network that has demonstrated superior performance in reconstructing overlapping digits on the MultiMNIST dataset. Capsule Networks are known for their ability to preserve spatial hierarchies in the data, making them particularly suited for tasks involving intricate and overlapping structures. To create a relevant dataset, we superimposed individual handwritten Greek characters to simulate the conditions found in historical palimpsests (Figure 1). The CapsNet model was trained on this dataset to reconstruct the two overlapping characters, learning to differentiate and extract each character accurately.

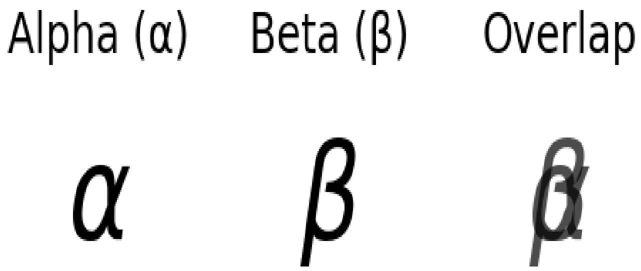

Figure 1 – The Greek characters α and β and the overlapping.

Subsequently, the same task was presented to a group of expert paleographers specializing in Greek scripts, who were asked to separate the overlapping characters. Their performance was documented and compared to that of the CapsNet model. Additionally, we explored a collaborative approach where the model's predictions were used as a starting point for the paleographers, aiming to evaluate the potential benefits of combining human expertise with machine intelligence. This comparison aims to identify the strengths and weaknesses of deep learning models in this context and to pinpoint specific cases where human expertise surpasses automated methods. Our findings will provide valuable insights into the areas where machine learning models need improvement and will guide future data collection efforts, focusing on edge cases where current models struggle. This study not only advances the field of automated text separation but also highlights the enduring importance of human expertise in the preservation of historical texts.

[1] A. Starynska, D. Messinger, and Y. Kong, "Revealing a history: palimpsest text separation with generative networks," *International Journal on Document Analysis and Recognition (IJDAR)*, vol. 24, no. 3, pp. 181–195, 2021.
[2] M. Perino, M. Ginolfi, A. C. Felici, and M. Rosellini, "A deep learning experiment for semantic segmentation of overlapping characters in palimpsests," *Proceedings of the 2022 IMEKO TC4 International Conference on Metrology for Archaeology and Cultural Heritage*, pp. 825–829, 2023.
[3] S. Sabour, N. Frosst, and G.E. Hinton, "Dynamic routing between capsules," *Advances in neural information processing systems*, pp. 3856-3866, 2017.

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Illuminating the Past: Integrative 3D Mapping and Chemical Analysis of Prehistoric Cave Art in Sicily and Malta

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Abstract – **This paper examines the application of 3D digital imaging techniques—terrestrial laser scanning, structured light 3D scanning, and digital photogrammetry—in documenting prehistoric cave sites in Sicily and Malta, specifically the Genovese Cave on Levanzo Island and Għar Ħasan in Birżebbuġa. These non-invasive technologies produce detailed three-dimensional models of cave interiors, capturing the intricate details of ancient rock art. The study highlights the precision of these methods in preserving, analyzing, and making the sites accessible for public and academic engagement through virtual reality platforms. Additionally, it discusses new findings from portable X-ray spectrometry, offering insights into the chemical composition of pigments used in the Genovese Cave paintings. This research underscores the significant role of modern 3D imaging in archaeological documentation and public heritage presentation, enhancing both scientific understanding and cultural appreciation.**

I. INTRODUCTION

3D digital imaging techniques, such as terrestrial laser scanning, structured light 3D scanning and digital photogrammetry have become pivotal in mapping prehistoric caves adorned with paintings and engravings. These technologies create highly accurate, three-dimensional models of cave interiors, capturing minute details and textures of the rock surfaces. While terrestrial laser scanning offers metrological accuracy for production of technical visualizations and light 3D scanning allows to map the fading traces of prehistoric rock art, digital photogrammetry contributes to generating realistic virtual environment for desktop or VR based public outreach experiences. Such a combined non-invasive approach not only aids in the preservation and documentation of fragile archaeological sites but also enables detailed analysis and accessibility for researchers and the public through virtual-based recreational experiences. This paper primarily focuses on best practices in the application of such an approach on one Sicilian and one Maltese prehistoric cave site, the Genovese Cave on Levanzo Island (Sicily) and Għar Ħasan at Birżebbuġa, Malta. Additionally novel data from portable x-ray spectrometry of the painted rock art of the Genovese Cave will also be discussed.

II. MATERIALS

The Genovese Cave (Cala dei Genovesi) on the Sicilian islet of Levanzo (Fig. 1) is an important archaeological and paleo-art site, showing evidence of use from the Paleolithic through the Neolithic periods. This site is noted for its petroglyphs and painted figures that date back to the Late Glacial period, around 14,000-12,500 years ago [1] [2]. The artworks, including naturalistic animal depictions and stylized human figures, reflect artistic shifts over millennia and suggest a continuity in artistic expression rather than abrupt cultural changes [3] [4]. This cave, a rare example of Ice Age art in Italy, offers a view into the integration of various artistic styles across different periods. The naturalistic images from the Upper Paleolithic era coexist with later, more schematic paintings, indicating a long-standing tradition of artistic evolution. Additionally, environmental factors like rising sea levels influenced the cave's art, altering both its content and placement over time [5]. In Malta, Għar Ħasan cave, situated along the southeastern coast near Birżebbuġa (Fig. 2), has also garnered archaeological interest. Early studies in the 1860s by naturalist Andrew Leith Adams and later explorations in the 1980s by Emanuel Anati revealed pigments depicting large bovids and deer-like animals, suggesting a

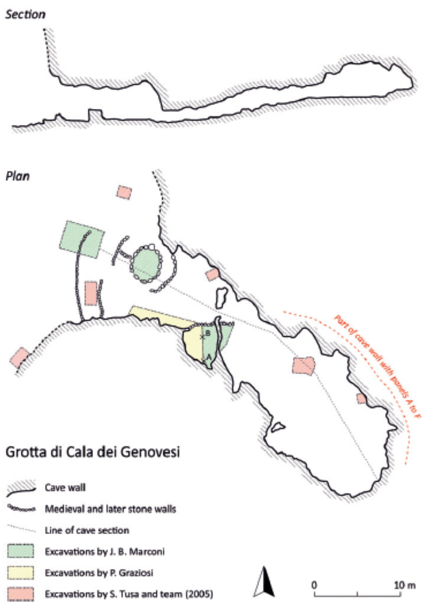

Fig. 1: Section and plan of the Genovese Cave (Tusa et alii 2013).

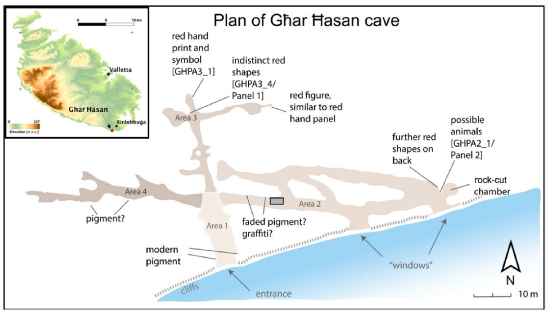

Fig. 2: Plan of Għar Ħasan cave (Guagnin et al., 2023)

Paleolithic origin. Despite its significance, the cave's accessibility has led to environmental damage and graffiti, compromising the integrity of its rock art. Both caves face conservation challenges. The Genovese Cave, as a private property like other significant Paleolithic sites such as Lascaux and Chauvet, suffers from visitor-induced alterations to its micro-climate [6]. To mitigate these effects and preserve the site, a 3D model has been created to simulate the cave's interior, allowing for a virtual public experience while protecting the actual site. Għar Ħasan's geomorphological features, shaped by the Magħlaq Fault, have created a unique network of passages that enhance its archaeological preservation potential [7] [8]. Yet, the deterioration of its rock art has led to restricted access to protect what remains. Moreover, the cave's lore, involving a tragic love story from the 12th century, adds to its cultural significance. Both the Genovese and Għar Ħasan caves exemplify the complex interplay between nature, history, and human activity, highlighting the need for advanced conservation techniques and responsible public engagement. These sites connect us to the artistic and cultural landscapes of prehistoric Europe, offering invaluable insights into our ancestral heritage while also requiring careful management to ensure their preservation for future generations.

III. METHODS

The Genovese Cave at Levanzo was extensively documented using 3D digitization techniques, utilizing a Faro Focus S150 HDR for a total of 11 scans (Fig. 3). Varied lighting conditions, combining natural and artificial sources, were managed during the survey.

Fig. 3: Genovese cave, terrestrial laserscanning (TLS) mapping

Additionally, digital photogrammetry mapping focused on the walls with paintings and engravings was executed using a 24.2MP DSLR Camera, capturing 800 high-resolution images. A Breukmann smartSCAN 3D-DUO structured light 3D scanner played a crucial role in documenting the cave art with a resolution of 0.35 mm per pixel, allowing detailed examination of the artworks and their condition (Fig. 4). Key analytical work included a portable X-ray fluorescence spectrometry (pXRF) study of about 100 painted figures to determine the chemical composition of the pigments used (Fig. 5). This non-destructive technique revealed significant details about the materials, such as high iron content in red figures indicating the use of ochre, and variations in elements like calcium and strontium in white spots, suggesting different compositional characteristics. Meanwhile, Għar Ħasan cave's 3D documentation involved terrestrial laser scanning with a Faro Focus S150 HDR (Fig. 6) under challenging conditions due to the cave's complex environment, including dimming light and uneven floor topography. This process produced a detailed 30,000,000-point point cloud model, focusing primarily on the accessible areas of the cave. This advanced mapping technique provided critical data for understanding the spatial and artistic nuances of this historically rich site, aiding in both preservation efforts and academic study.

Fig. 4: Genovese cave, light structured 3D scanning mapping (Tusa et alii 2013).

Fig. 5: pXRF study of the pigments of painted figures at the Genovese cave

Fig. 6: Għar Ħasan, terrestrial laserscanning (TLS) mapping

IV. DISCUSSION

The processing of 3D data from the Genovese Cave mapping produced its first metrologically accurate technical plan and related section views (Figs. 7-8). Despite aberrations from varied lighting, the dense point cloud retained a high level of realism in color mapping. The digital photogrammetry-based 3D model significantly enhanced the chromatic authenticity of the painted rock art (Fig. 9). However, neither the point cloud nor the photogrammetric models could capture the fading traces of the engravings, making structured light 3D scanning essential for documenting images on six panels of the cave's north-eastern wall.

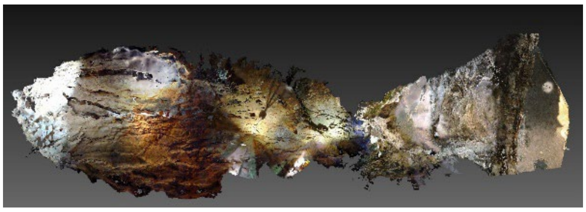

Fig. 7: Genovese cave, point cloud model, map

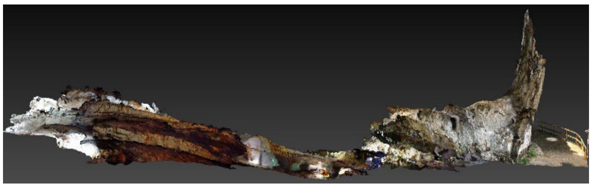

Fig. 8: Genovese cave, point cloud model, section view

pXRF analysis revealed that ochre was used for red figures, charcoal for black, and calcium carbonate, derived from dissolved limestone deposits by groundwater, for white figures. This analysis helps understand the material composition and techniques used by ancient artists.

Fig. 9: Genovese cave, digital photogrammetry 3D model

At Għar Ħasan, initial 3D mapping was intended to be followed by further campaigns, but these were put on hold due to the global pandemic. The initial documentation provided updated technical visualizations, correcting the morphological and metrological inaccuracies of the only previously known plan. These new section views offered better perspectives on the cave's vertical development (Figs. 10-12). However, due to the cave's dim lighting, the point cloud model lacked color information, complicating the identification of rock art during virtual studies. This initial effort underscores the importance of continuous documentation and the challenges posed by environmental conditions in archaeological conservation.

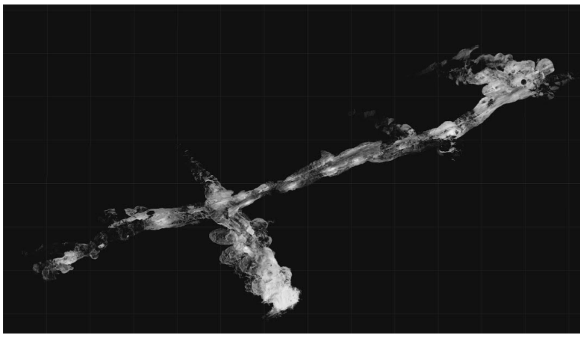

Fig. 10: Għar Ħasan, point cloud model, map Area 1 and part of Area 4

Fig. 11: Għar Ħasan, point cloud model, section view

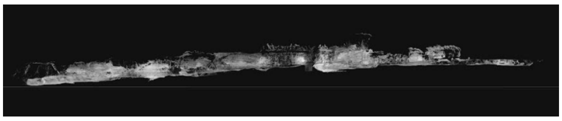

Fig. 12: Għar Ħasan, point cloud model, section view

V. CONCLUSIONS

In conclusion, the use of 3D technology not only facilitated a more accurate documentation of the rock art but also served as a crucial tool in assessing the preservation state of the engravings, revealing the impacts of environmental conditions and human interactions over the decades. This methodological approach represents a significant advancement in the field of rock art research, offering a new standard for the study and conservation of prehistoric artworks.

REFERENCES

[1] Di Maida, G, and M Mussi. 2018 [2022]. "The Sicilian Lateglacial Rock Art and Graziosi's Mediterranean Province." *Die Kunde N.F.* 69, pp. 83-98.

[2] Di Maida, G., M.A. Mannino, J. Zilhão, D.L. Hoffmann, M. García-Diez, A. Pastoors, C.D. Standish, et al. 2020. "Radiocarbon and U-Series Age Constraints for the Lateglacial Rock Art of Sicily." *Quaternary Science Reviews* 245 (October). https://doi.org/10.1016/j.quascirev.2020.106524.

[3] Tufano, E., Tusa, S., Mannino, M.A. and Thomas, K.D., 2012. Resoconto preliminare delle indagini stratigrafiche alla Grotta di Cala del Genovese. *Resoconto preliminare delle indagini stratigrafiche alla Grotta di Cala del Genovese*, pp. 391-402.

[4] Tusa, S., Di Maida, G., Pastoors, A., Piezonka, H., Weniger, G.C. and Terberger, T., 2013. The Grotta di Cala dei Genovesi–New studies on the Ice Age cave art on Sicily. *Praehistorische Zeitschrift*, *88*(1-2), pp. 1-22.

[5] Presti, V.L., Antonioli, F., Palombo, M.R., Agnesi, V., Biolchi, S., Calcagnile, L., Di Patti, C., Donati, S., Furlani, S., Merizzi, J. and Pepe, F., 2019. Palaeogeographical evolution of the Egadi Islands (western Sicily, Italy). Implications for late Pleistocene and early Holocene sea crossings by humans and other mammals in the western Mediterranean. *Earth-science reviews*, *194*, pp. 160-181.

[6] Bruyere, V., 2022. Lascaux IV, Chauvet II, Planet B. *SubStance*, *51*(1), pp. 88-102.

