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PROCEEDINGS

11th International Symposium on the Conservation of Monuments in the Mediterranean Basin

Exploring Material, Techniques and Information Management for Conservation, Urban Restoration and Cultural Heritage

17-19 of June 2024 Athens, Greece

Editors

Dimitrios KOUIS

Fulvio ZEZZA

Maria KOUI

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The 11th International Symposium on the Conservation of Monuments in the Mediterranean Basin was organized by:

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- *Department of Conservation of Antiquities and Work of Art*

National Technical University of Athens (Greece)

- *School of Chemical Engineering / Material Science and Engineering Department*

University of IUAV Venice (Italy)

- *Department of Architecture*

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Under the auspices of:

The International Group on the Conservation of Monuments in the Mediterranean Basin (IGCMM).

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Regarding Digital Technologies and their contribution to Cultural Heritage Management, ReasonableGraph.org is an open-source application developed by AltSol. The platform focuses on the proper repository organization, digital and descriptive cataloguing of documents, access, and management of ontologies.

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Part I

Opening Speeches

Welcome Speech

Dimitrios Kouis - Associate Professor, Department of Archival, Library and Information Studies, University of West Attica, Greece

Dear Rector,

Dear members of our University Board,

Dear Members of the Scientific and Organizing Committees,

Dear Presenters and Authors,

Dear Participants,

The **seven years** that have passed since the organisation of the previous Symposium have changed the world and each of us personally.

From practical and ethical perspectives, the COVID pandemic, the war in Ukraine, and the subsequent economic crisis made it impossible to organise the MONUBASIN Symposium under the terms and conditions that would bring the best possible outcome.

But today "**It's Gonna Be A Good Day**"!

With **great joy and emotion**, I welcome you to the 11th International Symposium on the Conservation of Monuments in the Mediterranean Basin held at the University of West Attica in Athens, Greece.

The combined efforts of five Academic Institutes made it possible for this conference to take place today. Namely

1. The Department of Archival, Library and Information Studies, and the Department of Conservation of Antiquities and Works of Art from the University of West Attica
2. The Department of Materials Science and Engineering of the School of Chemical Engineering at the National Technical University of Athens
3. The School of Chemistry at the Aristotle University of Thessaloniki
4. The Department of Architecture of the IUAV of the University of Venice and
5. the University of L Aquilla in Italy

The theme of our **11th MONUBASIN** is **"Exploring Material, Techniques and Technological Advances for Conservation, Urban Restoration and Management of Cultural Heritage in the New Era".**

The new era is characterized by recurring anthropogenic crises, climate change, the increase of conflicts in recent decades especially in the Mediterranean basin region such as: Bosnia and Herzegovina, Serbia, Syria, Algeria, Lebanon, Israel, but also in the broader region of the Black Sea such as: Ukraine, Georgia, Armenia, with incalculable disasters in museums, archaeological and urban sites.

In the field of technology, significant progress has been made in devices/techniques for the diagnosis and characterization of materials, as well as for conservation/restoration interventions in cultural heritage objects and structures. This progress has been facilitated by the development of non-invasive techniques and, more recently, the use of Artificial Intelligence (AI).

The Symposium's theme refers to the materials, techniques, and state-of-the-art technological advances used for damage assessment, rehabilitation, and restoration in urban environments, with a focus on sustainable and long-lasting conservation. It also encompasses aspects of cultural heritage management related to conservation/restoration procedures and techniques, as well as innovative approaches to promoting and presenting cultural artifacts to the public and relevant stakeholders in the new digital era of cultural heritage management.

We hope the Symposium will provide a forum for scientists, technicians, and experts in the conservation and restoration of monuments to present their work and exchange ideas and experiences.

More than 200 authors, attendees, exhibitors, and sponsors participated in this Symposium.

All the papers were critically reviewed by the members of the Scientific Committee, to whom I would like to attribute my deepest gratitude for all their essential effort and cooperation in this crucial aspect of the Symposium.

The proceedings will be published in the eProceedings service with Open Access by the National Documentation Center (EKT). ***eProceedings*** *is an innovative service for the electronic publishing and management of conference proceedings, helping researchers and academic institutions reach a wider readership and effectively promoting new ways of scholarly communication in full compliance with the principles of open access. Each paper in the proceedings will get a unique DOI and will be indexed by Google Scholar and other citation indexes.*

Additionally, two special issues in esteemed International Journals will be published to enhance the visibility and dissemination of the conference papers: Infrared Physics & Technology, by Elsevier, and the Journal of Integrated Information Management, by the University of West Attica.

I would also like to thank **Professor Fulvio ZEZZA** from the University IUAV of Venice, ITALY. He is the President of the Symposium and Coordinator of the International Group on the Conservation of Monuments in the Mediterranean Basin. Unfortunately, he was unable to be with us due to unforeseen personal issues. However, we will be able to see and hear him in the Opening Lecture titled "Exploring materials, techniques and technological advances for conservation, urban restoration and management of cultural heritage in the new era" in a little while.

Additionally, I would like to express my sincere gratitude to Professor Maria Koui for providing me with the opportunity many years ago to participate in the MONUBASIN conference events.

Additionally, I believe she deserves our gratitude, as she has been responsible for organizing most of the MONUBASIN conferences, including the one that starts today.

I would also like to thank

Stamatios BOYATZIS, Professor and President at the Department of Conservation of Antiquities and Works of Art at the University of West Attica

Ioannis KARAPANAGIOTIS, Professor at the School of Chemistry in the Aristotle University of Thessaloniki and

Stefano SFARRA, Associate Professor at the Department of Industrial and Information Engineering and Economics at the University of L'Aquila,

I would also like to express my gratitude to the Rector, Professor Panagiotis Kaldis, and his efforts that allowed us to host the conference at our university.

Many thanks should be extended to the Scientific and Organizing Committee members, whose contributions are considered of utmost importance for the success of the Symposium.

Additionally, I would like to express my gratitude to my colleagues for their assistance with the conference organization. Many thanks to Valia Triperina, Ioannis Drivas, Vasiliki Dritsa, Nikolaos Lazaridis, Manto Psallidakou, Georgia Kiriakaki, and Foteini Euthimiou.

Lastly, I would like to express my sincere gratitude to all sponsors for their generous financial support.

I hope you enjoy the conference and that it proves to be an event that will help you on both a scientific and professional level.

Opening Lecture

Exploring materials, Techniques, and Technological Advances for conservation, urban restoration, and management of cultural heritage in the new era

Fulvio Zezza, Coordinator of the International Group IGCMM (Conservation of Monuments in the Mediterranean Basin)

Authorities, Colleagues, and Participants all,

I have deep gratitude for all those who made it possible to continue, after the Covid pandemic, the route of our Conferences dating back to 1989. Allow me to open the Symposium with the preface **(fig,1)** of the first notice: "with great joy, but also emotion, we are pleased to announce that the University of West Attica, the National Technical University of Athens, the IUAV Architecture University of Venice and the Aristotle University of Thessaloniki will organize the 11th International Symposium on the Conservation of Munument in the Mediterranean Basin. The seven years that have passed since the organisation of the previous Symposium have changed the world and each of us personally. The COVID-19 pandemic, the war in Ukraine, and the subsequent economic crisis made it impossible, from both practical and ethical perspectives, to organize the Monubasin Symposium.

Figure 1

The Symposium opens today under the auspices of the International Group IGCMM that I have the honor of coordinating **(fig.2)**. Without the collaboration of our Universities and without sharing the organizational efforts made by the professors Maria Koui and Dimitrios Kouis, who carried out the preparation of the works with admirable competence, it would have been difficult to find ourselves in Athens to present and discuss the scientific contributions on the protection of the cultural heritage.

Figure 2

The values shared by IGCMM International Group are the monuments of the Mediterranean Basin **(fig. 3), which saw the birth and development of the great civilizations of the past and which guard the most important historical, archaeological,** and artistic patrimony of the world. Monuments and archaeological sites are integral to the history of cities and territorial colonization, in which humans have operated, and are today considered identity values by the communities that live there.

Figure 3

The monuments marked the most significant stages of antiquity, and although very little remains of those from the prehistoric period, the settlement structures and the multiplicity of coastal colonization characterize the urban polycentrism typical of the Mediterranean area.

History reminds us of the sacred rite of city foundation (**fig. 4**) and territorial colonization, during which monumental works dedicated to the gods were constructed. The spatial models and foundation rites were linked to hierarchical subdivisions and religion, and at the same time allowed citizens to recognize the reasons for choosing the site. In ancient times, city and community coincided: the all-encompassing enclosure of the former physically contained and socially identified the latter. Territorial control and the urban function, which are at the origin of the occupation of space and environment, have occurred according to a progression of civil society progressively extended from the Mediterranean towards the west. Protective walls and urban communities have constituted a widespread reality throughout the Mediterranean area. Of course, not all defensive walls were the same, as their design depended on the technological development of the citizens and were a function of the political and military concepts.

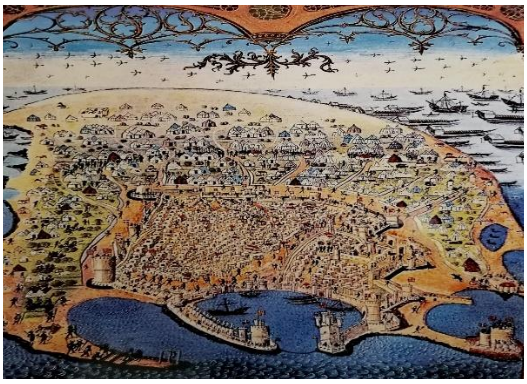

Figure 4

Athens **(fig.5)**, the most emblematic example in the history of symbiosis between political structure and society, built a huge fortified corridor among two parallel courtains, the so called Long Wall, in order to link the city to the fortress of the Pireo Harbour, for the supplies that the ships brought by sea and to organize their expeditions Many cities flourished in subsequent times were equipped with monuments and powerful defensive walls and continued to follow strategic and urban planning capable of interpreting the value of the sites and protecting the communities.

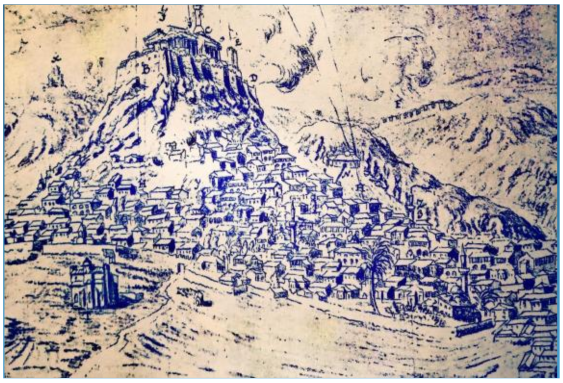

Figure 5

Nowadays, cities **(fig. 6) and citizens no longer seem to** recognize each other. Modern metropolises are often besieged by traffic and air pollution, eroded from within by the extension of tertiary consumption, degraded by dizzying expansion and the progressive loss of identity. Architectural historian Joseph Rykwert said that our cities seem the furthest from having an idea of themselves.

Figure 6

From this context emerges the scientific interest of the International Group, which, rather than dwelling on the aesthetic judgment of monuments in today's cities and territories (**fig. 7**), aims to investigate their intrinsic value to ensure their conservation. In this regard, I have the obligation to summarize the reasons, conceptual contributions, objectives, methodologies, outcomes of our meeting, and the challenges inherent in our scientific activity.

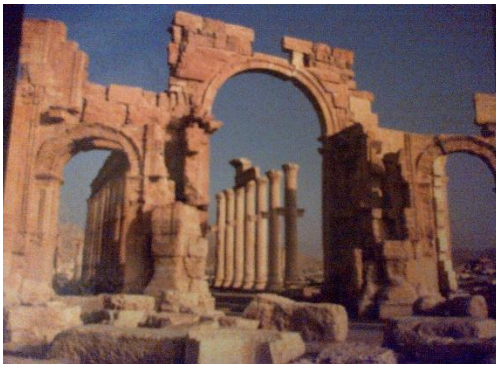

Figure 7

The initiative to form the Group **(fig. 8) was born to elaborate common information and strategies in the context of interdisciplinary research on** monuments exposed to natural and anthropogenic risks.

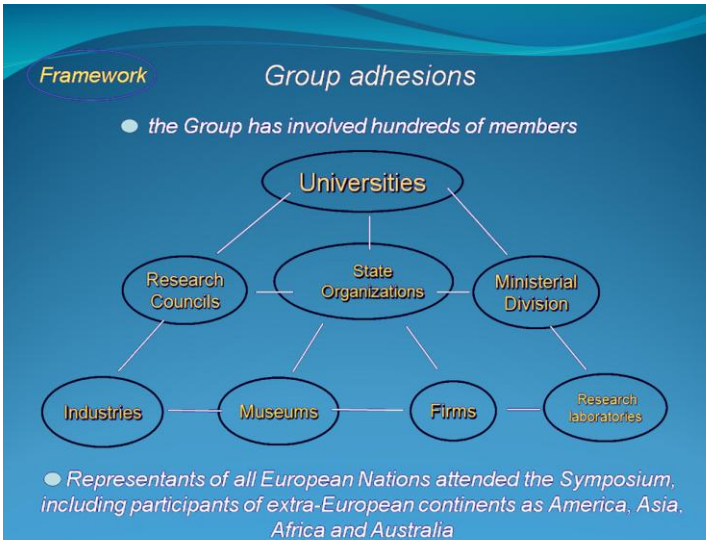

Figure 8

This initiative was linked to a lack of coordination among Mediterranean countries (**fig. 9**), despite their adherence to the UNESCO Convention, which is signed by **a total of 175 countries**.

Figure 9

However, it was favored by the projects launched by the European Commission through the Environment and Environment-Climate programs for the Protection and Conservation of Europe's cultural heritage. These projects **(fig. 10) will lay the foundation for a better understanding of the causes, effects, mechanisms, and consequences of stone decay, and** develop practices and technologies on a sound scientific and technical basis. Until the Group was founded, no one had presented organic proposals that could involve the entire Mediterranean Basin; therefore, the value of the Group lies not only in delving deeper into the issue of monument conservation but also in contributing to the protection and enhancement of the cultural heritage of Mediterranean countries.

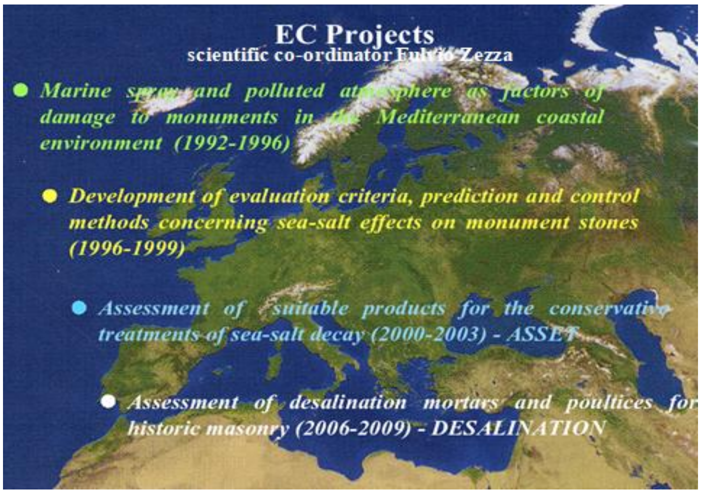

Figure 10

In this context, what conceptual contributions, intervention technologies, symposium outcomes, and challenges does the Group propose?

Regarding the conceptual contributions of scientific research, I often like to emphasize that a monument cannot be summarized in a single stone sample to be analyzed in a laboratory (**fig. 11**), but rather it forms a structure that responds to a series of environmental stresses. According to this perspective, the debate within the International Group aims to develop a synergistic approach focused on a deeper understanding of the damage caused.

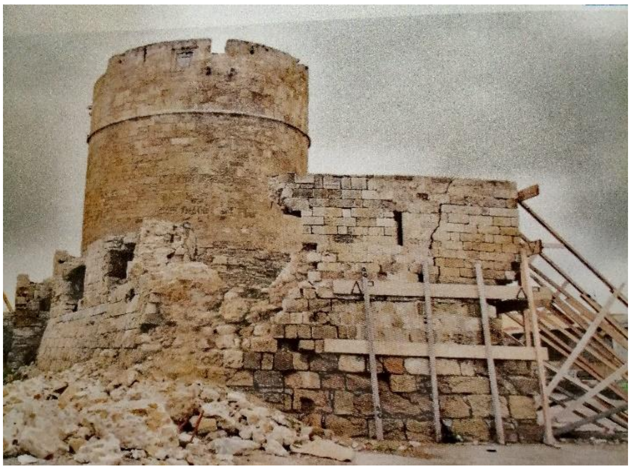

Figure 11

Over the last century, a growing trend has damaged a significant number of monuments in increasingly short periods. The architectonic structures, composed of various building materials, react to a wide range of stresses; therefore, stone decay, as well as natural and anthropogenic hazards, proceeds at the same rate and leads to the ruin of the monument.

Among the damage sources are those remarkable for air pollution (**fig. 12**). The great variety of compounds that circulate in the atmosphere enhances stone damage. The accumulation of organic and inorganic pollutants in the air tends to occur on the exposed surfaces of monuments and react with the mineralogical components of their substrates, lacking any form of regeneration.

Figure 12

The industrial development played a significant role in the formation of black crusts (**fig. 13**), which cover and disintegrate the substrates. In particular, the black crusts composed of sulphates (gypsum) are today the most visible consequence of the aggressiveness suffered by the monuments.

Figure 13

Sulphates often act in concert with marine aerosols (**fig. 14**), which are introduced directly into the atmosphere by the sea in the form of drops and minute particles. The salt spray provokes disaggregation, exfoliation, cracking, fissuring, and detachment.

Figure 14

The annual quantity of marine aerosol introduced into the atmosphere by the sea is estimated to be equal to 10^9-10^10 tons/year, so that dry depositions, rainwaters, and those of condensation contribute notably, with the help of sulphates (**fig. 15**), to the deterioration of the monumental patrimony.

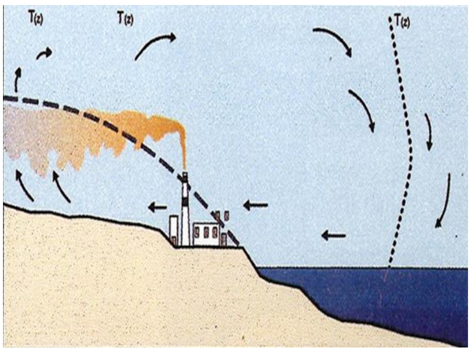

Figure 15

Moreover, the geological risks release the tremendous sight of the catastrophic events that have happened. Seismicity and volcanism, floods and landslides, as well as active tectonic and subsidence, threaten the safety of architectural structures. In monument conservation, the incidence of geological hazards (**fig. 16)** affecting monuments in the Mediterranean region has not yet been adequately addressed. It is also necessary to map the area at risk on both small and large scales. This field requires specialized investigations to forecast the effects of hazards, taking into account the interrelation between the vulnerability of the element at risk and the consequences of expected catastrophic events.

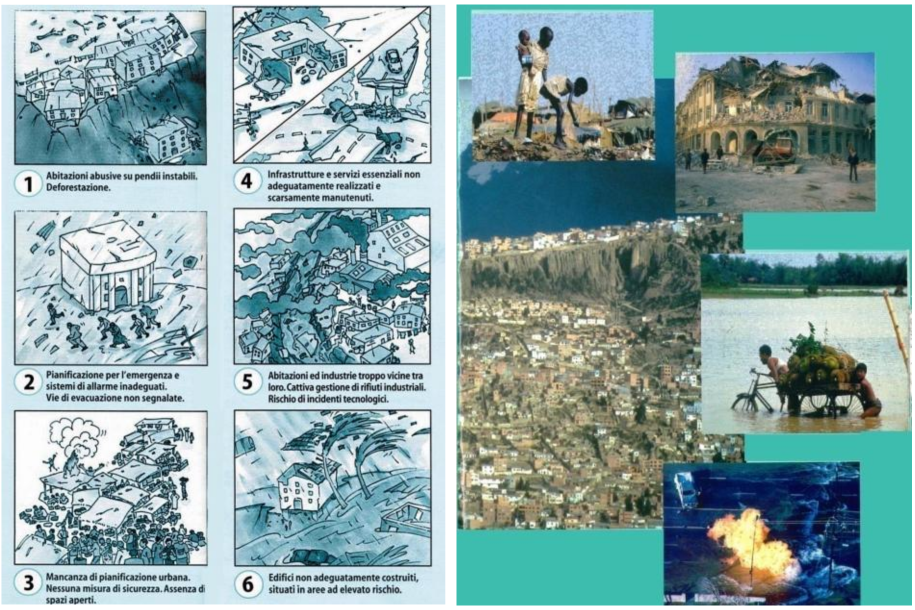

Figure 16

No less harmful are the war events **(fig.17),** which now, as then, spare neither human lives nor monuments. As for intervention technologies, in monument conservation, the risk conditions are a matter of growing concern. In risk management, it is a common task to provide advanced knowledge regarding the three different risk components: damage, vulnerability, and value of the element at risk.

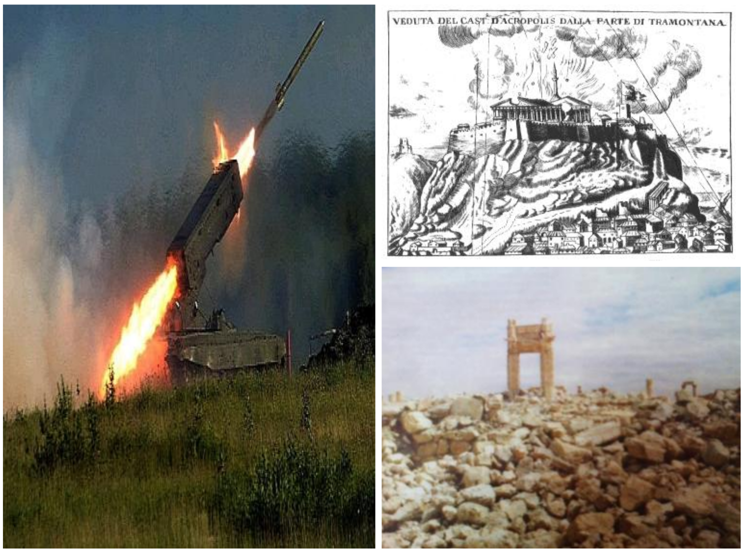

Figure 17

A correct procedure for stone conservation involves three phases of investigation: anamnesis, diagnosis, and therapy. In this way, the International Group intends to provide further findings for mitigating the risks, or rather, reducing the conditions of risk. We share the lines indicated by the European Commission within the Environment and Climate Programme, inspired by objectives aimed at strengthening the scientific basis for protection and rehabilitation measures. Moreover, we dedicate more space to the interrelation between monument and site: the failures are interpreted in terms of the dynamics of the architectonic structure, considered as a whole, and dependent on the intrinsic features and the environment that provoke aggressions of prolonged or sudden action. This approach progresses from understanding causes, mechanisms, and effects to quantifying damage, developing valid methods and technologies for interventions, and ultimately verifying environmental risks.

Besides, taking into account that the preservation of the architectonic structures is of fundamental interest for the economical, social and educational aspects, our efforts are steered towards suitable methodologies as integral part of the damage reduction policy which follow non-invasive analyses **(fig.18)**. The overall aim of the diagnosis is the characterization, quantification, interpretation and rating classification of stone dacay by means non-invasive techniques to assess the degree of damage, the distribution of weathering forms as well as the need of intervention.