[7] Gauci, R. & Scerri, S. 2019. A synthesis of different geomorphological landscapes on the Maltese Islands. *In:* Gauci, R. & Schmebri, J. A. (eds.) *Landscapes and Landforms of the Maltese Islands.* Switzerland: Springer.

[8] Guagnin M., Haburaj V., Groucutt H. S., Hoelzmann P., Gauci R., Vella N.C., Parisi C., Cassar M., Cassar Y., Asciak G., Scerri E. (2023), Evaluating possible prehistoric cave art in the central Mediterranean: Analyses of pigment traces and identification of taphonomic processes at Għar Ħasan, Malta, *Journal of Archaeological Science: Reports* 47, 103815, https://doi.org/10.1016/j.jasrep.2022.103815

Monitoring of thermal and colorimetric changes in outdoor exposed acrylic and alkyd paints: influence of environment, paint composition and wall orientation.

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Contemporary muralism has become a significant artistic movement in urban centres, serving as a tool for social and political communication. Artists explore themes such as cultural identity and social justice, creating murals that transform cities into open-air museums. However, these murals face deterioration due to exposure to environmental factors like sunlight and precipitation, and pollutants leading to discoloration and material losses [1]. In addition, temperature fluctuations can cause cracking and flacking of the paint layer because of the contraction and expansion of the materials (both, substrate and paint). Previous research highlights the decisive effect of solar radiation interaction with paint components (pigment and binder) as a crucial factor in the alteration process [2] being consequently very important the influence on the durability of the murals of the wall orientation. Despite rapid environmental deterioration of these murals, there is a lack of studies on preventive conservation strategies, such as protective coatings. Moreover, at the best of our knowledge, there are no studies that monitor the effect of environmental parameters (such as temperature) on the colorimetric changes that have occurred on the decorated walls. One of the difficulties of studies based on the analysis of environmental parameters is data collection, so that long-term monitoring requires extensive resources and high costs. However, machine learning (ML) techniques applied to the analysis of these environmental conditions, are able to create models to estimate, among other parameters, surface temperatures of murals. Once calibrated, these models can simulate temperature behaviours in different locations, simplifying the methodology, speeding up studies, and reducing costs [3,4].

This paper presents the initial phases of the SmArt project, which aims to develop a simulation system for the sustainable conservation of contemporary murals. The project focuses on creating an ML model to determine temperature distributions on paint mock-ups outdoor exposed and their relationship with their colorimetric changes, assessing murals' sensitivity in different locations. More in detail, key objectives include: (1) influence of the paint composition (alkyd and acrylic paints) on the deterioration level produced after exposure; (2) influence of the orientation of the wall on the deterioration level; (3) determining surface temperatures of murals through ML models and relating these to deterioration, and (4) evaluating the effectiveness of a commercial UV protective coating on painting murals. Understanding atmospheric impacts on murals will inform decisions on wall selection and maintenance strategies, helping prevent deterioration and optimize resources for preserving these artworks.

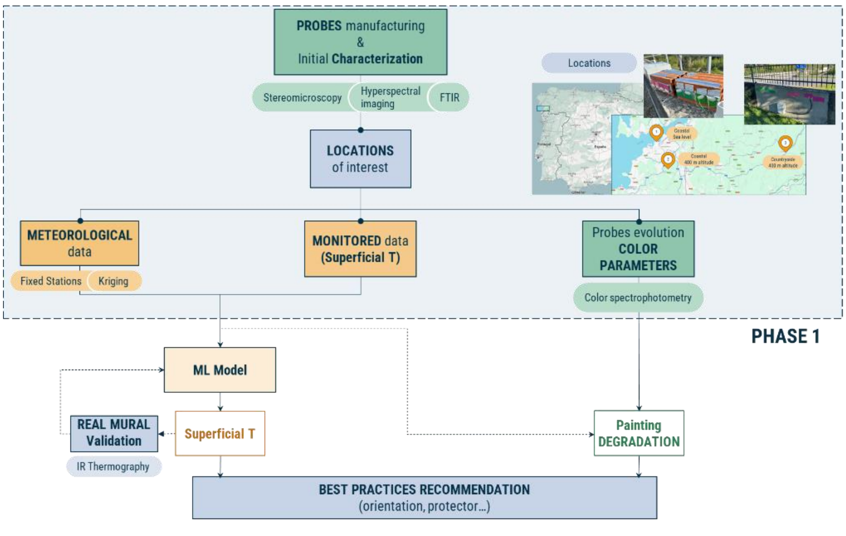

Figure 1 - Outline of the work that was carried out in the research presented.

To this end, a series of mock-ups with different paints (acrylic and alkyd paints, green and pink colours) were coated with a colour protector, with the aim of monitoring certain properties over time, such as their surface temperature and colour variation, considering parameters like orientation and the environment to which these materials would be exposed. More specifically, two acrylic and two alkyd paints were selected, along with a UV protector. During exposure, surface temperature was measured using T-type surface thermocouples attached to each surface, allowing for the continuous registration of the surface temperature. Moreover, colorimetric changes, mainly colour difference (ΔE^*_{ab}), were measured with a spectrophotometer every 45 days, considering the colour of the unprotected mock-up as reference. The impact of the

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protector on the samples was also evaluated through the ΔE^*_{ab}. After exposure, references and exposed samples were characterized using stereomicroscopy, hyperspectral imaging and Fourier-transform infrared spectroscopy (FTIR) for physical and chemical characterization. Three locations were chosen for samples placement: (1) coastal area, sea level (2) coastal area, 400 m altitude and (3) countryside, 400 m altitude. Samples were placed in each selected location with varying orientations, typically north and south (locations 1 and 3) and west (location 2). Additionally, aiming to study the effect of climatologic conditions on the paintings' degradation, meteorological data (ambient temperature, irradiance, etc.) were also obtained from fixed stations of the regional meteorological grid Meteogalicia [5]. Spatial interpolation using Kriging techniques was used to estimate meteorological variables at experimental sites.

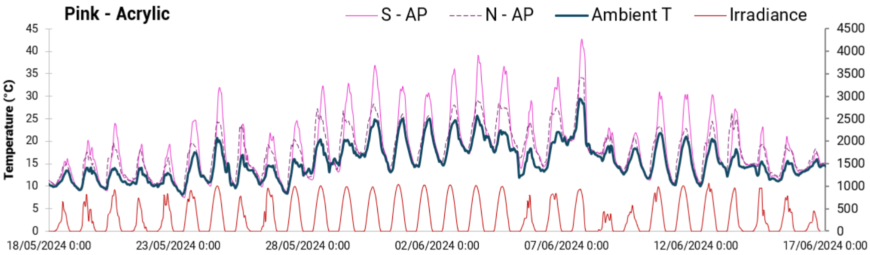

Figure 2 –Example of temperatures (surface and ambient) and irradiance profiles monitored in location (2) coastal area, 400 m altitude.

After the installation of the monitoring system and the first in-situ colour measurements, preliminary results have been obtained. Regarding the surface temperature distributions of the mock-ups, it was observed that these monitored signals were aligned with both ambient temperature and irradiance values collected from the meteorological sources (Fig 2). This confirms the effective implementation of the surface temperature monitoring system. Higher temperatures were recorded for both green and pink cases on the south-facing samples, reaching up to 5 and 8 ºC more than their northern counterparts during peak hours, respectively. No significant temperature variations were observed between the protected and unprotected samples.

Moreover, the application of the UV protector provoked more impact on the original colour of the samples painted with green alkyd spray, since it was the only sample with a colour difference higher than 3.5 CIELab units, which the visual threshold for a human eye [6].

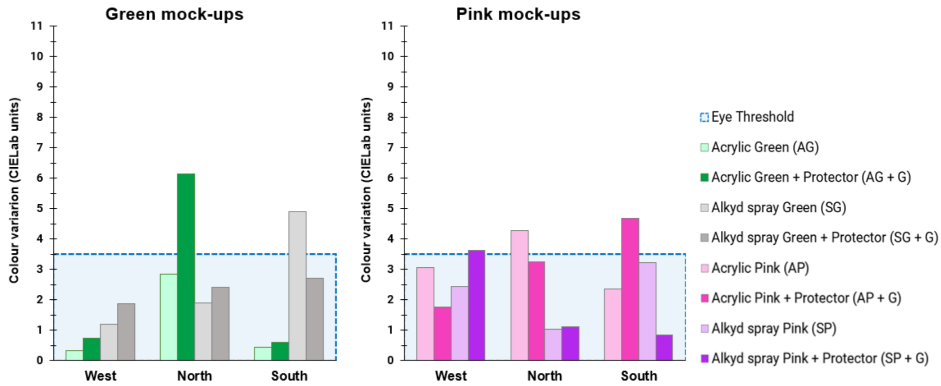

Figure 3 – Colour difference (ΔE^*_{ab}, CIELab units) at 45 days according to the type of painting, orientation and location.

Attending to the evolution of the colour variation over time during the first 45 days of monitoring (Fig. 3), UV protector did not reduce notably ΔE^*_{ab} values. Even in some protected samples (N-AG+G, W-SP+G and S-AP-+G), ΔE^*_{ab} were higher than 3.5 CIELab units. Without protector, for the north-orientated paints ΔE^*_{ab} was higher in the acrylic samples comparatively to their alkyd counterparts, while for the south-orientated paints, colour variation was higher in the alkyd paints. However, for the west orientated paints, a trend was not clear.

In conclusion, no relationship is found between the colour difference after prolonged exposure and the temperature reached by the surfaces of the paintings, regardless of the protector application. It would be necessary to extend the test to know the colour trend of both the paints and the protected samples.

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[1] T. Rivas, E.M. Alonso-Villar. & J.S. Pozo-Antonio. Forms and factors of deterioration of urban art murals under humid temperate climate; influence of environment and material properties. Eur. Phys. J. Plus 137, 1257 (2022).

[2] V. Pintus, S. Wei, M. Schreiner, Accelerated UV ageing studies of acrylic, alkyd, and polyvinyl acetate paints: influence of inorganic pigments, Microchem. J. 124 (2016) 949–961.

[3] M. Martínez-Comesaña, P. Eguía-Oller, J. Martínez-Torres, L. Febrero-Garrido, E. Granada-Álvarez, optimisation of thermal comfort and indoor air quality estimations applied to in-use buildings combining NSGA-II and XGBoost, Sust. Cities and Soc., 80 (2022), 103723.

[4] M. Pensado-Mariño, L. Febrero-Garrido, P. Eguía-Oller, E. Granada-Álvarez, Feasibility of different weather data sources applied to building indoor temperature estimation using LSTM neural networks, Sustainability 13 (2021), 13735.

[5] MeteoGalicia, "Rede meteorolóxica," 2022. Available online: https://www.meteogalicia.gal/observacion/estacions/estacions.action (accessed on 04 July 2024).

[6] .W Mokrzycki, M. Tatol, Color difference Delta E-A survey Colour difference ΔE-A survey, Machine, Graphics and Vision 20 (2011) 383–411. https://www.researchgate.net/publication/236023905.

Multi-analytical archaeometric investigations on Chalcolithic and Iron age pottery from Yumuktepe (Mersin, Turkey): preliminary results

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Figure 1 – Investigated pottery fragments of unknown manufacture from Yumuktepe (Mersin, Turkey).

The archaeological site of Yumuktepe *tell*, is located in the coastal plain of Mersin in Turkey. From the first excavation in 1930s to nowadays, 23 levels of occupation were found, spanning a very long period of more than 9000 years. The most ancient settlement dates from lower Neolithic (around 7000 BC), while the early occupation corresponds to the Arab and Byzantine Empire (800-1500 AD). Previous excavations have focused on the reconstruction of many aspects of the landscape, social and technological evolution of the different human groups settled at Yumuktepe, through an interdisciplinary approach, based on archaeobotany, archaeozoology, geology and archaeometry [1]. This work reports the first archaeometric studies on Chalcolithic (5000-4200 BC) and Iron age (1200-500 BC) settlements levels. They were excavated by the archaeological expedition of University of Salento (Lecce, Italy) and, until now, these levels are the least investigated from a diagnostic point of view.

We present the preliminary results on the archaeometric investigation of two groups of pottery fragments discovered in the two above-mentioned periods settlements, respectively (figure 1). In particular, a multi-analytical protocol is adopted, including optical microscopy (MO), X-ray powder diffraction (XRPD), scanning electron microscopy e microanalysis (SEM-EDS), micro-Raman spectroscopy and colourimetry, aimed at clarifying the manufacturing technologies evolution and provenance of these ceramic objects collected from two very different historical periods.

The mineralogical-petrographic information of the ceramic fabric allows us to classify the different samples on the basis of texture, granulometry of the temper clasts and voids, associated with both the shape and function of the archaeological object and with the different clay adjustment. Some peculiar petrographic details useful for provenance study are observed in a limited number of samples, such as microfossils remains, mainly attributed to *globigerinid* foraminifera, pyrite aggregates and various uncommon minerals [2].

Diffraction pattens are characterized by the presence of bulk minerals detected in all investigated samples: in the main temper clasts, quartz is mostly present, along with secondary plagioclase and K-feldspars. Abundant primary calcite is present in most of the samples corresponding to Chalcolithic level, while absent in the Iron age samples. Rare amphiboles are also present in the Chalcolithic samples and are rarely in the Iron age ones.

Micro-Raman spectroscopy provides comprehensive mineralogical information on manufacture and provenance issues, confirming the presence of the main sandy constituents, distinguishing the different polymorphs (sanidine, microcline, orthoclase, albite and anorthite). Moreover, it reveals the presence of abundant iron (II)-(III) and chromium (VI) ores of clastic origin, with variable composition and stoichiometry, in the form of hematite, magnetite, chromite, as well as, magnesiochromite, magnesioferrite and manganese oxides, both single and associated with the iron-rich oxides.

Of particular relevance to track the provenance, graphite or graphitic carbon inclusions are detected in carbonate and silicate clasts of some samples.

Finally, the integration of XRPD and micro-Raman spectroscopy data allows to identify the principal technological fingerprint phases, useful to discriminate the different samples by firing level, in particular: clayey phyllosilicate remains (illite/muscovite), TiO_2 polymorphs, clinopyroxene diopside, wollastonite and gehlenite.

Further chemical, traces elements and isotopic studies by SEM-EDS microanalysis and LA-ICP mass spectrometry are in progress, in order to tentatively identify the origin of the raw material (and thus the provenance) thanks to the upcoming chemical markers.

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This large dataset is used to classify the investigated artifacts based on their mineralogy, texture, morphology and micro-structures. Comparison among similar typologies of pottery from coeval foreign archaeological sites, and the related chemical composition, may give a deeper knowledge of the manufacturing, firing technology and trade routes during the Chalcolithic and Iron ages in Yumuktepe.

Acknowledgements
Financial support was provided by PRIN 20224X9ATP

[1] I. Caneva and G. Köroğlu, "Tumuktepe. A journey through nine thousand years," *Yayinlari*, 2010.
[2] P. S. Quinn, "Thin section petrography, geochemistry and scanning electron microscopy of archaeological ceramics", *Archaeopress*, 2022.