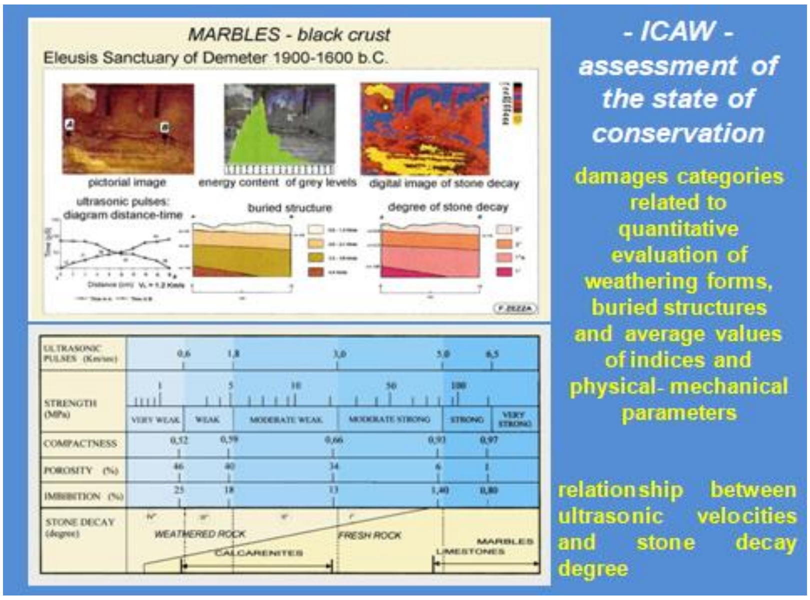

Figure 18

Regarding this, I would like to show you an example of digital images (**fig. 19**) that I processed for the Parthenon West Freeze blocks when I was invited by the head of the Documentation Office of the Acropolis Restoration Service to assess the effects of laser cleaning on marble surfaces before and after treatment.

Figure 19

To protect the materials and consolidate the structures using methods and technologies designed to preserve their artistic value, reducing vulnerability is our target.

As for Symposia outcomes, spreading the knowledge of such enormous richness and contributing to its safeguarding and enhancement has always been the objective of all those who care for the historical and artistic heritage (**fig. 20**).

Figure 20

The examination of the extraordinary cultural heritage of the Mediterranean Basin began with the 11th Bari Symposium (1989), which focused on the coastal environment and, in particular, on the theme of sea-salt-damaged monuments. The 2nd Symposium was organized in Geneva (1992) on the monothematic topic of the white marbles to establish the analytical techniques suitable for tracing back to the ancient quarries and to propose adequate products in conservative treatment. In Venice (1994) and Rhodes (1996), further knowledge was gained on the causes of weathering forms, as well as on the analytical methodologies for conserving monuments and historical complexes. The Symposia of Seville (2000) and Lisbon (2004) addressed the recovery of cultural heritage in cities and territories with environmental conditions. Water and cultural heritage were the themes of the Symposium of Orleans (2007), which began with the monumental patrimony of the Loire Valley. This was a once-in-a-lifetime opportunity to clarify the site's identity in terms of its natural resources, water, and cultural wealth as key elements for the project. Water shapes the territory, and before becoming an economic issue, contributes to the location of historical patrimony, such as abbeys, defense systems, and ancient bridges. Patras (2010), in turn, gives a further opportunity to highlight the focal points of the monument damage hazards and those of the rehabilitation technologies, inside of which are placed equally important topics, from the damage forms to the conservation products, from the test-application to the prevention measures for the monitoring and the maintenance, from the construction to the restoration. In turn, the Symposium of Ankara (2014) focused on integrated rehabilitation methodologies in conservation, stimulating new proposals as answers to the questions that products and conservative interventions must not cause damage to structures and that the performance of rehabilitation works must continue for the structure's lifetime. The Athens Symposium (2017), based on monument hazards and sustainable preservation, aims to deepen knowledge within the complex system of heritage-environment. Starting from the concept that damaged stone represents one of the most visible aspects of conservation, methodologies and techniques have been examined that are able to contrast or mitigate the occurrence of sudden and long-term events.

As for challengers, the theme of this Symposium, 'Exploring Materials, Techniques and Technological Advances for Conservation, Urban Restoration and Management of Cultural Heritage in the New Era', anticipates the Group's future leadership intentions. The new era is marked by recurring anthropogenic risks, including war and economic crises, as well as environmental changes, alongside impressive technological advancements such as artificial intelligence (AI) within the cultural heritage ecosystem. The theme of the Symposium refers to materials, techniques, and technological advances aimed at sustainable and long-lasting conservation, as well as promoting new approaches in the digital era for cultural heritage management. Within the theme are treated six topics: historical and structural aspects, natural and anthropogenic hazards, damage assessment, digital techniques, technologies for rehabilitation and sustainable preservation, planning, and cultural heritage management. Usually the attention of the speakers is focussed on the two categories into which the monumental heritage is conventionally divided **(fig.21)**: the first includes monument dating from prehistoric age to the fall of Roman Empire, the second includes the heritage ranging from the Middle Age to the Modern Age, such as castles, fortified systems, churces, palaces and historical centres. Each paper presented at the Conference deals with the recognition of the value of the artifact, drawing inspiration from the conservation criteria.

Figure 21

Monument preservation is of fundamental interest for the social, economic, and educational aspects, so that our efforts are steered towards the major conservation requirements that arise from research capable of formulating the compatibility among materials, architectural structures, environment, and management strategies. Spreading awareness of the Mediterranean heritage and contributing to its protection is the qualifying objective of those who care about the cultural identities of the countries that hold treasures of inestimable value.

I would like to conclude by thanking the Organizing Committee and the Scientific Committee who made it possible to provide the best welcome for the participants and to ensure the selection of communications for the dissemination of the most recent and significant results. I would like to express my appreciation to the participants for their continued contributions to the development of the topics on which our interdisciplinary approach to conservation is based. Convinced that our mission will always be supported by scientific knowledge in facing future challenges, I wish everyone a fruitful job.

Part II

Thematic Area 1 - Historical and Structural Aspects of Monuments

Preliminary Restoration Proposal for the Holy Monastery of "Kokkini Ecclesia" (Red Church) in Lefkada

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Abstract. The Holy Monastery of "Kokkini Ecclesia", a significant cultural and religious heritage site in Platystoma, Lefkada, presents a unique architectural and historical challenge for restoration and conservation efforts. The abstract outlines a preliminary restoration proposal based on detailed historical research, architectural analysis, and structural assessment conducted on-site.

The Monastery complex, characterised by its enclosed polygonal shape and central chapel, encompasses four wings, each housing various functions and structures. Historical sources provide fragmented information on the specific uses of these spaces, necessitating careful deciphering and interpretation through onsite investigation.

Through a thorough study of historical records and physical examination of the monument, the architectural configuration and original functions of the Monastery spaces have been elucidated. The Eastern wing housed administrative functions such as the Abbot guestroom, the "*Archontariki*" (monastery reception hall), and storage areas. The Southern wing accommodated storage and animal facilities on the ground floor and monks' cells on the upper level. The Western wing comprised guest rooms, a furnace chamber, possibly a kitchen, and the Monastery's refectory. The Northern wing exhibits remnants of buildings with undefined boundaries and configurations, posing challenges in determining their historical uses.

Based on the findings from historical research and onsite exploration, a proposed restoration plan, in a preliminary stage, has been formulated to preserve and revitalise the Holy Monastery of "Kokkini Ecclesia". The plan includes the following key components in brief:

1. Restoration of the Eastern wing (3-storey): Conversion of existing spaces into a library/archive room, prayer room, and administrative offices while preserving original architectural features.
2. Restoration of the Southern wing (2-storey): Adaptation of the ground floor for food storage and animal husbandry storage purposes, a bookshop, and reinstating monks' cells and Abbot's cell on the upper level.
3. Revitalization of the Western wing (2-storey): Recreation of the "*Archontariki*" (monastery reception hall), auxiliary kitchen facilities, guest rooms, and other Monastery facilities to accommodate modern needs while respecting historical integrity.
4. Interpretation of the Northern wing (2-storey): Integration of archaeological findings and historical research with the goal of add some of the missing services of the old Monastery, such as the Monastery's refectory and main kitchen and the synodal room.

This preliminary restoration proposal aims to strike a balance between preserving the historical authenticity of the Holy Monastery of "Kokkini Ecclesia" and ensuring its relevance and sustainability for future generations. By addressing the complex architectural and historical layers of the monument, this paper seeks to safeguard and give prominence to the rich cultural heritage of Lefkada's religious landmarks.

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Keywords: Preliminary Restoration Proposal, Holy Monastery of Kokkini Ecclesia, Architectural Heritage, Historical Research, Structural Assessment

PART A: HISTORICAL AND ARCHITECTURAL ELEMENTS

1 Introduction

In this paper, an attempt has been made to highlight and present the preliminary restoration proposal of The Holy Monastery of “Kokkini Ecclesia” (Red Church), a significant cultural and religious heritage site in Platystoma, Lefkada, based on detailed historical research, architectural analysis, and structural assessment conducted on-site. The execution of this preliminary phase was deemed necessary to create the fundamentals for the next Phases (Preliminary - Final - Implementation).

The Holy Monastery of the Annunciation of the Virgin Mary belongs to the region of the village Platystoma, on the slopes of Mount Skaros in the “basin” that constitutes the end of part of the mountainous mass in Lefkada [1]. The location of the Monastery combines the wild natural landscape, tranquillity, and isolation, but also has short access to nearby destinations and the sea. All these elements contributed to the establishment and development of the Monastery over time, resulting today in its long history. The sobriquet of the Monastery “Red Church”, probably comes from the stone and red clay with which the monastery church was built in the past [2].

The Monastery has been declared an archaeological site by Ministerial Decision 15904 (-ΦΕΚ- Government Gazette B΄, 473 / 17.12.1962). The decision mentions it as *“Monastery of the Annunciation of the Virgin Mary or Kokkini Panagia”.* Today, the Katholikon (Church) has been restored in a previous restoration stage, but all the other buildings of the Monastery remain in ruins. On the 11th of July, 2023, The Central Archaeological Council (CAC-ΚΑΣ) accepted the preliminary restoration proposal.

Fig. 1. Historical photograph, 1960s.

Fig. 2. Recent photograph, 2020.

2 Historical Overview of The Monastery

The timeline and historical overview of the Monastery [3] provide a comprehensive glimpse into its rich past, tracing its origins, significant events, and transformations over the centuries. Through this chronological framework [4], we delve into the intricate tapestry of the Monastery's history, shedding light on its cultural, architectural, and spiritual evolution, serving as a testament to its enduring significance and legacy [5]. Below a historical timeline, brief is followed:

- **(12th – 13th century)** | First historical references to the existence of the Monastery.
- **(1478) |** Reconstruction and expansion of the Monastery with new structures in 1478 after the destructive earthquakes of the 12th, 13th, and 14th centuries.
- **(1704) |** Collapse of the Katholikon (Church) and some structures of the Monastery after the earthquake of 1704.
- **(1722) |** Reconstruction of the Monastery and the Katholikon in 1722.
- **(1743) |** During the plague of 1743, the residents, affected by the disease, donated all their property to the Monastery, resulting in a sharp increase in its wealth and the imposition of heavy taxation by the Venetian authorities.
- **(1803) |** Taxation of the Monasteries was intensified in 1803 to support public education.

- **(1804-1805) |** The decree of 1804 proposed the confiscation of the property of wealthy Monasteries, and with the decree of 1805, the dissolution of the wealthy Monasteries was enacted.
- **(1810) |** In 1810, it was decided to return the property to the Monasteries by the British Administration (1810-1864).
- **(1817) |** In 1817, a decree was issued for a lower number of personnel/monks in the Monasteries.
- **(1821) |** In 1821, the Monastery became a stronghold of the leaders of the Greek Revolution, making a significant contribution to the National Struggle.
- **(1829) |** The Monastery retained 11 glebes (*metochia*) with significant property in 1829.
- **(1850) |** In the mid-19th century, there was a major economic and moral crisis in Greece, leading to significant repercussions for the Monasteries, such as encroachments on the Monastery's property, and a decrease in the number of monks and workers.
- **(1866) |** The Church of the Ionian Islands is incorporated into the Church of Greece in 1866 [6].
- **(1869-1890) |** The problematic management of Bishop Hieromonk Vissarion Katokhianos (1869-1890) led to the dismantling of the Monastery, reaching the brink of dissolution.
- **(1911) |** The period of hegemony of Hieromonk Sophronios Katopodis in 1911, during which the Monastery had an upward trajectory in all areas.
- **(1925) |** The 1925 Law on the Expropriation of rural land in favor of landless cultivators and the Law on the Organization of Administration of Ecclesiastical and Monastic Property contributed to the shrinkage of the Monastery's property and ultimately to its complete dissolution [3].
- **(1940) |** In the last years until 1940, there were 2 monks living, and until 1945, one layman. Since then, it has been completely deserted, and decades have led to its current state of abandonment.
- **(2003-2006) |** After the earthquake of 2023, the monastery suffered significant damage. However, rescue interventions were carried out in 2006 to prevent possible collapses, as a temporary activity.
- **(2002) |** In 2022, “Prothesis Office -Architectural and Civil Engineering Firm-” undertook the Preliminary Restoration Proposal for the Holy Monastery of “Kokkini Ecclesia” (Red Church) in Lefkada.

3 Pre-Existing Architectural Facilities of The Monastery Complex and Survey

3.1 Pre-existing architectural facilities of the Monastery complex

The complex of the Monastery had a closed polygonal shape, surrounded by the 4 wings in the outline within which the Katholikon (Church) exists. There were structures and other facilities around the closed premises, but historical sources provide confusing information about these uses.

The study of historical sources and references [7], combined with on-site research at the monument, led to the decryption of the architectural layout of the existing spaces and the estimation of the specific uses that developed in the past.

The **Eastern wing** (wing 1), a three-storey building, housed administrative functions such as the Abbot guestroom, the “Archontariki” (monastery reception hall) and storage areas.

The **Southern wing** (wing 2), a two-storey building, accommodated storage and animal facilities on the ground floor and monks' cells on the upper level.

The **Western wing** (wing 3), a two-storey building, comprised guest rooms, furnace chamber, possibly a kitchen, and the Monastery's refectory.

The **Northern wing** (wing 4) exhibits remnants of buildings with undefined boundaries and configurations, posing challenges in determining their historical uses.

A characteristic image, taken by German Wilhelm Dörpfeld (in 1903), shows the Eastern and Southern wings on their original form, before the abandonment of the Monastery. The Western wing appears almost in its current state (as a ruin) and the Katholikon at the center. This image serves as evidence for the design decisions made during the preliminary restoration proposal.

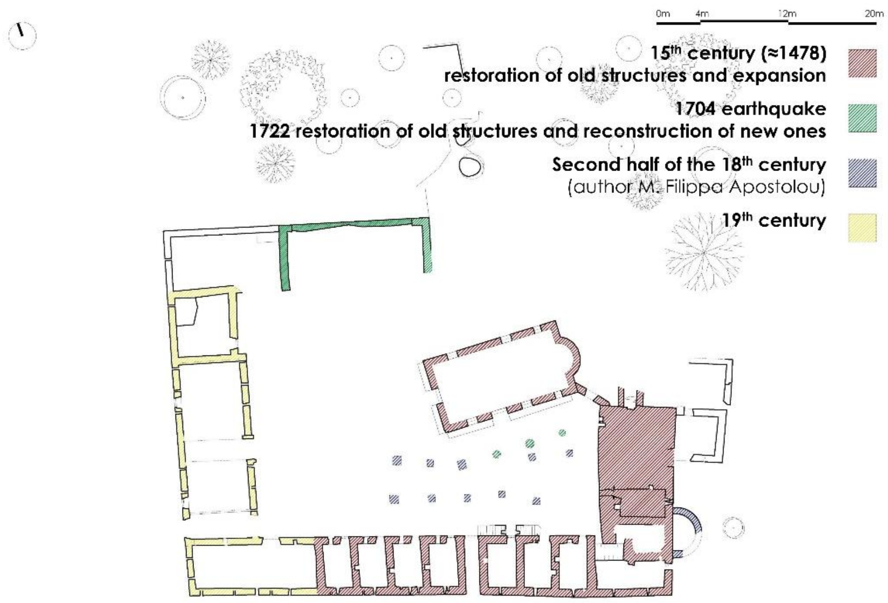

Fig. 3. Structural phases diagram of the Monastery [7].

3.2 Detailed survey on the Monastery complex

Surveying the ruins and premises of The Holy Monastery of "Kokkini Ecclesia", presented several significant challenges and complications. One of the primary difficulties we encountered was the state of deterioration and degradation of the structures over time, such as crumbling walls and collapsed roofs. Thick foliage and overgrown vegetation obscured many areas of the Monastery, making it challenging to navigate and conduct measurements, effectively obscuring many architectural details.

Furthermore, accessing certain areas for comprehensive measurement and assessment proved to be challenging. Thick vegetation and accumulated debris hindered the progress, requiring extensive clearing and cleanup efforts before the team process to the survey of the site.

Moreover, the complex layout of the monastery, with its interconnected wings (on the interconnection of the Eastern and Southern wings), added another layer of complexity to the surveying process. Navigating through the maze-like corridors and identifying distinct architectural features demanded meticulous attention to detail and thorough documentation.

Additionally, the lack of historical records on the Northern wing further complicated our task. Without comprehensive documentation from previous surveys or original architectural plans, we had to rely heavily on on-site measurements and comparative analysis to reconstruct the footprint of the Northern wing accurately.

Despite these challenges, the team persevered, dedicating significant time and effort to overcome each obstacle. Through careful planning, coordination, and collaboration with experts in historic preservation and architectural restoration, the Office

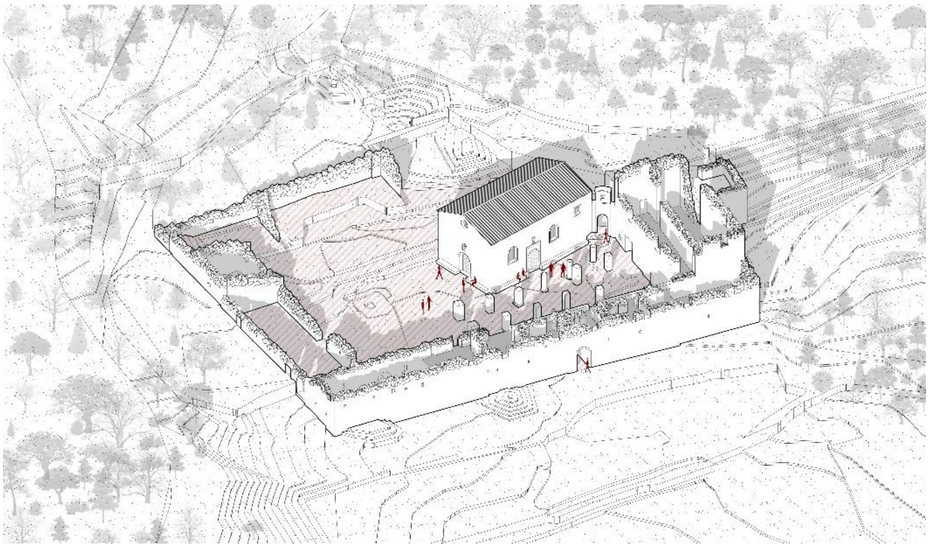

Fig. 4. Axonometric diagram of the existing Monastery.

was able to conduct a thorough survey of The Holy Monastery of “Kokkini Ecclesia”. The commitment to preserving this monument of cultural heritage drove the team to surmount these difficulties, ensuring that future generations could continue to appreciate and learn from its rich history.

PART B: ARCHITECTURAL PROPOSAL

4 New Architectural Program

The architectural program of the Holy Monastery, according to the proposal of the Preliminary Phase and with respect to the Monastery's history and the findings regarding the pre-existing architectural program, is structured as follows:

4.1 Eastern wing [3-storey building]

Reliquary- Sacristy room and MEP (Mechanical, Electrical, Plumbing) space (GF) 120 m^2
(staircase/elevator, WC, reliquary-sacristy room, MEP room [boiler room, machinery room, water supply room, fuel tanks, and generator room])
Library and Prayer room (1st floor) 120 m^2
(staircase/elevator, WC, reception area, offices, library, lobby, prayer room)
Library, living room, and office (2nd floor) 120 m^2
(staircase/elevator, WC, library, living room, office)

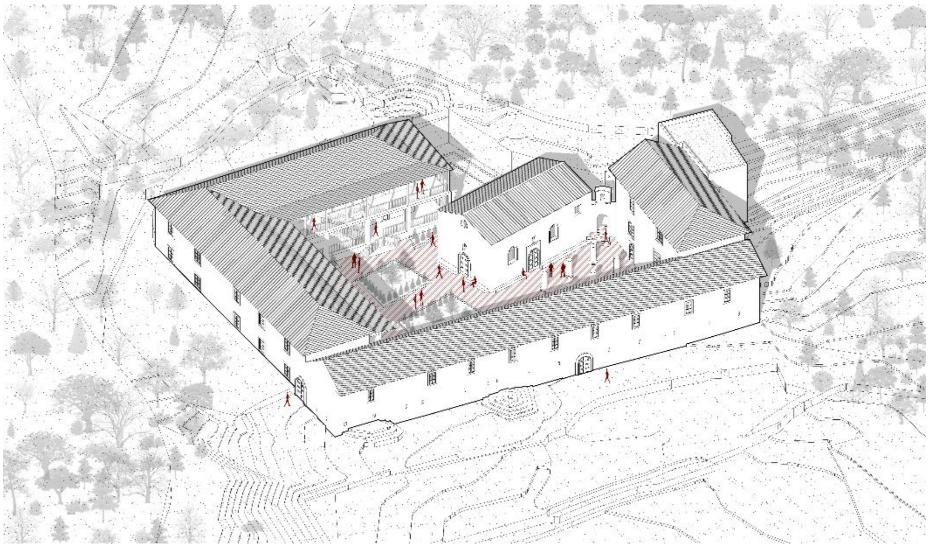

Fig. 5. Axonometric diagram of the new Preliminary Proposal.

4.2 Western wing [2-storey building]

“Archontariki” (Monastery reception hall) and kitchen (GF) 140 m^2
(Outdoor staircase, WC, auxiliary kitchen facilities in the north of the Western wing)
Bishops’ cells and Synodal kitchen (1st floor) 140 m^2
(Outdoor staircase, WC, 2 cells/dormitories, 2 Bishops’ cells, living room, Synodal kitchen in the north of the Western wing)

4.3 Southern wing [2-storey building]

Bookshop and storage spaces (GF) 200 m^2
(Outdoor staircase, food storage and animal husbandry storage purposes, laundry-dryers on the western side of the Southern wing)
Abbot’s and monks’ cells (1st floor) 200 m^2
(Outdoor staircase, the “diabatikon” (vaulted passage), Abbot's cell near the Eastern wing, 8 autonomous monks’ cells [13 m^2 with 1 bed, desk, wardrobe, and bathroom])

4.4 Northern wing [2-storey building]

Kitchen and refectory for 50+ people (GF) 140 m^2
(Outdoor staircase, WC, kitchen and food storage, refectory (dining hall) for monks and pilgrims for over 50 people)
Synodal refectory for 50+ people (1st floor) 140 m^2
(Outdoor staircase, WC, Synodal refectory (dining hall) for 50+ people)

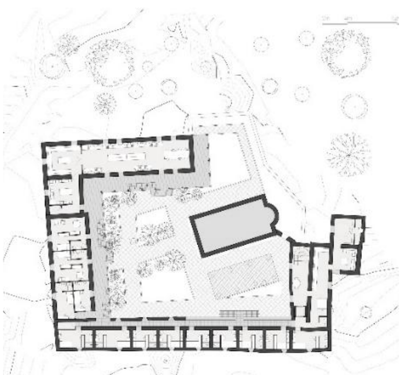

Fig. 6. Ground Plan, Preliminary Proposal

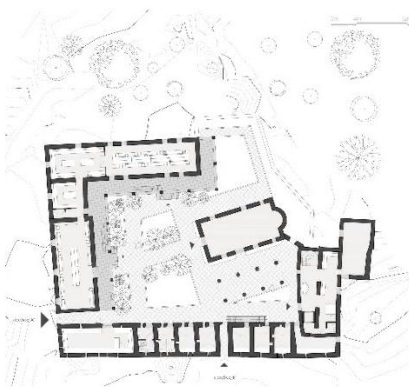

Fig. 7. Floor Plan, Preliminary Proposal

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Glass dry plates of Sopoćani: Analysis of the images as the research basis and the preservation of wall paintings

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Abstract. This paper deals with the preservation and scientific application of glass dry plates as cultural properties, showing the effectiveness of image comparison as an instructive part of the research basis of heritage studies.