A new approach for the identification of mode shapes of slender masonry constructions

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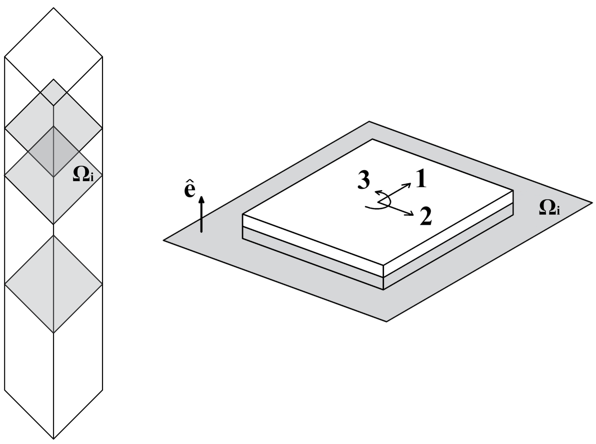

Figure 1: Representation of the theoretical model

Dynamic identification of historical masonry constructions is a challenging research area, involving an increasing number of scholars studying how to obtain reliable information from dynamic measurements, such as natural frequencies and mode shapes, for characterizing structural models and detecting damage [1]. Mode shapes, in particular, contain both global information, which is useful for studying the dynamic response of structures to dynamic actions, and local information, which can capture local structural variations, such as those induced by structural damage. Here, we propose a new mode shape identification approach that can be effectively applied to a vast class of cultural heritage structures [2]. Specifically, this class of structures includes slender masonry constructions with horizontal sections whose in-plane deformation can be neglected, under (small) ambient vibrations, compared to lateral deflection of the whole structure. Masonry towers that have good connections between orthogonal outer walls fall in this class of structures.

The aim of the proposed approach is to overcome some difficulties arising in practical applications. Indeed, the number of sensors is often limited, so it is usually necessary to perform different acquisitions to cover all the Degrees Of Freedoms (DOFs) necessary for characterizing mode shapes. Since Operational Modal Analysis (OMA) provides unscaled mode shapes [3], suitable merging techniques have to be employed for assembling partial mode shapes obtained from different acquisitions. These techniques typically require that during the acquisitions one group of sensors (reference sensors) is kept fixed on the structure, whereas the other sensors (roving sensors) are moved to cover all the DOFs of interest. Partial mode shapes are then assembled by scaling the different datasets with respect to the overlapping DOFs [4, 5].

The proposed approach is based on a theoretical model, which includes suitable kinematic assumptions (Figure 1), that a structure has to satisfy for the applicability of the approach. We show that, under these assumptions, mode shapes can be decomposed into two components: modal centers of rotation and modal rotations. Modal rotations depend on the scaling factors of mode shapes, while modal centers of rotation turn out to be independent of scaling factors. Based on these theoretical findings, we also develop a novel method for identifying these two components from vibration measurements. It is possible to recognize that modal centers of rotation are able to catch the main features of mode shapes, enabling interpretation of the data in terms of structural behavior. Moreover, contrary to modal rotations, modal centers of rotation do not depend on the scaling factors, so they can be identified from datasets having no overlapping DOFs. These features make our approach more efficient than classical mode shape identification and merging techniques. Numerical simulations have been performed to validate the method.

[1] F. J. Pallarés, M. Betti, G. Bartoli, and L. Pallarés, "Structural health monitoring (shm) and nondestructive testing (ndt) of slender masonry structures: A practical review," *Construction and Building Materials*, vol. 297, 2021.

[2] D. Camassa, A. Castellano, A. Fraddosio, and M. D. Piccioni, "A novel mode shape identification approach for structures having planes with rigid-like behavior," *[Manuscript submitted for publication]*.

[3] R. Brincker and C. E. Ventura, *Introduction to Operational Modal Analysis*. Wiley Blackwell, 2015.

[4] L. Mevel, M. Basseville, A. Benveniste, and M. Goursat, "Merging sensor data from multiple measurement set-ups for non-stationary subspace-based modal analysis," *Journal of Sound and Vibration*, vol. 249, no. 4, p. 719 – 741, 2002.

[5] E. Parloo, P. Guillaume, and B. Cauberghe, "Maximum likelihood identification of non-stationary operational data," *Journal of Sound and Vibration*, vol. 268, no. 5, p. 971 – 991, 2003.

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Unveiling the Secrets of Ancient Technologies: A Multianalytical Approach for the Comprehensive Characterization of Resinous Substances Employed as Adhesives in Archaeological Finds

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Resinous substances secreted by trees are often discovered in archaeological contexts, reflecting their extensive use in ancient times for their adhesive, waterproofing, and sealing properties. These substances were utilized in their natural form, such as pine and mastic resin, or underwent processes involving heat and distillation in order to obtain more refined products like pitch and tar. Birch bark tar was commonly employed in Northern Europe, while pine pitch was prevalent in the Mediterranean region [1], [2].

The present work aims to evaluate if the botanical source could impact the thermal characteristics of the resulting pitch/tar material. This objective arises from the hypothesis that different plant species or families might provide peculiar thermal properties to the obtained material, which could have influenced their selection and use in ancient times. To fulfil this objective, we analyzed a collection of over 30 tar and pitch reference samples made from resins of various botanical families or species, using methods based on analytical pyrolysis techniques. The reference samples were prepared from wood and barks of various deciduous trees (mainly from genus *Betula*) and conifers (mainly from genus *Pinus*).

Evolved gas analysis-mass spectrometry (EGA-MS) and pyrolysis gas chromatography-mass spectrometry (Py-GC/MS) were employed, as they have proven to be extremely suitable and versatile methods for studying complex organic samples from cultural heritage contexts [3].

These techniques allow for the detailed examination of the thermal degradation processes and the chemical composition of the pitch and tar samples. Through EGA-MS, it is possible to identify the specific compounds released at different temperatures, providing insights into the stability and performance of the materials, while the Py-GC/MS enable for obtaining the chemical fingerprints of these samples. By comparing the thermal profiles and chemical composition of these samples, we can infer how ancient artisans might have selected and processed resins to achieve desired properties for specific applications. Overall, this study highlights the significance of botanical sources in influencing the functional properties of resinous substances and underlines the importance of multianalytical approaches in archaeological research.

[1] M. Rageot et al., “Management systems of adhesive materials throughout the Neolithic in the north-west,” Mediterranean Journal of Archaeological Science, vol. 126, 2021, doi: 10.1016/j.jas.2020.105309ï.

[2] G. Langejans, A. Aleo, S. Fajardo, and P. Kozowyk, “Archaeological Adhesives,” in Oxford Research Encyclopedia of Anthropology, Oxford University Press, 2022. doi: 10.1093/acrefore/9780190854584.013.198.

[3] I. Degano, F. Modugno, I. Bonaduce, E. Ribechini, and M. P. Colombini, “Recent Advances in Analytical Pyrolysis to Investigate Organic Materials in Heritage Science,” Angewandte Chemie - International Edition, vol. 57, no. 25. Wiley-VCH Verlag, pp. 7313–7323, Jun. 18, 2018. doi: 10.1002/anie.201713404.

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Employing Gaussian Splatting on Local Devices for Surveying and Documenting Cultural Heritage

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Figure 1 – The Piazzetta di San Nicolò in Padua reproduced with the gaussian splatting survey method using PostShot software

The article presents a new approach for surveying both external and internal sites of significant historical and cultural importance and their virtual representation for the enhancement and dissemination of architectural heritage [1][2]. It specifically showcases a technique that involves the use of Gaussian splatting [3], a method capable of optimizing survey times starting from well-structured video recordings. By utilizing the new spherical camera Insta360 X4 and the ability to extract single videos in the four cardinal directions from spherical videos, it is possible to easily acquire the maximum amount of information about the surrounding space with a single video recording [4]. Through the PostShot software, available for download in its beta version, the installation of Gaussian splatting algorithms on proprietary hardware (equipped with the latest generation video card) has been made intuitive, without the need to set up an environment suitable for frameworks and without relying on external clouds.

The case study described is Piazzetta di San Nicolò in Padua (Figure 1): a space rich in history and with features well-suited for experimenting with this type of methodology. The square develops in a rather regular shape from the entrance on Via Dante where the Loggia Bombardieri with its frescoed lunettes is located; it then defines itself with Palazzo Meschini and Palazzo Brunelli-Bonetti and the Church of San Nicolò dating back to 1088. The vaults of the loggia and the entrance of the church constitute the most evident chiaroscuro zones, and the height of the bell tower provides an opportunity to study the strengths and weaknesses of this acquisition method. The results demonstrate the effectiveness of the method used, especially if the aim is to create immersive realities to document and analyze complex historical spaces, to disseminate and showcase what remains and what is no longer present but can be virtually reconstructed. This methodology adds a significant contribution to surveying and three-dimensional representation techniques, and even though it is still in an embryonic phase, it suggests new approaches that are increasingly accessible and easy to implement for the surveying of historical heritage.

[1] Palestini, C., Basso, A., Perticarini, M., 2022: Machine Learning as an Alternative to 3D Photomodeling Employed In Architectural Survey And Automatic Design Modelling. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLVIII, 191–197. https://10.5194/isprs-archives-XLVIII-2-W1-2022-191-2022
[2] Luigini A., Fanini B., Basso A., Basso D. (2020) Heritage education through serious games. A web-based proposal for primary schools to cope with distance learning, in VITRUVIO, International Journal of Architectural Technology and Sustainability, Volume5, n°2 (2020). Valencia: Poli Papers ed. https://doi.org/10.4995/vitruvio-ijats.2020.14665
[3] Kerbl, B., Kopanas, G., Leimkühler, T., Drettakis G., 2023: 3D Gaussian Splatting for Real-Time Radiance Field Rendering. ACM Transactions on Graphics, 42 (4), No 139, 1–14. https://doi.org/10.1145/3592433
[4] Morena, S., 2022: Application of action camera video for fast and low-cost photogrammetric survey of cultural heritage. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLVIII- 2/W1-2022, 177–184. https://doi.org/10.5194/isprs-archives- XLVIII-2-W1-2022-177-2022

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Design and Manufacture of a Device for Non-Destructive *in-situ* Corrosion Assessment

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Over 30 shipwrecks litter the seabed of the Maltese archipelago. As many of these wrecks were a result of collisions with naval mines or aerial bombings during the first and second world war, wrecks of ships such as the ORP-Kujawiak are resting on the seabed still carrying tonnes of unexploded ordinances and fuel oil [1]. This presents itself as an environmental conservation nightmare. Should the structure corrode to the point of collapse, these toxic chemicals would be released into the surrounding water, damaging the endangered flora and fauna that colonise the wreck, and pollute the water [2]. Furthermore, these wrecks now form part of the Maltese Island's history and should be monitored and conserved for future generations. Maltese marine archaeologists currently lack the tools to perform *in-situ* corrosion monitoring and preservation. Such tools can be employed to check whether an underwater metallic structure is passivated or actively corroding, in which case immediate remedial action has to be taken. In-situ corrosion monitoring does not disturb the wreck, which is an important consideration given that a significant portion of wrecks in Maltese territorial waters also serve as war graves.

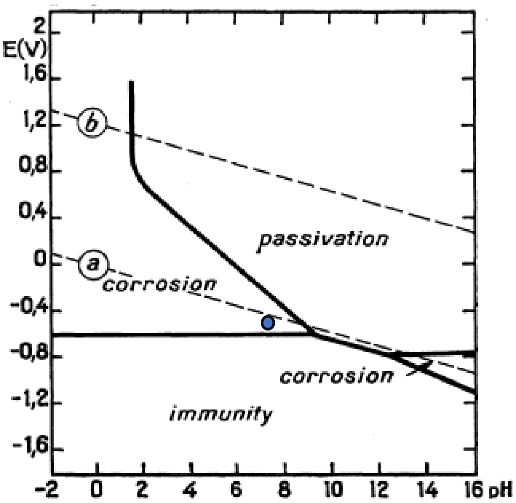

Fig. 1 – Pourbaix diagram for Iron in seawater [6]

A popular method of assessing corrosion behaviour was popularised by MacLeod and involves measuring the pH of seawater at the corrosion product / concretion layer-metal interface and the corrosion potential (E_{corr}) at that same area [3]. The corrosion potential is measured against a silver / silver chloride reference electrode, and multi-meter while the pH is determined using a flat-tipped pH probe connected to a pH meter. Meters and their corresponding probes need to be carried down to the wreckage site in a water tight pressure resistant carry case and the measuring probes need to be connected via cables to the meters inside the case [3]. The measured pH and E_{corr} for a particular spot on the wreckage are plotted on a Pourbaix diagram (Fig. 1) of the relevant metal under evaluation, and depending where the data plots, it can be deduced whether the localised area investigated is in an active, passive, or immune state of corrosion [4]. By assessing multiple points across the wreck and preferably over time, a general agreement of the corrosion state of the entire structure can be deduced. This information is important as it would allow the underwater conservation team at Heritage Malta to efficiently categorise wreck sites around the island, and put into effect a protection plan based on the state of their degradation, i.e. actively corroding wrecks will be given first priority over those that are passive to corrosion.

This work deals with the design, build, and test of an ergonomic, water-tight, pH and E_{corr} measurement integrated device for *in-situ* corrosion measurement, dubbed the IPPM (Integrated pH Potential Measurement). A preliminary market research for an off-the-shelf holistic instruments and carry case setup does not exist, making the development of a bespoke system, the only viable option. Measuring the pH and E_{corr} are not the only requirements of the device. Other important requirements are that the device must be (i) economic, preferably not exceeding a budget of 4000 Euro; (ii) ergonomic, to allow comfortable manipulation and operation when used underwater but also on land (easy access to instruments inside the case and easily cleaned); (iii) water-tight to a depth of 100 m (pressure resistant to 1 MPa); and (iv) must allow users to manipulate the instruments housed within the device whilst underwater. These set of requirements act as a baseline around which the design is built upon. The design of the device includes two main components: an exhaustive market research to find instrumentation fit to be used within the device; and the design of a portable casing suitable for housing the components purchased while facilitating easy gathering of data. For pH measurements, the

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Liquiline CML18 pH meter and CPF81E pH probe manufactured by Endress and Hauser were selected. The CML18 is a light, compact meter, with the ability to log pH readings, whilst the CPF81E is the only economical flat tipped pH probe able to withstand the required 1 MPa pressure. For readings of E_{corr} the EEVBlog 121GW was chosen for its ability to record and store data on an internal SD card. Silvion's SW100 flow through silver / silver chloride ($Ag/AgCl_{sea}$) reference electrode, which was chosen for its robustness and ability to withstand pressures far-beyond the required application pressure. A Landt manufactured platinum disc electrode was soldered to a multistrand copper wire and used as the working electrode.

To aid with the design of the device, and the logistics of housing and interfacing the instruments, Roozenburg and Eekels' basic design cycle was used [5]. A preliminary market search yielded several possible housings available for purchase which would house the instruments, however none of the readily available pressure vessels allowed for the possibility of providing the divers manual manipulation of the internally housed meters whilst underwater. The analysis consisted of a Quality Function Deployment (QFD), put together after an initial meeting with the primary stakeholders of the project, namely marine archaeologists and underwater conservators/conservation scientists with whom simple sketches and suggested layouts of the device were discussed. Along with the QFD, a failure-modes-and-effects analysis was conducted to identify potential failures of the future design to proactively attempt to avoid pitfalls in the design moving forward. A decision matrix was then used to select the best candidate out of three selected concept designs. A short questionnaire was prepared and sent to individuals with experience in the field, along with the selected design for constructive feedback. Feedback on the selected design was again sought from the same marine archaeologists/conservation scientists based at the University of Malta, and others abroad.