Wall paintings of the Sopoćani Monastery (founded in the second half of the 13th century) are recorded as glass dry plates, which have been deposited at the Institute for the Protection of Historical Monuments of Serbia. The glass plates were taken in 1954 as visual documentation, and the author has assessed the conservation state of the wall paintings by comparing them with glass plates which are under ongoing archiving. The comparative study is carried out by applying images from three different times: photographs recorded in 1926 before the first intervention of modern restoration, glass dry plate images dating 1954, and digital data taken by the author in 2017. By analyzing the differences between the multiple images of long intervals of time, the author clarified that wall paintings at Sopoćani are comprehensively in good condition. Besides image comparisons, the results of a field survey done by the author and field measurements carried out in 2017 for further discussion have been introduced. As a result, no critical damage to the mural structure or serious changes to its appearance were identified. The conservation state of the wall paintings remained satisfactory, mainly because the restoration works carried out between 1926 and 2017 had been modest enough, allowing the wall paintings to retain the stability of the original production.

Keywords: Grass dry plates, wall painting, Serbia

1 Introduction

1.1 Significance of the research and characteristics of glass plates

Photographic materials and visualizing processes have been remarkably progressing through recent centuries, while the processed images themselves were often left as older results apart from technological developments. Both microscopic and macroscopic ranges covered by these developments, so rapid as ever before, have been extending much further than the natural limits of normal human perception gained through the naked eyes or senses. Reports and papers have been published on the strength of scientific data gained from advanced analyses of material identification or even through non-contact virtual processes, somehow far from the reality of the heritage.

The point to be taken into account is that those historical works were the result of simple hands and eyes of artists, though highly trained and provided with relevant knowledge. As regards the preservation of cultural properties like wall paintings of historical value, such older visual information is of crucial importance when we open the process of conservation projects on the basis of the older but human scale of technology applied to the production of the heritage. Here lies the significance of this research. In parallel with the instrumental contribution made by advanced analyses to the conservation science, the significance of visual analog images where the situations of the heritage in the past were recorded should be reevaluated in view of the fact that they are authentic proof of the states and conditions of the recorded object at a certain time through the long history of a progressive process of deterioration. This inevitably entails that such images in the past should be conserved with due scientific care and methods in a similar way to the cultural properties themselves. This paper deals with the ‘Gelatin silver glass plate negative’, once used as photographic documentation, to propose their effective use towards better conservation in harmony with older analog techniques of painters in the past.

The ‘Gelatin silver glass plate negative’, commonly known as simply “glass plate”, had been the main photosensitive material since its industrialization in 1878 until the 1920s when it became gradually

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replaced by the film negative [1]. Glass plates, being feasible for long- term storage following the mass production, enabled the proliferation of photography both in number and popularity beyond the limit of conventional specialists. Thus, the visual information recorded on so many glass plates should be regarded as historical documents, not only for the half-century period but also for decades after the 1920s when they were still in use, besides the progressive spreading of modern, easier negative printing methods.

The glass plates kept in the Institute for the Protection of Cultural Monuments of Serbia have been examined and scanned by the author, with the aim of building up the database for the future conservation project of wall paintings of Sopoćani Monastery. The result of the analysis of the scanned images is given in this paper, with additional suggestions regarding the better way of the preservation of this collection with special regards of environmental factors.

1.2 Photography as historical archive

Photography can be broadly divided into two types: photography as art and photography as documentation. The latter can be further divided into different categories: news photos, scientific photos (taken with different light sources and films, microphotography), and photos for documentation and conservation, including visual archivistic materials. The photograph became applied in research in the 19th century: it was in 1839 when François Aragaud, who had created the sensation with the daguerreotype of the outside scenery taken by Joseph Nicephole Niepce, pointed out that the application of daguerreotypes could accurately and quickly copy archaeological material such as hieroglyphs (Aragaud, 1839)[2]. Furthermore, on 15 June in the same year of 1839, a bill submitted to the French government stated that "for archaeologists and naturalists, this device of Mr. Daguerre will become an indispensable means of their daily activities" [3]. From the very beginning of its invention, photography commanded the first position of the surest and everlasting record.

1.3 Sopoćani glass plates

The above-mentioned collection of glass plates is composed of approximately 1000 glass plates, among which 303 show Sopoćani monastery (hereinafter referred to as Sopoćani glass plates). The rest correspond to the other monastery buildings and their wall paintings in the territory of the ex-Socialist Federal Republic of Yugoslavia. Sopoćani glass plates were made by R. Delić and M. Lazarević in 1954 during a series of administrative documentation works ordered by the government. Since then, all plates have been left in an underground space without being examined or cataloged.

The size of plates is the so-called ‘half-plate (130 x 180 mm)’, commonly used in Europe at the time. Wrapped by glassine paper, each plate was put into a paper envelope, as is shown in Figure 1, and placed vertically in metal cabinets, shutting off the effect of light. Temperature and humidity, well-known factors accelerating the deterioration of the photosensitive material gelatine, seem to have been kept successfully low by chance. Air conditioning was not installed. However, they were just kept as plates made of glass, Sopoćani glass plates happened to be relatively in good condition. A few physical damages, such as cracks and scratches, are observed, which may have occurred during handling. The gelatine adherence to the surface of the glass is good enough, without any symptom of severe flaking or detachment. The manufacturing of plates was of high standard and, fortunately, the space where they were kept has long been alien from extreme changes in humidity. During the course of time, the inevitable silver mirroring has appeared along the periphery of the plates, which, however, has not invaded the images themselves. Such peripheral deterioration would be greatly softened if they were laid under a better conservation environment in the future.

2 Analytical method

Thanks to the two highly skillful photographers of Sopoćani glass plates, it is still possible to make the comparative analytical study. In addition, we have the oldest photographic records of Sopoćani taken in 1926. Comparison between photographic records of 1926, 1954 and 2017 were made by using Adobe Photoshop 2024.

The preparatory analytical comparison is made by superposing two images of the same surface to obtain the visual differences between the two. Absolute values of the superimposed images are measured on software. Fig.2 gives the result of this simple comparison of the partial images of the west wall of

Naos from 1954 to 2017. The difference is given as vacant areas. Compared with the two original images, these vacant areas exactly correspond to the additional complementary coloring done between 1957 and 2017.

Thus, the comparison of the two visual documentation may show not only certain developments of the deterioration but also traces of interventions done between the relevant periods. Visual records may offer clearer objective decisions for experts without hampering them by iconographical meanings or material characteristics. Detailed naked-eye observation may be somehow subject to the experience or knowledge on the part of the researchers, which should be effectively related with or adjusted by mechanical and purely analytical information as complementary data in the investigation of the heritage in situ.

Comparative analyses are useful if two photos were taken at relatively long distance of time. In such cases, one or both older photos happen to be short of exact correspondence due to the distortions or misalignment caused by the old mechanisms of cameras and characteristics of lenses. Distortions become wider in the periphery of images, which may occasionally be observed by the naked eye. The accuracy of image comparison can be improved by correcting such shooting distortions or adjusting the contrast of shading.

This simple method allows old photographs to be compared with new digital images, and the comparative information may well be of basic significance in the conservation projects by showing the degree and causes of deterioration or confirming the diagnosis of the suffering wall paintings. Advanced analytical equipment or large-scale field measurements are not always applicable whenever required at every site. Therefore, it can be expected that people involved in cultural heritage will make effective use of historical materials to widen and deepen their understanding of effective conservation by making use of the above-mentioned materials and software widely used worldwide.

On the other hand, it must be taken into account that the conversion from silver halide analog information to quantized-digital discrete data involves fundamental problems that go beyond mere mechanical media conversion. Digital technology is advancing at a dizzying pace in terms of both hardware and software, and converting data each time is a major burden, and unlike analog information, it also carries the risk that a small inconvenience may make it impossible to read any images at all. Digital data, while being easily processed and edited, may connote risks of losing its reliability if the process of data acquisition and storage is not well documented.

3 Assessment of the past restorations

Comparison of the three visual sources, those of 1926, 1954, and 2017, clearly shows that there had been a series of extensive architectural interventions, including structural additions, which may have altered considerably the external appearance of the church. Contrasting irrevocable alterations and additions in architecture, a comparison of photographic records from three different periods clarifies severe deteriorations or changes caused by both environmental and restorative factors are scarcely observed in the wall paintings drawn on the inner surfaces.

In Fig.3, partial images of the wall painting in the center of the south wall of the Naos are compared on the basis of the database made by the author from photographs taken in 1926, 1954, and 2017, respectively. The major change that occurred between 1926 and 1954 was the filling in of the missing area in the upper center of the screen. Although weathering and small-scale flaking on the right side of the screen are observed in the data, it should be noted that the 1954 image was taken at a higher exposure setting, which resulted in a brighter image being acquired overall. Therefore, we may safely conclude that the degree of abrasion was less in 1954 than visualized in the images of this year. On careful comparison of two images from 1954 and 2017, differences were observed on the right side of the screen, which demonstrates a certain intervention by additional complementary coloring applied to areas missing due to weathering and abrasion.

The image comparisons between the two different times show weathering over time but no symptoms of structural deterioration, i.e., progressive increase of structural cracks, biodeterioration, or conspicuous loss of the surface. In other words, it can be assumed that no critical deterioration threatening the structure had been occurring during the 91 years from 1926 to 2017, despite the fact that the building with its depicted surface had not been placed in a stable, safer environment like an exhibition hall of a museum: before 1926, it had been exposed to the severe climatic violence like strong wind and heavy rainfall for more than 200 years without roof covering, and crumbling stones or broken bricks had accumulated in the hall, and plants had grown both inside and outside. This architectural heritage, judging from visual documents, turned out to be exceptional in preservation and sustainable condition. One of the probable reasons for this lucky persistency of the building is ‘neglect’ in the good sense of the word; that is, the building had long been left uncared for without being suffered from harmful and disguised ‘repairing.’

Especially the comparative analysis between images from 1954 and detailed and close observations done by the author in 2017 has clearly shown that there had been no serious interventions that might have caused later negative effects upon the original. Minor interventions are: removal of older treatment, followed by modest re-treatments, and filling of gaps between the painted plaster and the wall. These interventions were done during restoration projects conducted in the last century. The author has confirmed that they are minimum treatments, clearly to be identified, and remain nothing particular to cause further side effects or deteriorations. Restorations or consolidations of cultural properties in the last century often tended to go beyond the limit of the ‘minimum intervention’. Materials and chemical products to be used in those works have frequently been tested, changed, and somehow improved. Considering this rush of restoration fever in the second half of the last century, the ‘steady calmness’ by which Sopoćani wall paintings have been preserved should be worthy of particular attention.

Sopoćani glass plates prove the persistent existence of the almost unchanging original inner surface since 1926 when the first modern repair project was started after the total abandonment of the Sopoćani monastery for more than 200 years. The fact, while emphasizing the importance of those plates as historical visual documents, may well make us suppose that the technique, as well as the material of both original painting and wall construction, were sufficiently high to secure the durability of the work against the long-term deterioration [4]. Although there remain no full records of the restoration works through the 20th century, we may safely assess, through detailed analysis, those interventions were of ‘minimum’ even from the advanced and rigorous standard of restoration we should follow today. Along with the efforts towards a complete and safer preservation of Sopoćani glass plates, we should make a more penetrating analysis of them as the basis of the in-depth evaluation of their significance and, if necessary, of their future protective restoration.

In Sopoćani Monastery, two services are given per day, morning and evening. Worshippers are relatively dispersed throughout one year, and congestion of visitors remains minimized even on the day of major events such as Easter. The seasonal and daily variations of the temperature and humidity in the church of Sopoćani show no serious acute curvature nor delicate peaks which may threaten the microclimate of the space (Table 1). The most difficult season is summer, when the temperature and humidity undergo severe daily variations (RH 29.3-50.6%, 19.4-23.9°C), but not to the extent of being exposed to sudden temperature and humidity changes, while winter months are stable with little daily variation (RH 54.5-57.5%, 3.5-4.0°C).

The climatic condition of the outside is a different issue. The outer surface is subject to the atmosphere with relatively larger changes in temperature and humidity. Especially the latter may cause a certain threatening effect, the highest degree being observed during winter months when there is much snowfall and rainfall. However, the outer surface displays no perilous phenomena leading to threatening progressive deterioration, such as condensation or salt damage. Microenvironmental changes, both inside and outside of the church, may certainly exert negative impacts on the wall paintings. Through detailed observation done by the author, however, the Sopoćani structure turns out to be in good and safer balance with the environment surrounding the vulnerable heritage, though additional microscopic monitoring should be continued to grasp minor invisible symptoms hidden in the structure. Fortunately, no serious natural disasters have occurred.

Wall paintings of Sopoćani had long survived more than 200 years of neglect and devastation. Our detailed examination further had brought out the fact that the well-balanced environmental condition had enabled the continuation of their long life without any serious damage into the 100 years since 1925 when the first modern survey was carried out at Sopoćani. During this period of recent 100 years, mural paintings were given marginal fillings and reinforcements that maintained the murals in the minimal state they were in at the time. Supplemental painting was manageably done to the extent of restoring their appearance. The philosophy of this maintenance work deserves full accolades compared to irreversible reinforcement procedures using concrete and synthetic resins together with excessive and peculiar coloring work, so frequently carried out in the mid-20th century. The author confirmed by detail in situ examination that Sopoćani wall paintings have been fortunately left free from complicated problems caused by the restoration materials, which is the outstanding contribution of the ‘modest’ restoration carried out from time to time through the difficult period of financial shortage.

4 Conclusion

While being out of use nowadays, glass plates may certainly contain valuable visual information of the past when they were used as indispensable photographic media. This paper reconfirms the importance of Sopoćani glass plates as components of digital archives to meet the needs of advanced studies regarding the church. As there still remain many undocumented plates, the author is trying to carry out the complete catalogued enumeration with additional analysis of their industrial-technological significance. Sopoćani glass plates are not yet stored under the proper preservation environment. The relevant research has clarified that the suggested environmental condition for the glass plates to be preserved is less than 65º Fahrenheit with minimal fluctuation (+/- 2 degrees), and ideal relative humidity is 30% RH with minimal fluctuation (+/-3 percent) [5].

As well as providing an adequate preservation environment, it is also necessary to store historical materials separately according to their deterioration symptoms and degree of deterioration in order to reduce risks during handling. Storing cracked glass dry plates in the same conditions as dry plates that are not cracked does not ensure the safety of both objects.

In parallel with the completion of the digital archive, it is of academic importance to secure as soon as possible such environmental conditions to house Sopoćani glass plates in order to promote the research of the history of restoration and to discuss the future project for the conservation of Sopoćani wall paintings.

Apart from some minor emergency or partial restoration works done as temporary measures, at least three major mural restorations have been carried out at Sopoćani in the last 100 years, the period in which the materials and philosophy of restoration have undergone significant changes in the field of conservation of cultural heritage. The conservation and restoration of the wall paintings at Sopoćani have been proved to be the least extensive and risky of similar interventions taken up worldwide. The author's survey has confirmed that the original durability and soundness of the wall painting is still effective in the sense of preservation today. The original strength of the wall painting should be appropriately taken into consideration in terms of positive functioning factor. The notable durability of Sopoćani wall paintings should be the basis of the long-term conservation of the murals in good condition. The guidelines or standards of the restoration program should be discussed extensively through the correct assessments and with respect to the high standards of the techniques used when the murals were first produced. Sopoćani glass plates certainly remind us of this modesty to be shared among the restoration experts in front of the heritage which survived from a far distance of time. Historic photographs that capture a different appearance from the present state have thus important historical value, which in their turn are comparable to that of the original object once photographed. The conservation and restoration of such visual images are nonetheless meaningful in making their utmost effective use on the part of restoration-conservation experts who should always pay due attention to the information hidden or provided by them.

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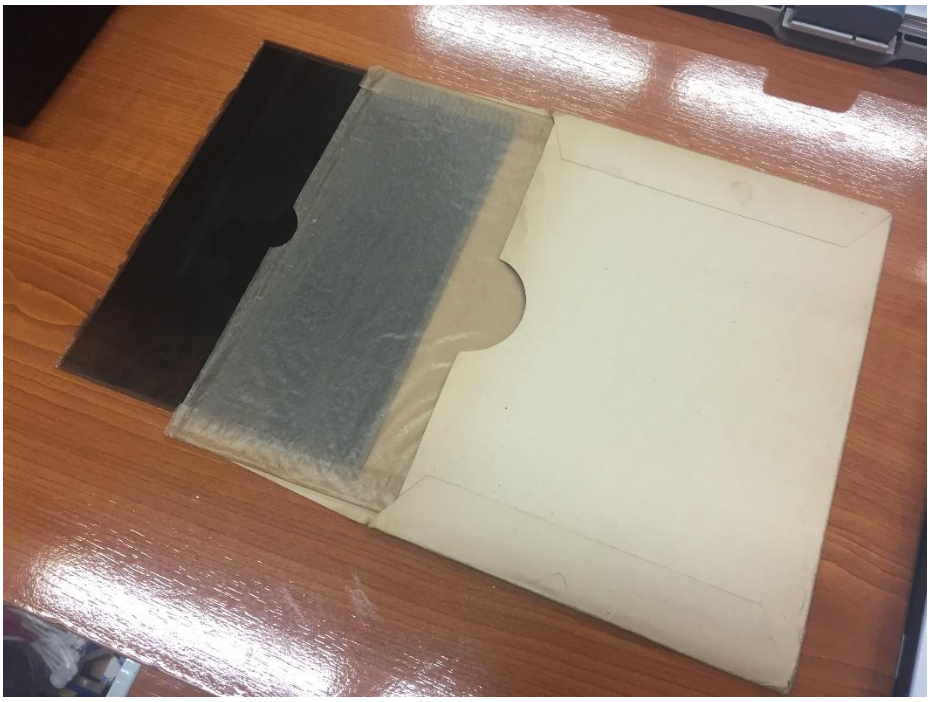

Fig. 1 - Sopoćani glass plate

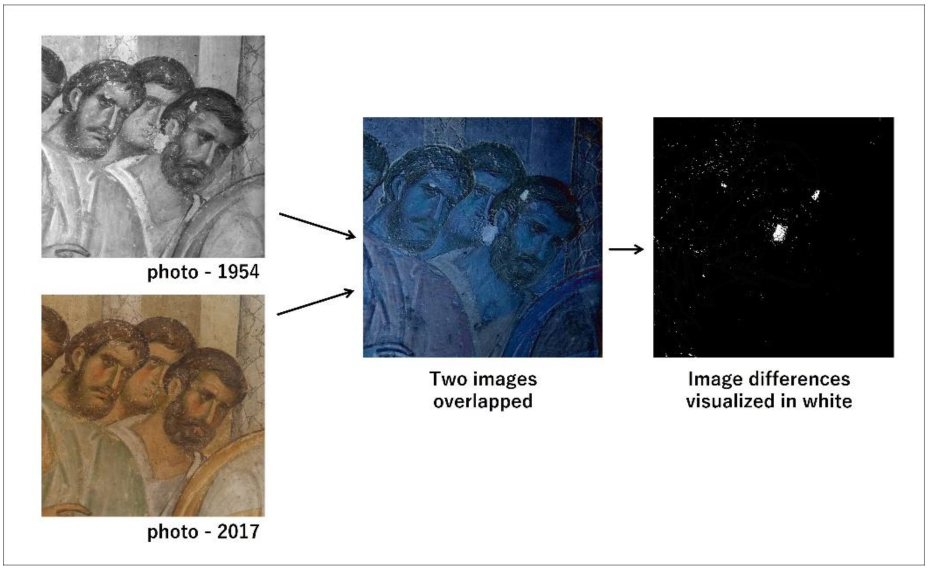

Fig. 2 - Example of the procedure of image comparison

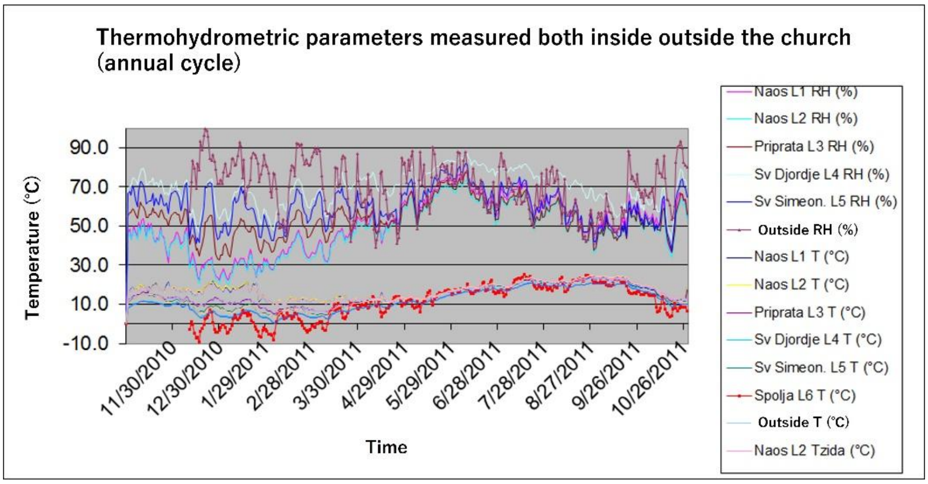

Table 1 - The seasonal and daily variations of the temperature and humidity in the church of Sopoćani

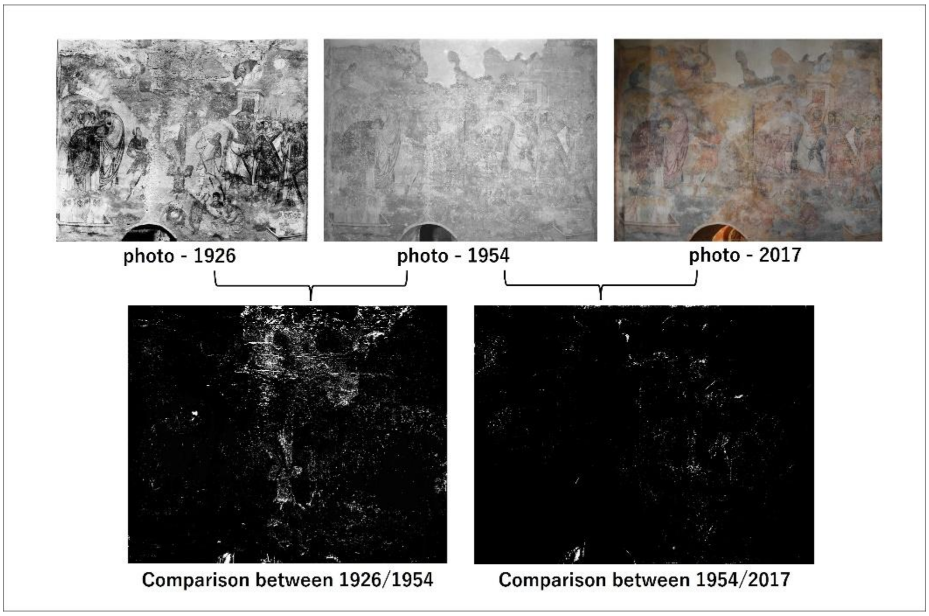

Fig. 3 - Comparison of the database made from photographs taken in 1926, 1954 and 2017

The Degradation of Stone. Studies and Reports in the 1950s on the Conservation of Stone Material in Florence.