To finalise the design, a material selection process and calculations for the thickness of the features of the device's outer casing needed to be made. The material selection process resulted in 316 stainless steel to be the most suitable material for the construction of the body of the device. For the viewing window, acrylic was selected. The device can be opened and closed via an O-ring sealed lid, and fastened with 10 concentric bolts. To pass cables from the meters inside the device to the outside probes and electrodes, 316 stainless steel cable glands were used. Shielding was also machined for the pH probe and the platinum electrode to protect from impact, using 316 stainless steel and nylon respectively. To allow divers to operate the meters whilst underwater, bespoke magnetically tipped switches were affixed to the front face of the device, whilst magnetically activated switches (held in recesses in the backside of the front face of the device) were soldered in place of the meters' buttons. Figure 2 presents a final conceptual design of the device. Leak testing of the device will be performed via a hydrostatic pressure test.

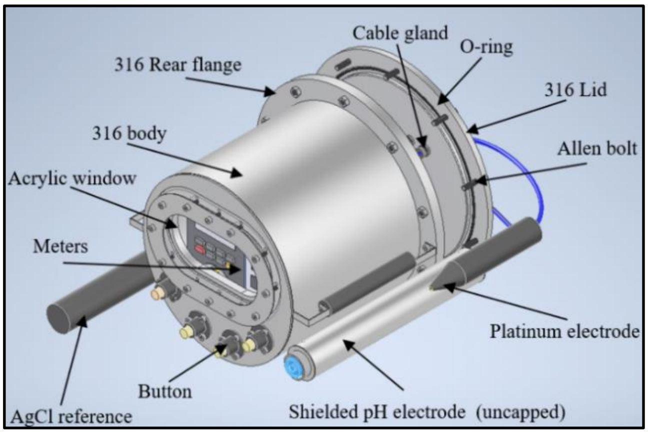

Fig. 2 – Final conceptual design for device to measure pH and E_{corr}

The measuring capability of the device was tested inside a seawater filled tank at the lab in which a low-carbon steel plate was submerged and allowed to corrode over a period of a month. The results of the test are represented by the blue dot on the Pourbaix diagram in Figure 1. A pH of 7.57, and an E_{corr} of -0.5 V (vs. S.H.E†.) shows that the steel plate is actively corroding.

The device is to be tested *in-situ* in late July 2024, where it will be used to gather corrosion data on a 70 m deep Supermarine Spitfire plane wreck.

[1] T. Gambin, Monitoring and Assessment of dumped munitions in the global ocean: an integrated approach (Lecture), Monitoring and Assessment of dumped munitions in the global ocean: an integrated approach, Birgu, Malta: Heritage Malta, 2024.
[2] N. Coertze, T. Gambin, M. Sausmekat, "When History meets Biology. Shipwrecks as Ecological Hotspots," in Tessaræ, Heritage Malta, 2023, pp. 48-53.
[3] I. D. MacLeod, "In-situ Corrosion Measurements of WWII Shipwrecks in Chuuk Lagoon, Quantification of Decay Mechanisms and Rates of Deterioration.," Frontiers in Marine Science., vol. 3, p. Article 38 , 2016.
[4] N. A. North , "Formation of coral concretions on marine iron," The International Journal of Nautical Archaeology and Underwater Exploration, vol. 5, no. 3, pp. 253-258, 1976.
[5] N. F. M. Roozenburg, J. Eekels , Product Design: Fundamentals and Methods (Product Development: Planning, Design, Engineering), Chichester: Wiley , 1995.
[6] M. Pourbaix, Atlas of Electrochemical Equilibria in Aqueous Solutions, Houston, Texas: National Association of Corrosion Engineers, 1966.

† SHE stands for standard hydrogen electrode. $E_{corr} = E_{AgCl} + 0.224$, where E_{AgCl} is the voltage read off the multi-meter

Listening wall: a preliminary investigation on the acoustic performance of an early warning system for aircraft in WWII

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Figure 1 – Listening wall (*muro d'ascolto* in Italian) in Messina (San Placido).

Today, we know the past through two types of evidence: the first concerns the written sources that attest to the existence and activity of certain architectural objects, the second concerns the remains that are still preserved and can be investigated on-site, serving as authentic testimonies of specific historical events and thus able to provide more accurate indications of human actions carried out in the past by our predecessors. In this last case, the research deals with a particular construction that requires the knowledge and application of the laws of acoustics in order to detect at a great distance the vibrations caused by the engines of aircraft, allowing the defenders to anticipate the anti-aircraft alarms. During World War I and in the years leading up to World War II, Great Britain spearheaded an extensive military anti-aircraft defence project [1]. The research aimed to locate gunfire and especially enemy aircraft using a variety of listening devices, including sophisticated masonry structures. In the course of the that project, two types of constructions were developed. The first one had a parabolic profile capable of collecting sound waves perpendicular to the mirror surface, while the second one was characterized by a hemispherical profile suitable for oblique sound waves. As a result of this strategy, rotating and stationary structures, the latter called *sound mirrors*, were built. The first documented sound mirror dates from around 1915 and it was designed as part of a long-range early warning system. Its primary function was to identify the noise produced by approaching aircraft out of the visual range. This was a critical requirement because the rumble of engines and propellers was significantly attenuated near shore, making it undetectable to the naked ear. The solution proposed by this technology was to amplify the sound waves using geometric stratagems [2]. Such sound waves were first reflected from the concave surfaces of the mirror onto the caustic, which is the area between the center of curvature of the mirror itself and the surface of the plate. The reflected waves were then concentrated at a point on the caustic surface perpendicular to the angle of incidence, along a line passing through the center of curvature. Sound mirrors were designed according to the frequency components, i.e., the fundamental frequency, of the sound waves produced by the aircraft of that period. Generally [3], these had a wavelength between 15 ft (about 4.6 m) and 18 ft (about 5.5 m), which corresponds to a frequency range of about 60 Hz to 70 Hz. This implied that the size of the mirrors could be relatively limited. Under optimal atmospheric conditions and free of any auditory interference, 200 ft (about 61.0 m) acoustic mirrors could detect aircraft up to 25 mi (about 40 km) away, although they could not estimate altitude. In contrast, the smaller 30 ft (about 9.1 m) acoustic mirrors, which could determine altitude instead, had a maximum range of just over 10 mi (about 16 km) [4]. It is evident that the patrol aircraft and the sound mirrors could not simultaneously work due to the dominance of aircraft noise over the other sources. The location of the sound mirror was also an important parameter of interest. If it was too close to the sea, marine waves breaking on the beach or rocks would produce a significant noise effect [5]. However, the development of acoustic mirrors was hampered by the advent of radar, an instrument capable of detecting aircraft at much greater distances, about 60 mi (about 97 km) at the time. However, unlike radar, which uses radio waves, acoustic mirrors operate passively, reducing their detectability by appropriate systems. It should also be noted that as early as 1933, aircraft capable of speeds approaching 250 mph (about 402 km/h) were being designed. Thus, the acoustic mirrors could only provide a warning of about 6 minutes, which was of course totally insufficient to allow interception by defending fighters [6]. The listening wall (*muro d'ascolto* in Italian) [7] is a specific sound mirror that was built at the beginning of the World War II in several countries in Europe. In addition to detecting sound waves

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generated by enemy aircraft, the listening wall was also used to determine the approximate direction, altitude, and distance of the same aircraft. These constructions consisted of three sectors of 120° each with a parabolic profile. Such profiles were covered with smooth plaster to ensure optimal reflection of the sound waves towards the focal point. This focal point was located in a pit known as the *listening pit* (*fossa d'ascolto* in Italian), with a depth of 1.6 m. An operator responsible for the survey was hidden inside. The position of the aircraft was estimated by means of a suitable scale drawn on the surface of the mirror. At the present time, two similar listening walls are still available: one in Messina, Italy (San Placido, Figure 1) and one in Leros, Greece [8]. Specifically, for the Messina listening wall, the diameter of the whole structure is approximately 19.64 m, its perimeter is 61.66 m, and its height is 2.30 m. In particular, taking the Messina listening wall as an example, it is noteworthy that it was part of a broader system that also included some listening pits situated at a short distance on an elevated plateau. These consist of two listening pits of equal size and another pit placed in the center, which were not involved in the present experimentation as they have already been extensively covered in other studies. The survey of the listening wall was carried out using the aerial photogrammetric method with a drone equipped with an RTK module. The photos obtained were processed in the Agisoft Metashape software, which, by identifying homologous points in the various images, creates the 3D model, ensuring a faithful three-dimensional reconstruction of the current state and the extraction of all the metric data useful for the study of the building.

Due to the lack of technical documentation on this military structure, the three-dimensional reconstruction is crucial for a detailed analysis of how the listening walls operated, including their strengths and limitations. In this context, ongoing computer simulations are being conducted to evaluate the acoustic performance of the listening wall. Preliminary results show the correct functioning of the parabolic wall of the structure under test. It is evident from Figure 2 how the scattered sound pressure level reaches its maximum value in a region in front of the parabolic wall, quite close to the focal point. Further simulations are ongoing to assess the operational effectiveness of the structure, provide a deeper understanding of its role in early warning systems, and contribute to the broader study of historical military engineering.

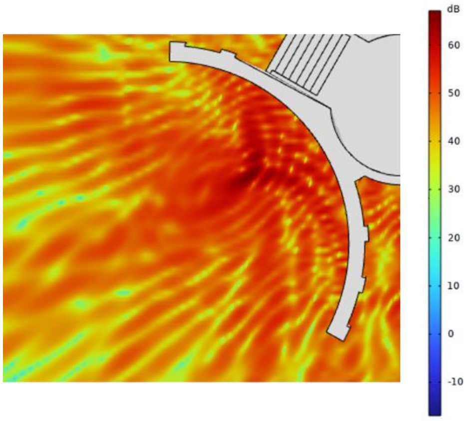

Figure 2 – Simulated scattered sound pressure level in the region around the Messina listening wall.

This work has been partially funded by European Union (NextGeneration EU), through the MUR-PNRR project SAMOTHRACE (ECS00000022)

[1] R. N. Scarth, "Echoes from the sky: a story of acoustic defence", *Hythe Civic Society*, pp. 4-10, 1999.
[2] P. Judkins, "Sound and fury: sound and vision in early UK air defence", *History and Technology*, vol. 32, pp. 227-244, 2016.
[3] "Long-Distance Listening with Sound Mirrors", *Document AVIA12/132*, London, October, p. 14, 1932.
[4] R. Ganchrow, "Perspectives on Sound-Space: The Story of Acoustic Defense", *Leonardo Music Journal*, vol. 19, pp. 71-75, 2009.
[5] Report No. 67 and 87, "Progress Report of the Acoustical Section", AVIA 23/64, 1920.
[6] D. Zimmerman, "Tucker's Acoustical Mirrors: Aircraft Detection Before Radar", *War & Society*, vol. 15, pp. 73-99, 1997.
[7] https://www.dodecaneso.org/news/il-muro-dascolto-di-s-placido-messina/
[8] https://www.ww2wrecks.com/portfolio/battlefield-archaeology-the-ww2-listening-wall-of-leros-interview-with-luciano-alberghini-maltoni

Sub-GHz Resonators for Non-Invasive Moisture Monitoring in Cultural Heritage Applications

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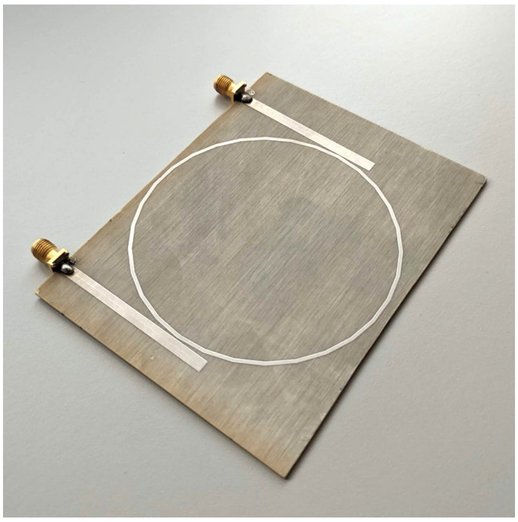

Figure 1: Photo of the developed two-port microstrip ring resonator meant for the non-invasive evaluation of moisture level in stone materials.

This short abstract presents the development and preliminary investigation of a microstrip ring resonator designed for the non-invasive detection of moisture content in stone materials, particularly those used in cultural heritage applications. The resonator, fabricated using the inkjet printing technology, operates within the sub-gigahertz frequency range, making it suitable for portable and low-cost field measurements. The device operating principle relies on the shift in resonance frequency, which correlates with changes in the dielectric properties of the material under test, thereby enabling the estimation of moisture content.

In the context of cultural heritage, the preservation of artifacts and historical structures is of paramount importance. Environmental factors, in particular moisture, pose significant threats to these valuable materials [1]. Traditional methods for monitoring the moisture content in stones and other materials often involve invasive techniques that might cause further damage to the artifacts [2]. Therefore, the development of non-invasive, accurate, and reliable moisture sensing methods is crucial. Microwave resonators offer an ideal solution to this challenge. Their non-contact nature and high sensitivity make them suitable for monitoring the moisture content of stone materials used in cultural heritage sites [3, 4]. The application of microwave technology in this field not only helps in the conservation of these artifacts, but also provides data that can help in understanding the deterioration processes and in planning effective conservation strategies.

The goal of this research is to develop a planar ring resonator that can be used for the non-invasive monitoring of moisture content in cultural heritage stone materials. The sensor proposed is a two-port microstrip ring resonator operating in the frequency range from 0.5 GHz to 1 GHz. Typically, the resonant frequency of a microstrip ring resonator is dependent on its geometry and the dielectric properties of the material constituting it (e.g., the substrate dielectric constant). In this specific case, the chosen substrate is the Rogers RO4003C, characterized by a dielectric constant (ε_r) of 3.38. However, microstrip technology allows the propagation of the electromagnetic wave both within the substrate ($\varepsilon_r = 3.38$) and in the air ($\varepsilon_r \approx 1.0$). Therefore, it is more accurate to refer to the effective permittivity (ε_{eff}), which falls between the values for air and the selected substrate. It can be calculated using the following formula [5]:

$$\varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + 12\frac{h}{W}}}\right) \tag{1}$$

where h is the substrate thickness and W is the width of the microstrip line. The resonant frequency f_r of the microwave device is approximately determined by the value of this effective permittivity and the geometry of the device:

$$f_r = \frac{c}{2\pi r\sqrt{\varepsilon_{\text{eff}}}} \tag{2}$$

where c is the speed of light in vacuum and r represents the ring radius of the resonator.

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When a material with a specific dielectric constant is placed near the microstrip ring resonator, part of the air is replaced by the material, thus slightly altering the effective permittivity value and, consequently, modifying the device resonant frequency, as indicated by the previous formula. Specifically, from Eq. (2), it is evident that as ε_{eff} increases, the resonant frequency decreases. Once the relationship between resonant frequency and the dielectric constant is known, after proper calibration, the microwave device can be used to estimate the dielectric constant of unknown materials, such as construction materials whose dielectric properties can vary based on their moisture content [6, 7].

The design of the sensor prototype has been optimized through computer simulations. After selecting the geometry, it is then fabricated using the inkjet printing technique by means of the Voltera NOVA printer.

The preliminary investigation of the developed prototype begins with calibrating the Anritsu MS4647B vector network analyzer (VNA) to ensure accurate measurements. The calibration uses a standard SOLT (Short-Open-Load-Through) method. Once calibrated, the VNA is configured to sweep the frequency range of interest, specifically from 0.5 GHz to 1 GHz, which encompasses the operational working frequency of the sensor.