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Abstract. The paper examines the issue of the deterioration of stone materials in architecture. The problem is framed by highlighting the main trends observed throughout history, then delving deeper into the intense debate that took place in Florence during the mid-1950s. In the past, conservation interventions for stone materials were carried out with the aim of protecting the surfaces of the materials, but in the 19th century, the importance of internal consolidation of the stone began to be understood, thanks in large part to significant progress in the industrial field. The earliest techniques used silicates. Renowned restoration projects, such as that of Notre Dame in Paris, showcased the use of the first consolidation treatments, marking them in history as precursors of stone hardening. From the early 20th century onwards, institutions such as the Royal Museum of Berlin and the Central Institute for Restoration in Rome played a key role in the development of conservation techniques, laying the foundations for contemporary conservation science. This paper specifically aims to examine the debate on monument conservation in 1950s Florence. At the center of the discussion were the respective directors of the *Opificio delle Pietre Dure* in Florence and the Istituto Centrale per il Restauro. Through archival research and a careful reading of published sources, it has been possible to reconstruct the trends and positions of the two institutions regarding the conservation techniques of stone surfaces, as well as to bring to light the products used in the restoration of the most important Florentine monuments.

Keywords: Stone conservation, Consolidants products, Opificio Pietre Dure.

1 Contextualization of the scientific problem

The issue of the deterioration of stone materials used in decoration and construction has existed since ancient times, with evidence of this problem found in geographically diverse regions. Most written sources, particularly the oldest ones, originate from Europe, where references to classical treatises are frequently found even in more recent publications. However, the oldest treatments, although not prominently featured in the literature, are attributed to the Egyptian civilization [1]. This civilization was among the first to address the need to prevent and delay the processes of alteration in stone materials exposed to atmospheric agents. This was achieved thanks to their extensive knowledge of mummification processes, which were later applied to ornamental materials as well [2]. Other examples of the use of natural protective agents in antiquity can still be observed today among some indigenous populations. In the early construction of buildings with raw earth, there was a need to make the external surfaces impermeable through the cyclical application of natural protective agents. This example, although not related to stone construction, introduces another important aspect of the history of conservation treatments: the timing of the intervention. In ancient times, materials were treated from the early stages of construction without waiting for the degrading action of atmospheric agents, and the intervention was repeated cyclically.

Starting in the 19th century, perspectives on intervention began to change, influenced by significant scientific progress, towards a more "definitive" approach. The great confidence that avant-garde practitioners had in new industrial products led to the first treatments for consolidating disintegrated materials, which involved the initial techniques of silicification. The restoration of Notre-Dame Cathedral in Paris, conducted by Eugène Viollet-le-Duc and Jean-Baptiste-Antoine Lassus, is particularly notable. This project employed the first silicates for hardening the stones of the external surfaces. Although the debate on this topic has not yet been fully resolved, it can be stated that treatments prior to the 19th century – regardless of the techniques used – were solely aimed at protection, not consolidation. It was only from

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the 19th century onwards that chemical and physical knowledge advanced enough to understand the importance of consolidation in its technical-scientific operation. The term "consolidate" was used with this specific purpose for the first time only at the beginning of the 20th century, and it was officially adopted at the end of the 1970s following the outcomes of the first *UNI-NorMaL study commissions*.

In antiquity, the application of natural products was carried out cyclically, especially on the most prestigious and representative monuments. The interventions that are most documented were performed on valuable stone materials, such as marble and travertine. One of the countless examples is the treatments conducted on Trajan's Column in Rome. Studies from the last century have highlighted the presence of ancient conservation layers on the column's surface, found both in the casts from the 17th century and those from the 19th century. Among the oldest techniques, the use of waxes and oils, originally referred to as "ganosis," is undoubtedly one of the most frequently mentioned in literature. It is often found documented in major reference texts. [3]. In Vitruvius's work "De Architectura" and Pliny's "Naturalis Historia," methods for polishing marble surfaces of statues and constructions are mentioned, in some cases also serving conservation purposes. The refinement of techniques and material processing developed during the classical era persisted through the centuries, spanning through medieval and Renaissance art. Particularly, studies conducted in Italy starting from the late 1960s by the National Research Centers focused on the conservation of stone materials, with a particular emphasis on the Renaissance period [4], particularly from the Centro Cesare Gnudi in Bologna, forming the foundation of the knowledge we have today. The studies conducted, starting with the research on the façade of San Petronio in Bologna [5], led to the rediscovery of numerous conservation techniques carried out in antiquity, inaugurating a new research direction. The scope of studies conducted in Italy by research centers – thanks also to extensive dissemination through publications and international conferences – influenced global scientific activity. In particular, in Spain, starting from the mid-1970s – the end of the Franco regime– research intensified in the field of conservation and restoration, with particular attention to techniques used in previous eras. There was significant focus on the remains of Islamic art – present for almost a millennium, especially in the region of Andalusia – with great interest in both structural and surface materials and construction methods. Already, a study conducted at the end of the 20th century on the original materials of the Alhambra in Granada highlighted the presence of ancient conservation applications on the perimeter wall of the *Abencerrajes* – the oldest portion of the *Alcazaba* – and on the Noria Tower of the *Albercones*. [6].

Fig. 1. Giorgio Ghelfi, 2024. Detail of the facade of the Palace of Charles V within the Patronato de la Alhambra y el Generalife.

These treatments were dated to the early Nasrid period, around the 11th century AD, and consisted of patinas based on gypsum and other natural compounds, including red pigment, which is also significant for giving the Alhambra its name, al-Ḥamrā, "the red" in Arabic. The same study also highlighted other treatments of organic origin (oils and casein), which were found on the internal walls of the buildings.
Recent studies on the facades of the Palace of Charles V [7] – built starting from 1527 by order of Emperor Charles V, designed by Pedro Machuca [8], and now annexed to the Patronato de la Alhambra y Generalife – have highlighted a layering of strata on the surfaces of the facades. Investigations have also identified the various materials composing these layers, highlighting the different treatments carried out in various periods. Among these treatments are layers of organic nature–oils and waxes–layers of siliceous origin and multiple layers composed of lime and gypsum. This example serves to illustrate the numerous techniques that have been used in different eras, some of which can now only be identified in certain cases with the aid of modern investigative tools. In many artifacts, extensive interventions have been carried out–especially with aggressive surface polishing–that have irreversibly erased traces of the past. The scientific study of surface conservation treatments–especially for stone surfaces–began in the 19th century, spurred by the Industrial Revolution, which provided new chemical and physical knowledge. However, it was only in the 20th century that studies intensified on the phenomena of stone deterioration. In the 19th century, particularly in France and Germany, historical monuments served as true laboratories where various treatment methods were experimented with, including silicates and derivatives, mastics, cement, and the first silicon esters. In the early decades of the 20th century, the increase in urban pollution showed the first repercussions on the conservation status of monuments, prompting national and international institutions to delve deeper into the problem of material degradation. This condition led to the formation of the first research groups with the aim of scientifically studying the causes of deterioration processes through systematic analysis of chemical and physical processes.
One of the earliest and most important institutions was the *Royal Museum* in Berlin. This laboratory became a model for other museums worldwide, thanks in part to the figure of Friedrich Rathgen, a

pioneer in the field of conservation and applied chemistry in cultural heritage preservation. Between the 19th and 20th centuries, this institute published significant works, such as "Die Konservierung von Altertumsfunden [9]" – a reference text throughout the 20th century in the field of conservation – and initiated the first scientific experiments on consolidating products. From the 1920s onwards, other laboratories were established, such as the *Research Laboratory of the British Museum*, the *Straus Conservation Center of the Fogg Art Museum in Cambridge* (Massachusetts), the *Laboratoire pour l'étude scientifique des peintures of the Louvre Museum* in Paris, the *Gabinetto di* Pinacologia e Restauro in Naples, and the *Gabinetto Restauri* in Florence.

2 The debate on monument conservation in Florence during the 1950s

Delving into the mid-20th-century debate on stone conservation, it is impossible not to assign a primary role to the Istituto Centrale per il Restauro, particularly during Cesare Brandi's tenure. Since its establishment in Rome in 1939, the ICR (Istituto Centrale per il Restauro) has been one of the most significant research centers in the field of conservation and restoration. In addition to conducting intensive scientific research, the Institute maintained research collaborations with leading restoration laboratories nationally and internationally, also contributing to the establishment of other research centers, such as *The National Gallery of Ireland* and the *Restoration Institute of Cairo* in Egypt. From the 1950s onwards, the ICR became increasingly concerned with the serious problem of "stone crumbling," responding to numerous requests received from Italian Superintendencies in previous years [10]. The issue of monument degradation was so severe that it became one of the primary research fields of the ICR during that period and in the subsequent decades. The institute's chemistry department collected samples from Italy's most important monuments and tested them with products from market-available companies, assessing their effectiveness and durability. Additionally, on-site application tests were conducted, as evidenced by interventions at the Arena di Verona (Verona, Veneto) and the archaeological site of Heraclea Minoa (Agrigento, Sicilia). The institute initiated a nationwide awareness campaign on the issue of stone degradation, establishing relationships with numerous institutions. Of particular significance– an aspect to be explored in this contribution– is the collaborative relationship with the *Opificio delle Pietre Dure* in Florence regarding methods for consolidating stone surfaces. The OPD (Opificio delle Pietre Dure*)* – founded in 1588 by Grand Duke Ferdinando I de' Medici–was already a prominent and renowned institution in the restoration field worldwide by the 1950s. It began its restoration activities in the latter half of the 19th century, dedicating itself entirely to the conservation field in the 20th century. The relationships reconstructed through research conducted in the archives of both institutions [12], combined with the main bibliographic sources, refer to some correspondences between the respective directors of that period, Cesare Brandi and Lando Bartoli. In the same year that the Ministry of Cultural Heritage and Activities issued the *ministerial circular on November 25, 1959*, titled "Conservation of sculptures exposed to atmospheric agents," Brandi contacted Bartoli to obtain information regarding a restoration intervention conducted by the OPD five years earlier on the Canonici Door of the Cathedral of Santa Maria del Fiore in Florence. Brandi's interest arose following an inspection at Giotto's Campanile, during which he also observed the restoration intervention on the Canonici Door. The director of the ICR was highly sensitive to the issue of stone consolidation, and the results of the ICR Chemistry Department's research did not yield satisfactory results. Many efforts of the department were invested in experimenting with the first acrylic resins, predecessors of the "famous" *Paraloid B72* – used in the 1960s on the surfaces of the Siena Cathedral – without achieving acceptable results.

Bartoli's response reached the ICR just two days after Brandi's initial letter and provided a detailed description of the restoration operations previously carried out on the Canonici Door. The intervention took place in March and June of 1953, and consolidation was achieved by immersing various parts of the marble decorations–particularly the candelabrum and lintel of the door–in a bath containing a silicate solution. This bath was held in a completely tin-plated metal container adhered to the object and moved accordingly to the area being treated. As Bartoli further explained, the duration of the bath for each area was between 3 to 4 days, and the silicate solution used corresponded to *a dose of 1 kilogram of salts diluted with 7 liters of water at a temperature of 40°C*. Great attention was paid to maintaining the temperature of the bath consistently, achieved through the use of an electric heater that compensated for nocturnal temperature variations with daytime levels. Bartoli also emphasized that during the restoration work, they chose not to apply a waterproofing agent after the consolidation treatment to avoid potential alterations in the marble's coloration. Finally, he also specified the origin of the products used: *Flintox* *salts*. A product patented by the company *RIW (Remember its Waterproof)* in England was marketed in Florence by Tommaso Accorti, located on Via de' Pecori, Florence. Within the OPD archive, a brochure for the *Flintox* product was also found, although it described *Flintox Crystals* rather than *Flintox Salts*. The brochure described it as "a complex mixture containing fluosilicates" and prescribed its use in the same quantities as those used for the Canonici Door: *1 kilogram per 7 liters of water*. It is, therefore, plausible to consider that it is the same product. Along with the report, Lando Bartoli also sent a list of restorations carried out by the OPD in previous years that involved the consolidation of stone materials. From 1929 to 1931, the triforia of the arcades of the Church of Orsanmichele in Florence were restored; from 1949 to 1950, interventions were made on the rose window of the Orvieto Cathedral using a 20% waterproofing solution; from 1951 to 1954, both Angevin monuments and the rose window of the Santa Chiara church were restored in Naples; in 1948-49, the Fountain of the Cathedral of Perugia was restored; in 1959, the portal of the Evangelist in Ravenna was restored, and in 1953, the Canonici Door and the statue of Donatello from the Opera del Duomo were restored in Florence. In these last two cases, as reported by documentary sources, *Flintox* products were used. Additionally, for the Donatello statue, a waterproofing agent–*Toxloxpore*–was applied through immersion. *Toxloxpore*, also manufactured by *RIW*, was described as a "weatherproof and weather-resistant waterproofing solution that ensures an effective and durable coating."