Different samples with known dielectric constants are then placed in proximity to the resonator. The materials selected for this study have dielectric constants that range from 2.2 to 10.2, which are within the typical values for stone and construction materials [3, 8]. Each sample is carefully positioned over the resonator, and the VNA records the shift in the resonant frequency. The data obtained from the experiments are plotted in Fig. 2 to illustrate the shift in resonant frequency as a function of the dielectric constant. The measurements reveal a nearly linear relationship ($R^2 = 0.98$) between the resonant frequency and the dielectric constant of the tested materials within the range of interest. As the dielectric constant increases, the resonant frequency of the sensor decreases. This inverse relationship is consistent with the theoretical predictions, thereby confirming the validity of the developed sensor prototype. Future work will focus on further validating the system with various stones and construction materials commonly used in cultural heritage sites, aiming to enhance the accuracy and applicability of this novel sensing approach.

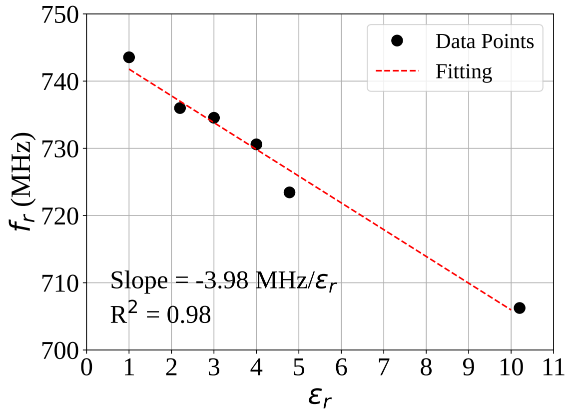

Figure 2: Resonant frequency shift as a function of dielectric constant for various materials placed near the microstrip ring resonator.

This work has been partially funded by European Union (NextGeneration EU), through the MUR-PNRR project SAMOTHRACE (ECS00000022).

[1] J. Huang, Y. Zheng, and H. Li, "Study of internal moisture condensation for the conservation of stone cultural heritage," *Journal of Cultural Heritage*, vol. 56, pp. 1–9, 2022.

[2] R. Agliata, R. Greco, and L. Mollo, "Moisture measurements in heritage masonries: A review of current techniques," *Materials Evaluation*, vol. 76, no. 11, pp. 1478–1487, 2018.

[3] E. Piuzzi, G. Cannazza, A. Cataldo, E. De Benedetto, L. De Giorgi, F. Frezza, G. Leucci, S. Pisa, E. Pittella, S. Prontera *et al.*, "A comparative assessment of microwave-based methods for moisture content characterization in stone materials," *Measurement*, vol. 114, pp. 493–500, 2018.

[4] G. Gugliandolo, A. Altadonna, A. Arena, M. Arena, L. Calabrese, G. Campobello, G. Crupi, D. Iannazzo, F. Passalacqua, F. Todesco *et al.*, "Microwave transducers for moisture content characterization of cultural heritage materials," in *IMEKO TC4 International Conference on Metrology for Archaeology and Cultural Heritage*, 2023.

[5] D. M. Pozar, *Microwave engineering: theory and techniques*. John wiley & sons, 2021.

[6] A. Joshaghani, M. Balapour, and A. A. Ramezanianpour, "Effect of controlled environmental conditions on mechanical, microstructural and durability properties of cement mortar," *Construction and Building Materials*, vol. 164, pp. 134–149, 2018.

[7] L. Mollo and R. Greco, "Moisture measurements in masonry materials by time domain reflectometry," *Journal of materials in civil engineering*, vol. 23, no. 4, pp. 441–444, 2011.

[8] S. Wang, Q. Sun, N. Wang, and L. Yang, "Variation in the dielectric constant of limestone with temperature," *Bulletin of Engineering Geology and the Environment*, vol. 79, pp. 1349–1355, 2020.

The violet shades of logwood-based inks: investigating the influence of inorganic salts by spectroscopy and mass spectrometry.

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The spread of logwood bark (*Heamatoxylum Campechianum* L.) in Europe as a dyestuff dates back to the 16th century. However, its incorporation into ink formulations only began in the 18th century, firstly as an additive in iron gall inks (iron gall logwood inks) and later as the main component (logwood inks). Renowned for their broad spectrum of achievable colours and their non-corrosive impact on paper, logwood inks have been used by many artists, for instance by Vincent van Gogh in his drawings [1]. While the spectroscopic properties of logwood inks have been extensively discussed in the literature [2,3], a gap remains in correlating those with the corresponding molecular profiles. The effects of different ink recipes on their final composition have yet to be investigated, and the potential synergy between spectroscopic and chromatographic techniques remains unexplored in elucidating this aspect.

In this work, several 19th-20th century formulations of logwood inks, differing in inorganic salts, additives, and oxidation time, were selected and reconstructed according to historical recipes. An in-depth investigation of the organic components was performed on reference mock-ups of logwood inks (on either glass and paper support) by Raman spectroscopy and liquid chromatography coupled to diode array and tandem mass spectrometric detectors (LC-DAD-ESI-Q-ToF) [4]. Raman analysis yielded spectra predominantly characterised by bands associated to the -COH bending, -C=O and aromatic -C=C- stretching, highlighting significative shift of vibrational modes depending on the inorganic salts used in the ink recipe. Thus, the specific profiles observed in the Raman spectra of Al-, Al/Cu-, Fe-, and Cr-based logwood inks can serve as a unique fingerprint for each ink type, aiding in their non-destructive differentiation and identification. Moreover, an optimised LC-DAD-HRMS method for iron gall ink analysis [4] was applied for detecting logwood ink's components, enabling us to detect compounds never or seldom reported in the literature (such as G-compounds and hematein derivatives). Additionally, we correlated the data acquired by LC-DAD and Raman spectroscopy by evaluating the relative areas/intensity of chromatographic peaks and of specific Raman bands, respectively. Together, they offer valuable insights on the rate of oxidation of haematoxylin to hematein, particularly in relation to different ink recipes.

Summarising, our research could lead to important insights in logwood inks investigation. On the one side, we confirm that Raman spectroscopy is a powerful diagnostic tool for discriminating inorganic salts in logwood inks, and this holds significant promise for conservation efforts applied to paper artworks. On the other hand, we deepened our knowledge on their composition in terms of organic molecular profile by applying ultra-sensitive chromatographic and mass spectrometric methods, expanding the available molecular markers dataset for logwood inks identification. The proposed method is particularly valuable in forensic and heritage science, where the composition of inks can offer crucial insights into the origin and authenticity of documents or artworks.

[1] H. Neevel, M. Van Bommel, N. Lingbeek, R. Zwikker, M. Vellekoop, Non-invasive analysis of Van Gogh' s drawing inks, 15th Trienn. Meet. ICOM-CC. (2008) 278–284.
[2] S.A. Centeno, P. Ropret, E. del Federico, J. Shamir, B. Itin, A. Jerschow, Characterization of Al(III) complexes with hematein in artistic alum logwood inks, J. Raman Spectrosc. 41 (2010) 445–451. https://doi.org/10.1002/jrs.2455.
[3] S.A. Centeno, M. Bronzato, P. Ropret, A. Zoleo, A. Venzo, S. Bogialli, D. Badocco, Composition and spectroscopic properties of historic Cr logwood inks, J. Raman Spectrosc. 47 (2016) 1422–1428. https://doi.org/10.1002/jrs.4938.
[4] A. Ferretti, F. Sabatini, I. Degano, A Model Iron Gall Ink: An In-Depth Study of Ageing Processes Involving Gallic Acid, Molecules. 27 (2022). https://doi.org/10.3390/molecules27238603.

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3D imaging methods for tool mark analysis in the Late Medieval wall paintings at Ħal Millieri, Malta

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Figure 1 – Detail of the Ħal Millieri wall paintings with depictions of St. Agatha and St. Blaise.

The Chapel of the Annunciation at Ħal Millieri, Żurrieq, contains some of the best surviving wall paintings from the medieval period in Malta. The site and paintings are a testament to ways of life and artistic activity in Malta during a period for which there is limited documentary evidence, and which remains open for new research [1- 3].

A project to conserve the Ħal Millieri wall paintings was recently initiated by the Department of Conservation and Built Heritage of the University of Malta. The project offers a unique opportunity to study the materials and manufacture of these paintings, primarily to inform the development of appropriate conservation interventions, but with the potential to also uncover information that can enhance our understanding of medieval Maltese artistic practice.

The wall paintings at Ħal Millieri date to the late 15th C and were applied on lime plaster, probably using a mixed fresco technique [4, 5]. Detailed visual examination of the painted surfaces has revealed the presence of a multitude of tool marks, made during the application of plasters and paints, which tell a story about the materials, processes, and working methods used to create the paintings.

Published literature on wall painting technology generally reports localized observations of tool marks related to setting out/preparatory techniques (e.g. snapped lines, compass incisions, etc.) with an emphasis on planning stages for the painted composition [e.g. 6, 7]. No studies were identified which systematically document and analyse the distribution of all tool marks visible on wall paintings, including those related to plaster application. The study of tool marks relies primarily on detailed *in situ* examination of the wall painting surface, followed by photography and graphic documentation (most often manual or digital mapping). The process is time-consuming and can be prone to error, if marks are overlooked or misidentified. These challenges are exacerbated by factors such as the large surface area of wall paintings, difficulties of access, and inadequate lighting – all of which may partially explain the infrequency of comprehensive tool mark studies in the literature.

However, digital technologies offer new possibilities for exploring the wealth of information recorded in plastered surfaces. For the study of the wall paintings at Ħal Millieri, a combination of photogrammetry, reflectance transformation imaging (RTI) and light detection and ranging (LiDAR) are being used to record and explore tool marks identified during *in situ* visual examinations. Though these methods are frequently used to document and study three-dimensional surface features of cultural heritage materials, including wall paintings [e.g. 8-11], to the best of our knowledge this is the first time the combination has been applied to the study of tool marks associated with the application of wall painting plasters.

Our preliminary results suggest significant implications for understanding the technical and artistic practices in Malta at the time, with potential to also shed light on the transmission of artists' techniques around the Mediterranean in the Late Medieval period.

This project, carried out in collaboration with postgraduate conservation students, highlights the importance of integrating academic research with practical conservation efforts, and the value of combining traditional examination methods with cutting-edge 3D recording and modelling technology.

[1] M. Buhagiar, *The Late Medieval Art and Architecture of the Maltese Islands*. Valletta: Fondazzjoni Patrimonju Malti, 2005.
[2] C. Vella, *The Mediterranean Artistic Context of Late Medieval Malta, 1091-1530*. Malta: Midsea Books, 2013.

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[3] C. Vella, In the Footsteps of Antonello da Messina: the Antonelliani between Sicily and Venice. Malta: Midsea Books, 2022.
[4] P. Zanolini, "Appendix: Restoration report," in *Hal Millieri: a Maltese casale, its churches and paintings*, A. T. Luttrell, Ed., Valletta, Malta: Midsea Books, 1976, pp. 104–108.
[5] R. De Angelis *et al.*, "The Church of the Annunciation at Ħal Millieri: Preliminary Condition Report," Malta Centre for Restoration, 2002.
[6] S. Lazzeri, "Ricognizione visiva," in *Progetto Piero della Francesca. Indagini diagnostico-conoscitive per la conservazione della "Leggenda della Vera Croce" e della "Madonna del Parto,"* G. Centauro and M. Maffioli, Eds., Florence: Alinari, 1989, pp. 259–284.
[7] A. Brysbaert, "Painted plaster from Bronze Age Thebes, Boeotia (Greece): a technological study," *Journal of Archaeological Science*, vol. 35, no. 10, pp. 2761–2769, 2008.
[8] R. Clarricoates and E. Kotoula, "The potential of Reflectance Transformation Imaging in Architectural Paint Research and the study of historic interiors: a case study from Stowe House, England," *Journal of the Institute of Conservation*, vol. 42, no. 2, pp. 135–150, 2019.
[9] E. M. Molacek, K. Smith, K. Eremin, L. J. Cooper, and G. Rayner, "Re-Discovering a Roman Wall Painting at Harvard: New Research on a Fragment from the Villa at Boscotrecase," *Studies in Conservation*, vol. 65, no. 5, pp. 296–311, 2020.
[10] W. Rose, J. Bedford, E. Howe, and S. Tringham, "Trialling an Accessible Non-Contact Photogrammetric Monitoring Technique to Detect 3D Change on Wall Paintings," *Studies in Conservation*, 2022.
[11] A. Fiorini, "Scansioni dinamiche in archeologia dell'architettura: Test e valutazioni metriche del sensore LiDAR di Apple," *Archeologia e Calcolatori*, vol. 33, no. 1, pp. 35–54, 2022.

Efficacy evaluation of a new nanolime for extensive and eco-sustainable consolidations of architectonic surfaces. The case study of the church of St. Francesco all'Immacolata in Ortigia (Italy)

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Figure 1 – The façade of the S. Francesco all'Immacolata Church, in the historical centre of Ortigia (SR).

Maintenance of the cultural heritage assets can significantly affect the partial or even the complete loss of their values. In case of restoration, the use of appropriate materials and techniques in the renovation process represents one of the pillars to respect the original substrates to operate in according to sustainable practices.

Since their introduction in the conservation of historical and decorative surfaces, $Ca(OH)_2$ nanoparticles suspensions, also called *nanolimes*, pointed the necessity to fulfil the crucial request of compatible consolidation treatments. In fact, when exposed to air, nanolimes react with CO_2 giving rise to the formation of a new micro-calcium carbonate network onto and inside the deteriorated surfaces, "naturally" restoring the same matter that time had degraded (i.e., the binder or the fine carbonatic matrix) in all carbonatic-based substrates (mural paintings, stuccoes, stones, and historic mortars) [1]. However, this perfect match between nanolimes and the original matter only occurrs if water is present during the reaction, assuring the completeness of the well-known carbonatation process [2]:

$$Ca(OH)_{2(s)} + CO_{2(g)} + H_2O_{aq} = CaCO_{3(s)} + 2H_2O_{aq}$$

However, nanolimes are commonly dispersed in short-chain aliphatic alcohols (ethanol or isopropanohol), negatively affecting the completeness of the carbonatation process as well as the penetration depth of the consolidation treatment [3], resulting in a reduced treatment efficacy [4]. Not least, all the interventions on the architectural heritage require the consolidation of large surfaces, where the alcoholic nanolimes are subjected to inflammability risks but also great release of volatile organic compounds (VOCs) in environmen.

At the University of L'Aquila, we developed an innovative and sustainable method to produce nanolimes in water, working at room temperature and ambient pressure, by means of an exchange ion process characterized by low energy/time consumption and no toxic wastes, (European Paten EP 2880101B1) [5]. The produced nanolimes consists in dispersione of pure $Ca(OH)_2$ nanoparticles, dispersed in water, without any organic additives or secondary products deriving from the synthesis process. The eco-friendly features of this new nanolimes dispersions are also associated by the completeness of the carbonatation process, an extraordinary penetration depth, leading to good consolidating efficacies, as observed by several scientific results reported in literature [6 - 8].

Recently, the academic spin-off of the University of L'Aquila SNAPTECH Srl, thanks to a scale-up technology, has brought to the market these aqueous nanolimes, called NANOLAQ, with a production of 1400 l/week, able to satisfy even extensive applications on large surfaces.

In this work we present the results of a pilot worksite, carried out to test the on-site efficacy of NANOLAQ disperisons in the surface consolidation of the limestones on the facade of the historic Church "S. Francesco

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all'Immacolata" in Ortigia, (Sicily, Italy), (Figure 1). The Church of St. Francesco all'Immacolata, attached to the homonymous monastery, is located in Piazza Corpaci, in the heart of the historic center of Ortigia, a small island which is the historical centre of the city of Syracuse, Sicily. In 1225, the Church became the seat of the fathers of the Order of St. Francesco, and it was restored and enlarged in the mid-fourteenth century. Subsequently, in the mid-fifteenth century, the structure was reconfigured with the transformation of the orientation and the construction of the cloister structures. Damaged by the earthquake of 1693, a new renovation transformed the building in late Baroque-style. The Church has an articulated façade, characterized by a rhythmic succession of concave and convex lines, with recesses and protrusions along the entire height. The façade, divided into two orders of columns and pilasters with Corinthian capitals, is enriched by a decorative apparatus, consisting of bas-reliefs with floral and foliate elements, ending with a niche bordered by large volutes. The emblem of the Franciscan Order is placed on the top of the entrance portal, depicting two arms holding a Cross. On the right side of the building, the old bell tower is recognizable, transformed into a clock tower in the second half of the 19th century.

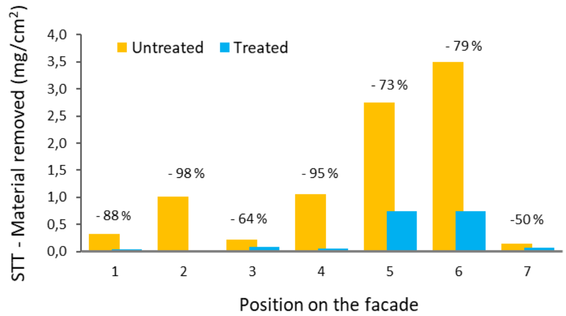

Figure 2 – STT results from different positions on the façade. The efficacy, (% reduction in the material removed in treated areas respect to untreated), is reported for each position.

The NANOLAQ dispersions are applied by airbrush at a concentration of 10 g/l. The treatments are repeated two or three times, in relation to low (LD) or high degraded (HD) areas respectively, with an application yield up to 1 liter/m^2, and any release of organic volatile compounds (VOCs) in the environment, as well.

The effectiveness of the NANOLAQ treatments is evaluated, by compared untretated (UT) and treated areas (T), in terms of: a) surface cohesion, by means of the Scotch Tape test (STT), b) mechanical resistance in depth, by the Drilling Resistance Measurement System (DRMS). Parallely, investigations are performed to assess the chemical and mineralogical composition of the stone, as well as the characterization and the carbonatation process of the nanolime particles. Microscopic studies are carried out by scanning electron microscope (SEM) to directly observe the formation of the calcite micro/nanocrystals arising in the original stone samples, after the carbonatation process.

The results show a strong increase in the surface cohesion of the treated areas, with a reduction in the material removed in the treated areas ranging from 50 % up to 98 % in the LD and HD areas, respectively, as shown in Figure 2. An average increase of the drilling resistance of the treated stone surfaces, mostly in case of the most degraded surfaces, is measured, up to 3 cm in depth.

Concerning microscopic investigations, they reveal, at low magnification (2.000 X), a better homogeneity in the observed surface when tretated with the NANOLAQ dispersions, without completely closing the pores. When observed at high magnification (40.000 X), the presence of new networks of fine scalenohedral calcite crystals is observed, acting as a binder between small original grains of the stone (Figure 3)

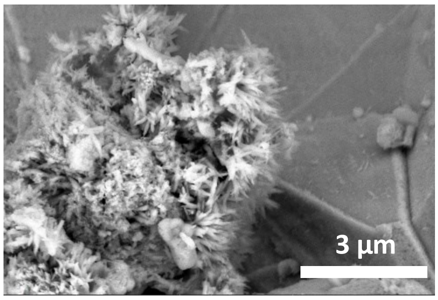

Figure 3 – SEM image at 40.000 X magnification. The network of the new nano and micro-calcite crystals

[1] B. Salvadori, and L. Dei, "Synthesis of $Ca(OH)_2$ nanoparticles from diol", *Langmuir*, vol. 17, pp. 2371–2374, 2001

[2] C. Rodriguez-Navarro, T. Ili´c, E. Ruiz-Agudo, K. Elert, "Carbonation mechanisms and kinetics of lime-based binders: An overview", *Cement and Concrete Research*, vol. 173, pp. 107301, 2023

[3] G. Borsoi, B. Lubelli, R. van Hees, R. Veiga, A. Santos Silva, "Understanding the transport of nanolime consolidants within Maastricht limestone, *Journal of Cultural Heritage*, vol. 18, pp. 242–249, 2016

[4] S. Tzavellos, G.L. Pesce, Y. Wu, A. Henry, S. Robson, R.J. Ball, "Effectiveness of nanolime as a stone consolidant: a 4-year study of six common UK limestones", *Materials*, vol. 12, p. 2673, 2019

[5] G. Taglieri, V. Daniele, L. Macera, C. Mondelli, "Nano $Ca(OH)_2$ synthesis using a cost-effective and innovative method: Reactivity Study", *Journal of American Ceramic Society*, vol. 100, pp. 5766–5778, 2017

[6] V. Daniele, G. Taglieri, L. Macera, G. Rosatelli, J. Otero, A.E. Charola, "Green approach for an eco-compatible consolidation of the Agrigento biocalcarenites surface", *Construction Building Materials*, vol. 186, pp. 1188–1199, 2018

[7] G. Taglieri, V. Daniele, L. Macera, A. Mignemi, "Innovative and green nanolime treatment tailored to consolidate the original mortar of the façade of a medieval building in L'Aquila (Italy)", *Construction Building Materials*, vol. 221, pp. 643–650, 2019

[8] S. Iafrate, G. Sidoti, F.E. Capasso, M. Giandomenico, S. Muca, V. Daniele and G. Taglieri, "New Perspectives for the Consolidation of Mural Paintings in Hypogea with an Innovative Aqueous Nanolime Dispersion, characterized by Compatible, Sustainable, and Eco-Friendly Features", *Nanomaterials*, vol. 13, pp. 317-335, 2023

Comparison of the Radon Exhalation Rate of building materials of particular historical and artistic interest: preliminary results on Ignimbrite Campana, Modica stone and Mendicino stone.

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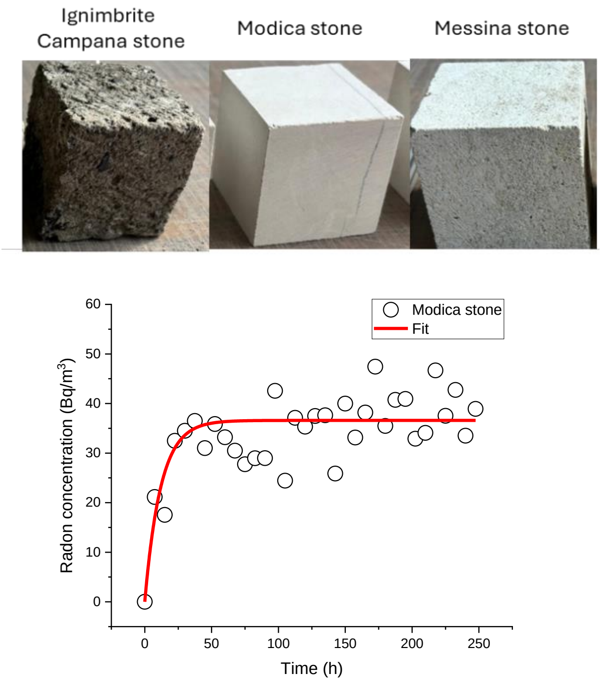

Figure 1. Analyzed samples and graph of analytic method for estimating the Radon Exhalation Rate

Radon (Rn-222) is a naturally occurring radioactive gas produced by the decay of Ra-226 (uranium series), which is prevalent in various geological formations. Its radioactive properties and ability to seep into buildings make radon a significant health risk, particularly for lung cancer upon prolonged exposure.[1][2] Consequently, understanding radon exhalation from building materials is critical for assessing indoor air quality and implementing effective mitigation strategies. Building materials can contribute significantly to indoor radon levels, depending on factors such as material composition, porosity, and environmental conditions like humidity and temperature.[3][4] High radon exhalation rates from building materials can significantly elevate indoor radon concentrations, posing health risks to occupants. Therefore, it is crucial to identify and mitigate potential sources of indoor radon to ensure a safe living environment.[5] The motivation for this study, within the framework of the ATHENA project is to establish a new protocol for the systematic and comprehensive characterization of various building materials commonly used in historical monuments, focusing on their radon exhalation rate. Experimental measurements were conducted on samples from historical underground quarries in southern Italy using the closed chamber method. Principal results compare radon exhalation rates of three different lithotypes with the intention to study further laboratory processing methods, including accelerated aging tests and treatments with commercially available consolidants. This comparison aims to understand the impact of pollution and climate factors on radon release and to evaluate the effectiveness of different consolidants in reducing radon exhalation while maintaining compatibility with the substrate.

This study specifically investigates the radon exhalation rates of various stony materials, including Ignimbrite from Campania, Modica stone, and Mendicino stone.[6][7][8] The materials were prepared by heating them to 110°C for one hour to assess the impact of humidity on radon release rates. This preparation step is essential to reduce moisture content, which can influence radon emission. Subsequently, the samples were cut into cubes of approximately 5 cm per side, as a regular shape facilitates accurate calculation of the radon exhalation surface area. These prepared samples were then

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placed in a cylindrical steel accumulation chamber connected to a RAD7 radon detector. The chamber's air was dried using a desiccant and a DRYSTIK system, ensuring minimal humidity and forming a closed loop with the RAD7 to measure radon levels effectively. A high voltage of 2500 V was applied to the chamber walls, enabling the detection of alpha particles from polonium isotopes. The RAD7 detector utilized the ^{218}Po peak to calculate radon concentrations, leveraging the rapid equilibrium between ^{218}Po and ^{222}Rn, achieved in approximately 15 minutes. The radon growth curve was monitored over a 10-day period to ensure accurate equilibrium measurements.

Results indicated that under controlled conditions, the radon concentration from the samples increased exponentially before stabilizing at an equilibrium value. This study provides valuable insights into the radon exhalation rates of Ignimbrite, Modica stone, and Mendicino stone under controlled conditions. The results underscore the significance of material composition, porosity, and environmental factors in determining radon release rates. By understanding these properties, construction professionals can make informed decisions to minimize indoor radon exposure, thereby enhancing occupant safety and health. The findings also emphasize the necessity for ongoing monitoring and regulation to maintain safe indoor environments. Ultimately, this research contributes to the broader understanding of radon dynamics in building environments and supports the development of safer construction practices to protect public health.

[1] L.J.R. Nunes, A.F. Curado, S.E.I. Lopes, The Relationship between Radon and Geology: Sources, Transport and Indoor Accumulation, Appl. Sci. 13 (2023). https://doi.org/10.3390/app13137460.

[2] A. Grzywa-Celinska, A. Krusinski, J. Mazur, K. Szewczyk, K. Kozak, Radon — The Element of Risk . The Impact of Radon, Toxics 8 (2020) 1–20.

[3] A.P.D. Baltrocchi, L. Maggi, B. Dal Lago, V. Torretta, M. Szabó, M. Nasirov, E. Kabilov, E.C. Rada, Mechanisms of Diffusion of Radon in Buildings and Mitigation Techniques, Sustain. 16 (2024). https://doi.org/10.3390/su16010324.

[4] L.J.R. Nunes, A. Curado, S.I. Lopes, Indoor radon mitigation strategies: The Alto Minho region (Northern Portugal) practical case, Indoor Built Environ. 33 (2024) 269–286. https://doi.org/10.1177/1420326X231194877.

[5] T.K. Abed, M.A. Fayad, A.A. Al-Amiery, H.A. Abdul Wahhab, J.K. Mohammed, H.S. Majdi, Radon gas emission from home appliances: Understanding sources, implications, and mitigation strategies, Results Eng. 22 (2024) 102133. https://doi.org/10.1016/j.rineng.2024.102133.

[6] F. Forni, O. Bachmann, S. Mollo, G. De Astis, S.E. Gelman, B.S. Ellis, The origin of a zoned ignimbrite: Insights into the Campanian Ignimbrite magma chamber (Campi Flegrei, Italy), Earth Planet. Sci. Lett. 449 (2016) 259–271. https://doi.org/10.1016/j.epsl.2016.06.003.

[7] L. Bergamonti, I. Alfieri, A. Lorenzi, A. Montenero, G. Predieri, G. Barone, P. Mazzoleni, S. Pasquale, P.P. Lottici, Nanocrystalline TiO 2 by sol-gel: Characterisation and photocatalytic activity on Modica and Comiso stones, Appl. Surf. Sci. 282 (2013) 165–173. https://doi.org/10.1016/j.apsusc.2013.05.095.

[8] A. Mastandrea, F. Muto, C. Neri, C.A. Papazzoni, E. Perri, F. Russo, Deep-water coral banks: An example from the “Calcare di Mendicino” (Upper Miocene, Northern Calabria, Italy), Facies (2002) 27–42. https://doi.org/10.1007/bf02667704.

Bridging Gaps in Blue Expertise through a Triple Transition Training Model for the UCH field: new challenges in uBlueTec project

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The evolving landscape of the Blue Economy reveals significant gaps in blue skills and expertise [1], especially regarding sustainability and the adoption of zero-carbon, technology-driven solutions. Addressing these gaps necessitates advancements in underwater (UW) technologies, which are crucial for various sectors, including marine biodiversity and cultural heritage conservation. Nevertheless, a major challenge remains: the shortage of qualified professionals proficient in implementing UW technologies within the green and digital transition, particularly in the Underwater Cultural Heritage (UCH) field.

To tackle these challenges, the uBlueTec project - Training framework on Underwater Technologies as a key enabler for blue career development – [2] introduces a comprehensive triple transition training and skills development model, focusing on green, blue, and digital skills. This model aims to foster enduring partnerships between universities, vocational education and training (VET) providers, industrial clusters, and small and medium-sized enterprises (SMEs) within blue economy value networks. More specifically, the uBlueTec skills-development model aims to:

a) develop educational materials and curricula to facilitate skills enhancement in state-of-the-art UW technologies with a green and digital focus;

b) pilot the developed assets within higher education (HE) and VET institutions to validate effectiveness and relevance;

c) establish a Hub on UW technologies, serving as a permanent capacity-building structure to sustain collaboration among stakeholders;

d) deploy a recruitment platform for blue jobs, offering online courses and facilitating the seamless matching of labour force skills with industry demands. Additionally, the platform will serve to identify and address skills gaps at regional, national, and EU levels, and also to attract and nurture young talents through initiatives like Career Days and Entrepreneurial Bootcamps, to foster a vibrant ecosystem of skilled professionals in the blue economy.

By implementing targeted training programs, the uBlueTec project seeks to bridge the existing skills gap [3], offering hands-on experience with state-of-the-art UW technologies. This initiative enhances the employability of participants while also aligning with broader goals of environmental conservation and economic growth. Through collaboration between educational institutions and industry stakeholders, uBlueTec aspires to cultivate a skilled workforce capable of driving the future of the blue economy, emphasising sustainability and cultural heritage preservation.

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[1] Directorate-General for Maritime Affairs and Fisheries. Skills and career development, https://oceans-and-fisheries.ec.europa.eu/ocean/blue-economy/skills-and-career-development_en, last accessed 2024/07/05.
[2] uBlueTec project website, http://www.ubluetec.eu, last accessed 2024/07/05.
[3] Ferreira et al., "uBlueTec - Training framework on Underwater Tecs as key enabler for blue careers development", OCEANS 2024 International Conference, Singapore, 14-18 April 2024

A comparison of different modulation strategies for inspecting fresco paintings using thermography

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Introduction

Fresco painting is a method of applying water-based pigments to plaster, typically on wall surfaces. Fresco painting faces several issues related to its preservation, including moisture, salt crystallization or building movement, which can cause cracks or detachments. These environmental issues, in addition with past improper restoration can cause further damages to the original artwork. A meticulous examination of the pertinent data and the formulation of an effective conservation strategy is pivotal to solve the mentioned issues. Thermography is a well-known non-destructive evaluation (NDE) technique, widely used in several industrial fields. Among the numerous benefits of thermography, its contactless nature and ability to inspect large areas in a short time make it an invaluable tool for the analysis of cultural heritage items, such as fresco paintings. For this reason, the scientific community is increasingly interested to make it more affordable and cheaper. This work focuses on the analysis of a mock-up of a fresco painting consisting of different layers. Several forms of modulating strategies for the heat emission, i.e. Long Pulse Thermography (LPT) [2], Pulse-Compression Thermography (PuCT) [3], and Multifrequency Lock-In Thermography (MFT) [4,5] are tested to verify which approach is the most suitable one, leveraging qualitative results.

Results

The measurement setup is composed of a portable function generator, i.e. a TiePie HS5 Handyscope, for generating the different waveforms. The heating system is composed of four LEDs with a nominal power of 100W each. To modulate such a heating system, a homemade Pulse Width Modulation (PWM) controller was realized. The thermal camera is a Xenics Onca-MWIR-InSb. The specimen it is a mock-up realized on a series of perforated bricks of 250x250 mm.

The different modulation strategies used in this work are depicted in Figure 1(a), while the respectively thermal outcomes are depicted in Figure 1(b).

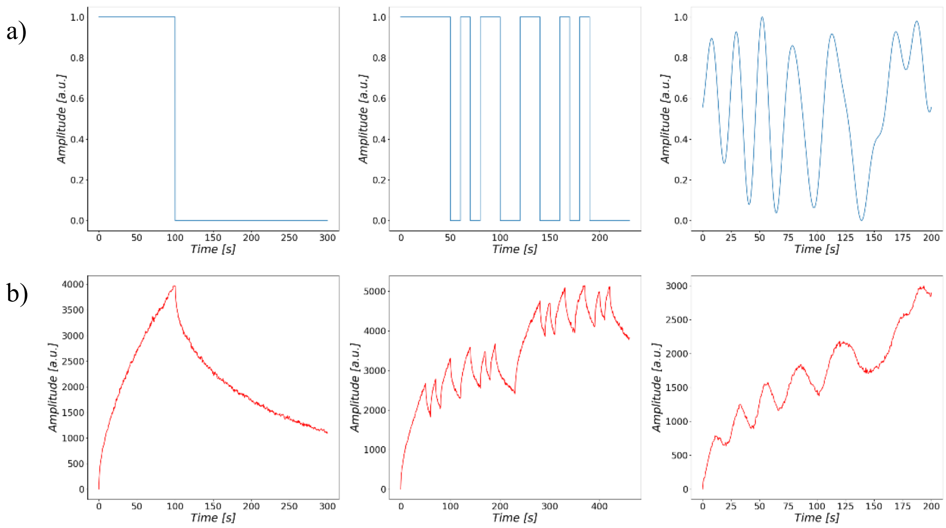

Figure 1 – (a) Different modulation strategies and (b) respective output for a single pixel frame by frame.

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The results of each modulation strategies are reported in Figure 3. All the employed techniques identify painting detachments faithfully (see the black/white spots on the top of each subplot), while LPT and PuCT make a plaster detachment located in the bottom right. Furthermore, MFT analysis allows a reconstruction at different depth of the specimen to be performed with a single measurement.

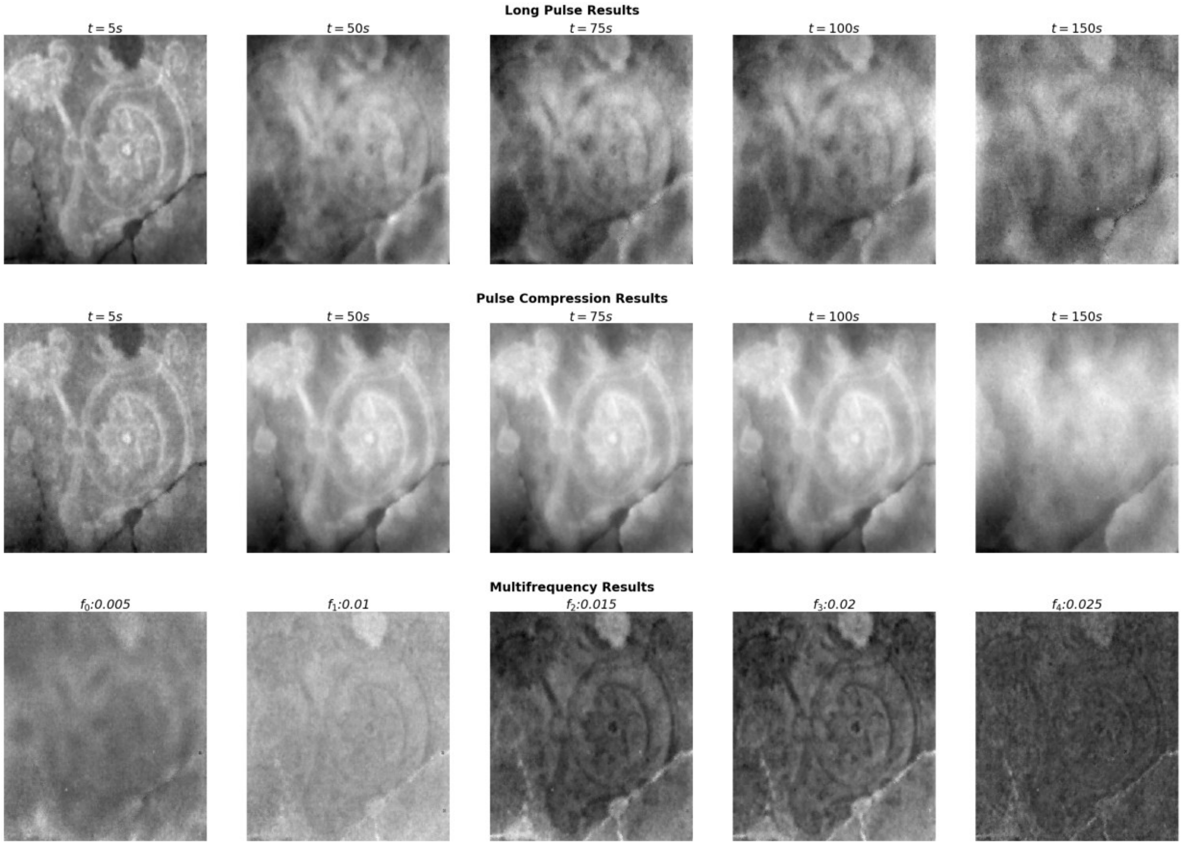

Figure 2 - Results obtained for the different modulation strategies

Conclusions

The comparison of different modulation strategies in active thermography is here presented. The employed techniques can identify macro defects faithfully. Further investigations will be aimed at comparing the techniques quantitatively to establish their sensitiveness to detect defects buried at different depths.

Acknowledgements

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References

[1] Ferrarini, G., et al. "Calibration of thermal nondestructive testing methods on mock-up historic masonry." Thermosense: Thermal Infrared Applications XL. Vol. 10661. SPIE, 2018.
[2] Sfarra, Stefano, et al. "Diagnostics of wall paintings: A smart and reliable approach." Journal of Cultural Heritage 18 (2016): 229-241.
[3] Ricci, M., Zito, R., & Laureti, S. (2024). Pseudo-noise pulse-compression thermography: a powerful tool for time-domain thermography analysis. arXiv preprint arXiv:2405.00598.
[4] Ricci, M., et al. "Optimized simultaneous Multi-Frequency Lock-in Thermography."
[5] Laureti, S., Bison, P., Ferrarini, G., Zito, R., & Ricci, M. (2024). Simultaneous Multi-frequency lock-in Thermography: a new flexible and effective Active Thermography scheme. NDT & E International, 103144.

From Dicearchia to Puteoli to Pozzuoli: Continuity of Urban Design and Analysis of Architectural Presences through the Tools of Digital Urban History

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Figure 1. Top: Aerial photo of Rione Terra, Regione Campania, 1984; Bottom: Aerial photo of Rione Terra today, Google Earth 2024.

On March 2, 1970, the Rione Terra, the ancient center of Pozzuoli (a municipality in the Phlegraean area in the Province of Naples) , was evacuated due to the bradyseismic crisis that affected the city. Shortly after the evacuation, the first excavation operations were initiated by the Archaeological Superintendency, and after years of abandonment, in 1993, the Campania Region launched a recovery and enhancement program. Thus, archaeological investigations were started, which are still ongoing today, gradually bringing to light the remains of the urban fabric of the ancient Roman acropolis. [1]

In 194 BC, the Romans founded the maritime colony of Puteoli on the tuff rock, one of the main ports of the Mediterranean. Besides the acropolis, the colony also extended on the plateau formed by the tectonic terrace of La Starza. Hence, a "lower city" could be identified, facing the port area where public buildings, the Forum, and the emporium were constructed, and an "upper city" where Roman patricians built their residences, taking advantage of panoramic points near the castrum. Additionally, the upper city was home to the most prestigious monumental buildings, such as amphitheaters, theaters, and baths [2]. The opening of the new port on the Tiber, first by Claudius and then by Trajan, led to the decline of Puteoli. In the following centuries and throughout the Middle Ages, seismic phenomena led to a contraction of the settlement on the acropolis. The ground uplift and demographic growth occurring from the 13th century, during the Angevin rule, led to a new configuration of the 'civitas', later confirmed by the Aragonese. Following the bradyseism of 1501-1503, the area facing the rock re-emerged. From 1536, Viceroy Don Pedro de Toledo promoted the reconstruction program of the ancient village and, after the eruption of 1538, the construction of a new settlement at the foot of the rock. [3]

In the following centuries, the city's expansion on the plain continued, and by the 19th century, Pozzuoli had become the major center of the Phlegraean area [4]. From the second half of the 19th century, the construction of industrial plants and infrastructures gradually altered the urban fabric, further modified by 20th-century interventions.

The urban evolution of Pozzuoli and its history boast an extensive bibliography, though numerous questions remain regarding a phase preceding the Roman period. Before Puteoli, the rock of the Rione Terra likely hosted Dicearchia, a city founded around 530 BC by a group of Samians fleeing the tyrant Polycrates. The archaeological investigations conducted so far have revealed traces of the urban layout of the Roman colony, but some finds confirm the rock's occupation in the Greek-Archaic period. [6 – 7 - 8]

The research project, initiated a few months ago, aims to investigate the evolution of the urban fabric of Pozzuoli, particularly the rock of the Rione Terra, attempting to unravel some questions about the form of the Greek colony. This study will be conducted using the tools of Digital Urban History and, specifically, HGIS (Historical Geographic Information System) [9]. Following a careful investigation of the archival, bibliographic, and iconographic evidence

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related to the city of Pozzuoli, ongoing in these initial months of research, the material and data collected will be gathered in a GIS environment, resulting in a georeferenced database, which can be expanded and queried on various layers. Recent research trends aim to integrate HGIS with HBIM (Historic Building Information Modeling) [10], thereby creating a comprehensive database that also includes information on the built heritage.

The investigation conducted so far has allowed for a preliminary reconnaissance of significant bibliographic and iconographic material for understanding the form of Pozzuoli's urban layout, from 16th and 17th-century views to modern scientific cartography, which emerged around the mid-18th century, to aerial photogrammetric surveys starting from the early 20th century [3 – 2 - 4]. The cadastral maps, dating for Pozzuoli to 1847, play a central role in reconstructing the history and urban stratification, depicting the urban fabric in detail before significant 20th-century alterations. [4 – 11]

Also of great relevance are the archaeological maps created following the excavations carried out during the 1990s [11], as well as more recent cartographic elaborations that depict the current state of the Rione Terra's archaeological heritage and, therefore, the traces of the Roman layout. [1].

This is complemented by an extensive bibliography describing the evolution and history of Pozzuoli, from ancient texts to the most recent studies. In Strabo's "Geography", written in the Augustan age, Pozzuoli is described as a naval port of the Cumaeans "situated on a height" [3]. Numerous studies conducted in the second half of the 20th century have examined the possible relationships between this Cumaean settlement and the colony founded by the Samians in 530 BC, i.e., the ideal city of Dicearchia. [5 – 12 - 7].

Moreover, studies on bradyseism, periodic vertical oscillations of the ground of metric scale connected to the volcanic activity of the Phlegraean Fields, cannot be ignored. The first studies on the subject were conducted around the 18th century, initially focusing on the macellum, erroneously known as the Temple of Serapis. More scientifically accurate studies are attributed to A. Parascandola [13] in the mid-20th century, who, analyzing the site's historical, archaeological, and geological events, developed the first summary graph of the flegrean coast's emergences and submersions. A more recent study by Pappalardo and Russo [13] integrated Parascandola's known data with subsequent geoarchaeological evidence, refining the definition of the coastline.

The methodology implemented allows for the systematization of data, documents, and information already investigated but never simultaneously examined, offering a new perspective and an innovative process for analyzing a multi-layered urban fabric like that of Pozzuoli, particularly in light of recent seismic phenomena that have once again highlighted the site's extreme vulnerability. This process will result in a georeferenced database (GIS) that forms the basis for the historical analysis of the urban center and its landscape, enabling appropriate comparisons with current urban and building stratification. The historical-architectural-archaeological heritage will thus be related to the site's orographic, geological peculiarities and the seismic phenomena that have always naturally influenced the urban evolution of Pozzuoli and, consequently, the Rione Terra rock.

The research outcome can become a fundamental tool for the bodies responsible for territory protection and management and a solid analytical basis for policies aimed at preserving urban identities and planning future recovery and conservation interventions in historic cities.

[1] C. Gialanella, R. Immarco, L.M. Proietti, M.L. Tardugno, *Puteoli. Il percorso archeologico del Rione Terra*, Naus Editoria, Napoli 2022.
[2] T. Colletta, *Pozzuoli città fortificata in epoca vicereale. Una mappa inedita conservata alla Biblioteca Nazionale di Parigi*, in Storia dell'Urbanistica Campania/I. Pozzuoli, Edizioni Kappa, Roma 1988, pp. 8 – 3.
[3] A. Buccaro, *Napoli e Pozzuoli in età vicereale: ritratti dell'evoluzione urbana*, in SANCHEZ GARCIA Encarnacion (edited by), Don Pedro de Toledo. Rinascimento meridionale: Napoli e il vicerè Pedro De Toledo. 1532 – 1553, Tullio Pironti editore, Napoli 2016, pp. 707 - 732.
[4] R. Giamminelli, A.L. Rossi, *Il centro antico di Pozzuoli: rione Terra e borgo*, Sergio Civita Editore, Napoli 1987.
[5] R. Adinolfi, *Ricerca sulla fondazione e sul periodo greco di Dicearchia*, in Puteoli: studi di storia antica, Azienda autonoma di soggiorno, cura e turismo di Pozzuoli, Pozzuoli 1977, pp. 7 – 26.
[6] R. Adinolfi, *La facies protostorica e precoloniale di Pozzuoli e nuovi studi sulla fondazione di Dicearchia*, in Puteoli: studi di storia antica, Azienda autonoma di soggiorno, cura e turismo di Pozzuoli, Pozzuoli 1989, pp.
[7] S. De Caro, C. Gialanella, M. Jodice, *Il rione Terra di Pozzuoli*, Electa, Napoli 2002.
[8] F. Zevi, Puteoli, Banco di Napoli, Napoli 1993.
[9] A. Buccaro, A. Mele, T. Tauro, *Forma Urbis Neapolis. Genesi e permanenza del disegno della città greca*, artem, Napoli 2023.
[10] N. Brunoa, F. Rechichia, C. Achille, A. Zerbia, R. Roncella, F. Fassib, *Integration of Historical GIS data in a HBIM system*, in The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLIII-B4-2020, 2020 XXIV ISPRS Congress, 2020
[11] A. Buccaro, C. De Seta (edited by), *Iconografia delle città in Campania. Napoli e i centri della provincia*, Napoli 2006.
[12] R. Annecchino, *Storia di Pozzuoli e della zona Flegrea*, Pozzuoli 1960.
[13] M. Salvatori, *Archeologia sommersa nel Mediterraneo. Tutela, restauro, valorizzazione*. Edizioni Scientifiche Italiane, 2010

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3D GPR model for mapping underfloor burials

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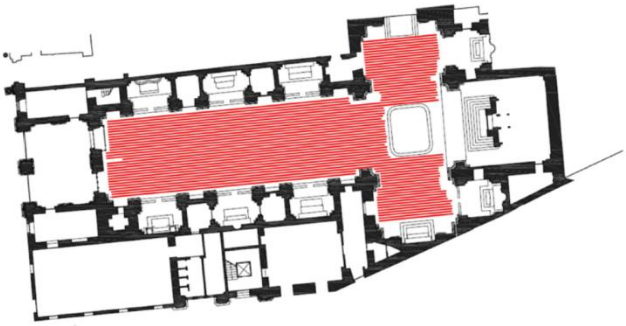

Figure 1 – GPR profile grid

Detailed ground penetrating radar investigations were carried out in the church of San Francesco d'Assisi in Trapani (Sicily, Italy) with the aim of reconstructing the presence of possible underfloor burials. The church with the adjacent convent of the Order of Friars Minor forms a monumental aggregate of Classical-Renaissance style, founded in 1272.

The georadar investigations were carried out using the Georadar instrumentation of IDS – Engineering dei Sistemi s.p.a. – RIS MF HI-MOD model. The instrument is equipped with a 200-600 MHz multi-frequency antenna, which allows high performance in detecting anomalies in the subsoil. This system is capable of generating, capturing, amplifying, filtering and archiving signals and allows the acquired data to be displayed in real time. This allows immediate evaluation of the data, thus allowing the modification of the acquisition parameters directly in situ. In this way it is possible to optimize the quality of the acquisition, avoiding further repetitions of measurements and reducing the time necessary for investigation operations.

For the investigations, only the monostatic configuration with a 600 MHz antenna was used, considered suitable to achieve the best definition and depth in relation to the objectives to be investigated. In particular, 77 GPR profiles were acquired (fig. 1a), for a total of approximately 1400 metres. An acquisition range of 60 ns was used for the 600 MHz antenna. To transform the traveltimes of the reflected waves into "reflector depth", it is necessary to estimate the value of the speed of the electromagnetic waves, and therefore the value of its average dielectric constant. The investigation depths were estimated considering an average electromagnetic wave propagation velocity of approximately 0.1 m/ns, obtained from the slopes of the reflection hyperbola present in the data. Using this average value for all profiles performed, the maximum survey depth reached is approximately 3 metres.

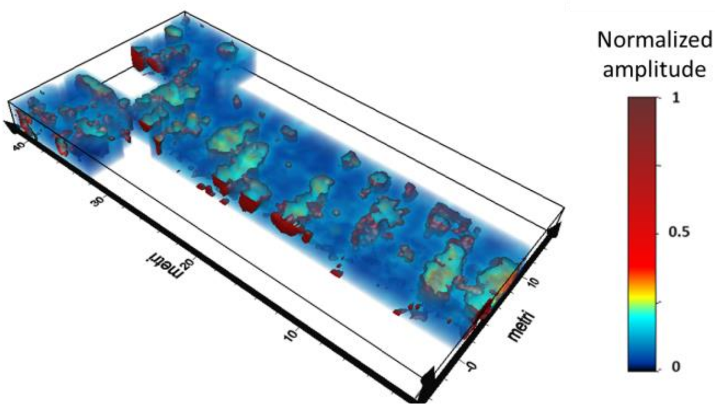

Figure 2 – 3D GPR model

After the processing of the individual GPR profiles, the data were reorganized into a 3D GPR model (fig. 1b), up to a maximum depth of 3 metres. The 3D model highlighted some anomalies that can be interpreted with the presence of buried structures and/or voids which were highlighted through a red isosurface.

The detail of the identified anomalies made it possible to reconstruct a model of the buried structures using images and documentation obtained during one of the restoration interventions of the church.

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Non-invasive techniques for characterizing the pigments applied on wall houses from Roman Apulum (Romania)

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Dacia became a Roman province during Emperor Trajan`s rule (after AD 106) and was reorganized (Fig. 1) by the next emperor, Hadrian, who decided to divide it into three (Dacia Porolissensis, Dacia Superior, and Dacia Inferior), ruled by a Governor, who had his headquarter in Apulum (Alba Iulia City). Thus, after AD 168-169, Apulum transformed into the political and military capital of the Roman province - Dacia, an important urban centre of the Empire. In the past 136 years, numerous archaeological finds enriched the history of Roman Apulum and Roman Province Dacia with new data. Among the high amount and diverse categories of discovered artifacts, numerous wall-painted fragments are mainly from civil houses. Various pieces were described, analysed from a stylistic point of view, but they were not investigated in terms of non-invasive analytical techniques to elucidate the painting methods and the used materials. In this context, this study aims to identify and characterize the pigments employed by Roman painters in decorating the houses from Apulum, as well as to identify the painting technique. To achieve this goal, fragments of Roman painting wall recently discovered in three different archaeological sites inside the ancient Roman Apulum were selected and studied using non-invasive analytical techniques (optical microscopy and vibrational spectroscopy). They have different colors and shades, such as red, green, blue, white, yellow, ochre, brown, and admixtures. To establish the potential materials used for wall painting, 14 pigment samples were analysed by vibrational spectroscopy.

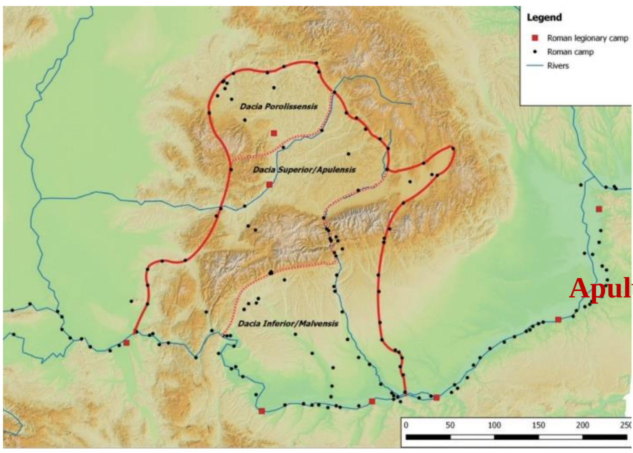

Figure 1. Map of Roman Dacia after the administrative re-organization of Emperor Hadrian [1](Opreanu, Lăzărescu 2016, fig. 15).

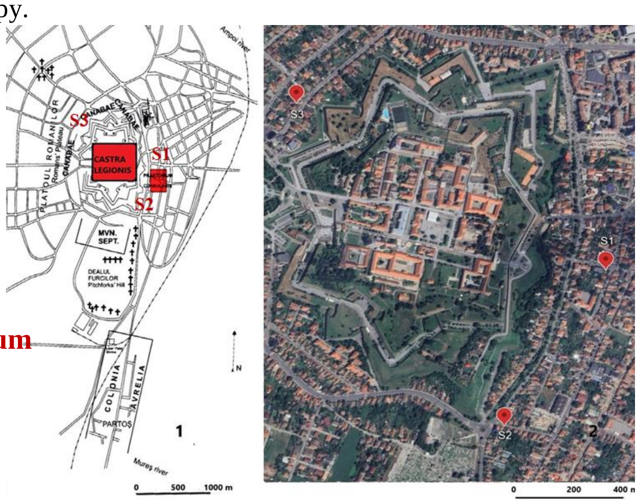

Figure 2. General map of Apulum (left side) [2], pl. III with S1, S2, S3; Google Earth capture (right side) highlighting the S1, S2 and S3 archaeological excavations sites.

The samples included in this study come from archaeological excavations (named S1 to S3) located inside the ancient Roman Apulum II (Fig. 2.1-2), part of the site Municipium Septimium Apulense (the Canabae of the Roman legionary fort) – the canabae legionis that became a municipium (municipium Septimium Apulense) in AD 197.

The samples APL-1 to APL-6 (Fig. 3) representing wall painted fragments discovered in the room located in the central-western part of the trench were collected from S1 (Fig. 2), located at 360 m East from the Roman legionary fort of Legio XIII Gemina, 200 m North from Governors` Palace (Pretorium consularis), and 90 m from the excavations undertaken in 1962 by Ion Berciu and Alexandru Popa [3]. The current address of the site location is Dimitrie Cantemir Street, no. 15 A. The archaeological excavations were undertaken between 2021 and 2022 on a surface of 269.29 m^2.

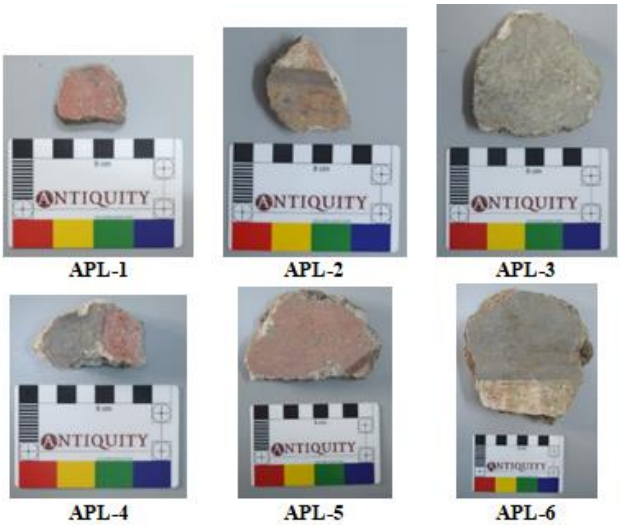

Figure 3. Samples APL-1 to APL-6 collected from S1 site.

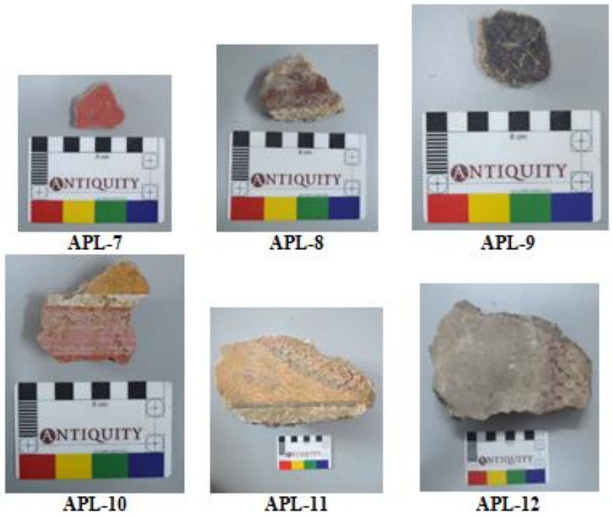

Figure 4. Samples APL-7 to APL-12 collected from S2 site, square C.

The samples APL-7 to APL-12 consisting in wall painted fragments and red painted floor fragments (Fig. 4) were collected from the S2 site (Fig. 2), located to the Western part of the Roman necropolis on Dealul Furcilor-Podei, to the South-East of the Roman legionary fort of 13th Twin Legion (Legio XIII Gemina), and South-West from the Governors` Palace - excavations of A. Cserni, D. Berciu, V. Bolindeț [4]. The current address of the site location is Dimitrie Cantemir Street, no. 15 A. The archaeological excavation occurred in 2019 on a surface of 140 m^2, divided into three squares tagged from North to South with A, B, and C. The samples APL-13 to APL-15 (Fig. 2, 5) were collected from the third site (i.e., S3), located to the Western limit of the canabae of the Roman legionary fort, at 300 m from the castrum. The current address of the site location is Aurel Vlaicu Street, no. 20 C. The archaeological excavation occurred at the end of 2023 on 225 m^2 surface. Eleven archaeological complexes outlined by tranches of dismantled walls were discovered. The samples are part of a dismantled wall called Z1.

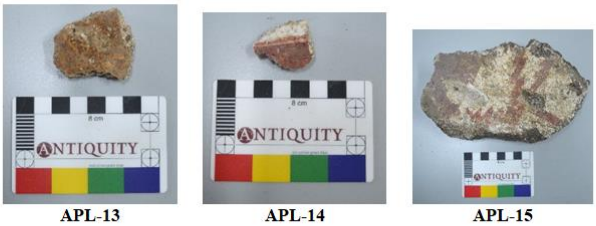

Figure 5. Samples APL-13 to APL-15 collected from S3 site.

The main spectroscopic methods used to detect the vibrations of atoms in molecules are based on the absorption process of infrared radiation and the phenomenon of inelastic Raman scattering. These methods are widely used in practice to provide information about the molecular structure, to identify substances based on characteristic spectral "fingerprinting" and to quantitatively or semiquantitatively determine the amount of analyte in a sample. Particularly, the pigments were investigated using non-invasive and non-destructive techniques such as micro-Fourier transform infrared spectroscopy (micro-FTIR) and Raman spectroscopy. To confirm the results of non-destructive techniques selected micro-samples were also subjected to optical microscopy analysis. The obtained spectra were processed with Opus8 software (micro-FTIR) and were compared with the existing spectra in the spectral databases specific to each technique. In conclusion, several non-invasive techniques are applied to characterize the pigments, being the first step in archaeological analysis, prior to other invasive methods, which should only complement them, obtaining some more detailed results.

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[1] C.H. Opreanu, V.A. Lăzărescu, "The province of Dacia". In C.H. Opreanu and V.A. Lăzărescu (Eds.), Landscape Archaeology on the Northern Frontier of the Roman Empire at Porollissum. An interdisciplinary research project, Mega Publishing House, Cluj-Napoca, 2016, pp. 49-111.

[2] I. Piso, "Inscriptions d'Apulum: (Inscriptions de la Dacie Romaine - III 5)", Mémoires de l'Académie des Inscriptions et Belles Lettres, Paris, XVI–XXI, 2001.

[3] R. Ota, V. Rusu-Bolindet, D.G. Anghel, "Reconstituire Istorico-Arheologică: Săpăturile Preventive Efectuate în Anul 1962 la Palatul Guvernatorului Consular al Daciei Romane de la Apulum", *Acta Mvsei Apvlensis, series Archaeologica et Anthropologica*, LVII, 2020, pp. 149–216.

[4] V. Rusu-Bolindeț, "The praetorium consularis from Apulum. A symbol of official power in the province of Dacia", in Authenticity and Experience. Governer`s palaces of Roman imperial period and the limes, Zoltán Havas (ed.), Proceedings of the international conference, Budapest, 5-6 November 2018, pp. 97-121.