Research in the archives of the Opificio delle Pietre Dure institute has revealed references to other types of treatments conducted in Florence during the same period but not endorsed by the institute itself. The development of industrial preparations of silicon esters, particularly "silicones," during the 1940s allowed for the introduction of new families of products onto the market. These products, categorized as "organic silicon-based compounds," are predecessors of "ethyl silicate." As documented in an article published in the "Bollettino Ingegneri" in 1959 [13], the dissemination of these products was extensive, and with the favorable opinion of the Superintendence for Monuments of Florence and the Fine Arts Office of the Municipality, widespread application on damaged architectural works undergoing restoration began. Following an initial trial conducted on the exterior surfaces of the Church of Orsanmichele, treatments were applied to various buildings, including Palazzo Pandolfini in Via San Gallo, Palazzo Boutorline in Via dei Servi, the facade of the Basilica of San Marco, the obelisks of Santa Maria Novella, the old Porta S. Gallo, Palazzo Strozzi, the new headquarters of Fondiaria in Piazza della Libertà, and some portions of the facades of S. Maria del Fiore. Through archival research, it can be determined that the product used for the facades of the Church of Santa Maria del Fiore was applied in 1958 and was called "Nubex," a silicone-based water repellent from the British industry J. Freeman Sons & Co. Ltd, Cementone Works, and marketed in Florence by the ACEF Consortium, located at Via Aretina 59, Florence.

The "silicones" were not appreciated by the director of the OPD, Lando Bartoli, as stated in his letter dated January 27, 1960, addressed to the Ministry of Antiquities and Fine Arts. He believed that the application of silicones served exclusively a protective purpose and not a consolidating one. This is why no interventions carried out by the Institute with the use of these products are found, except for this purpose. On the contrary, consolidation using fluosilicates was preferred. This method of consolidation stemmed from the significant influence of Piero Sanpaolesi, the technical director of the Restoration Workshop of Florence within the Uffizi Gallery, who, in the 1940s, was considered almost definitive on a national scale. However, in the following decades, some works consolidated with this technique began to show serious signs of degradation, to the point of choosing to abandon it.

3 Conclusions

In summary, the conservation of stone materials has a long history marked by a continuous evolution of techniques and materials influenced by scientific studies and practical experiments. Collaboration between institutes and the development of new technologies have played a fundamental role in the progress of conservation techniques. The snapshot provided by the Florentine scenario of the 1950s highlights the various factors that characterized national and international restoration. Despite some research centers beginning to apply a well-defined methodological process, knowledge in the field of materials was not sufficient to adequately address degradation and alteration factors. There was still a restoration practice lacking in the knowledge that would only begin to emerge from the 1970s, such as the nature of the material and the analysis of degradation and alteration factors. Especially in the case of silicones, applications were made "en masse" without considering the different lithotypes. Another fundamental aspect was the test of time. The importance of testing and monitoring products was not yet fully understood, leading to hasty evaluations without waiting for the test of time. Additionally, another aspect of further study by the author will be the significant submerged scenario of those artisan workshops where, despite international trends, interventions continued to be carried out with traditional techniques and products.

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Characterization and origin of ancient metallurgical slags from the ancient settlement of Archampolis, Euboea Island, Greece

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Abstract. In the present study, metallurgical slags were investigated and characterized concerning their mineralogy, chemistry, and texture. The slag samples were collected close to the ancient village of Archampolis, located on southern Euboea Island, Greece. The aim of the study was to define the kind of archaeometallurgy, i.e., extraction of copper, silver, or iron, as well as to suggest possible sources of the ores which were used as raw materials burned in the kilns. Qualitative mineralogy and texture of the slags were performed using X-ray diffraction (XRD) and scanning electron microscopy (SEM-EDS). The determination of the major and trace elements of the samples was performed by X-ray fluorescence (XRF). By combining all analytical results, it was concluded that the metallurgy was applied for iron extraction, as the samples consisted of ferrous, glassy slags, while one sample was interpreted as a semi-melted host rock containing the original minerals. Geochemically, it turned out that certain slag pieces are enriched in Cu, As, Pb, and Tl, which indicates a possible origin of the initial ferric ore from the oxidization of the mixed sulfide ore. Such primary and oxidized polymetallic mineral deposits occur in the area of south Euboea Island, some of which have been exploited since the Antiquity. Another possible source could be Andros Island, being the closest area to Archampolis seawards, which hosts significant deposits of iron ores, most of them exploited for centuries.

Keywords: slags, ancient metallurgy, iron, wüstite, fayalite, Euboea

1 Introduction

The Aegean Region was one of the first to enter the Bronze Age in the Mediterranean. As such, there was an early development of metallurgy in the area, which included lead, silver, gold, copper and later iron. The metallurgy and craft specialization in the Aegean begins in the Late Neolithic-Early Bronze Age. The analysis of four models of boats made of lead that have been found in a burial of the Early Cycladic age (3400-2100 B.C.) on the island of Naxos suggested that the source of the ore was probably Siphnos Island (Gale and Stos-Gale, 1981). Lead is found in the Early Bronze Age record on several Cyclades islands, i.e., Antiparos, Despotikon, Kea, Syros, Amorgos, Ios, Milos, Kimolos, Anafi, Thera, and Naxos (Vaxevanopoulos et al., 2022). Lead metallurgy is also known in Early Bronze Age contexts in Cycladic settlements on the Raphina and Agios Kosmas coasts, Attica, on Crete, Lesbos, Lemnos and at Troy (Gale and Stos-Gale, 1981).

Several islands of the Aegean contain Pb-Ag-Zn (±Cu/As) mixed sulfide ores. Henceforth, since most of the lead ores in the Aegean and the Greek Mainland also contain Ag, the exploitation of lead was probably a key factor for the development of silver metallurgy as well, via a process known as cupellation. The earliest findings of metallurgy in Greece also include some rare gold objects from Macedonia dated in the latest stages of Late Neolithic at Sitagroi, Dikili Tash, Demetra, Aravissos, and

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the Early Bronze Age stages at Perivolaki (Photos, 1987). Literature data is indicative that northern Greece is most likely the richest gold-bearing region in Greece. However, evidence regarding the exploitation and production of gold deposits in the area during prehistory is poor (Vavelidis and Andreou, 2008).

The smelting of copper ores begins shortly after silver metallurgy, and copper objects, as well as slags, broken crucibles, and furnace linings, occur in the Late Neolithic age in Mainland Greece in a number of places, which include tin, arsenical and more rarely antimonial bronzes (Photos, 1987; Tylecote, 1992; Pelton et al., 2014; Nerantzis et al., 2016; Nerantzis et al., 2017). In Crete, the beginnings of metallurgy appear in Early Minoan I (2400-2200 B.C.), and the main center seems to be in the Mesara plain in the south. Most of the finds of this period are arsenical coppers, and dilute bronzes (3.14, 3.16% Sn) do not appear until the Middle Minoan I (2000 B.C.). These findings suggest that tin supply was heavily depended on trade routes and whenever there was a shortage of it, Sb and As local sources were used as an alternative solution (Tylecote, 1992).

The Iron Age in Greece began towards the end of the 11^{th} century B.C. The use of iron is considered to have started earlier in South Greece than in Macedonia, though the dating remains uncertain (Photos, 1987). From the LBA (1600-1200 B.C.), there is ample evidence of iron metallurgy in various places of Greece in the form of rings, small plaques pendants, nails, rings, and knives but also metallurgical slags (Waldbaum, 1980; Photos, 1987; Backe-Forsberg et al., 2006). However, even though during the 1050-900 B.C., there are findings of an the abundance of iron artefacts, the replacement of bronze with iron is a slow process. Bronze alloys continue to be dominant in this period as well as in the next centuries, while it is used for spearheads and arrow tips (Photos, 1987). The aim of the present study is to analyze slag samples in order to define the kind of metals extracted in Archampolis and also to suggest possible sources of the raw materials which were burned in the kilns.

2 Geological Setting

The studied area is located in the southeastern part of Euboea Island, which comprises the Attic-Cycladic Massif (ACM) and is a member of the Intermediate Tectono-metamorphic Zone of the Hellenides orogen (Papanikolaou, 1984).

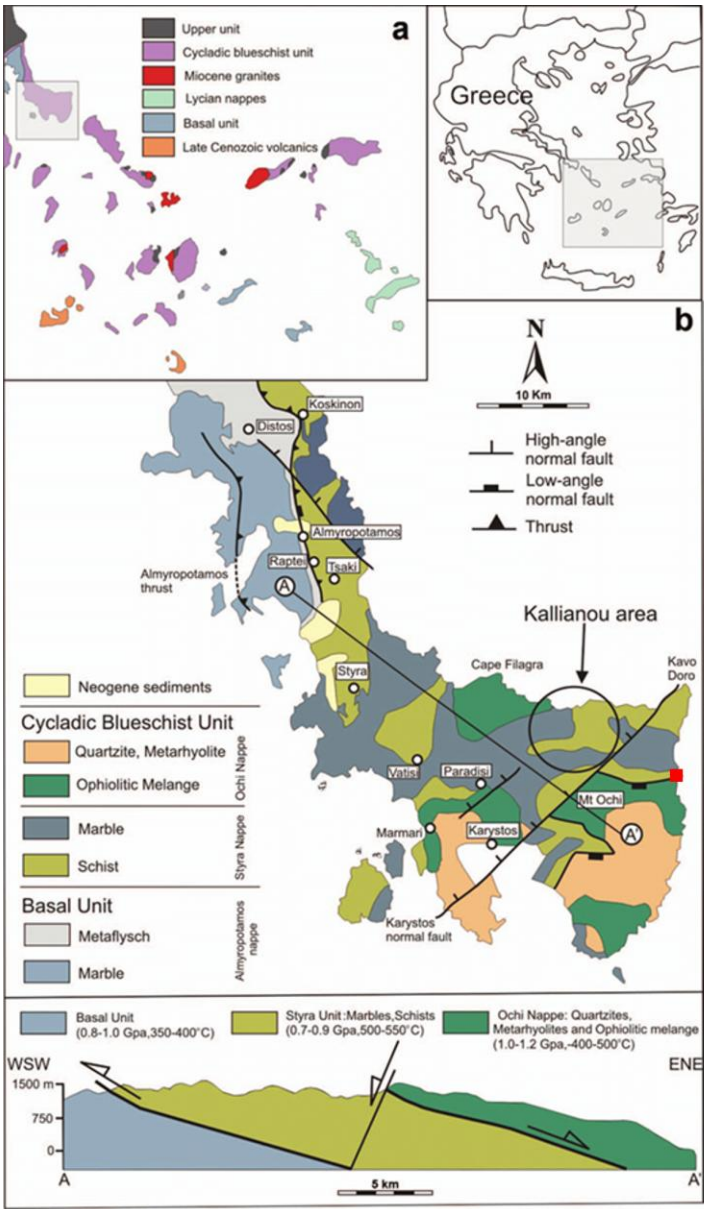

Fig.1: Simplified geological map of Southern Euboea with the Kallianou area marked in a circle and the Archampolis area with a red square (modified from Bindi et al., 2013)

The ACM was created during the Alpine orogeny and consisted of metamorphic rocks created in High Pressure / Low Temperature (HP/LT) conditions. The Karystos area consists of two litho-stratigraphic units: the "Styra" Nappe and the "Ochi" Nappe. The "Styra" Nappe is the local appearance of the Northern Cyclades Unit on the island of Euboea (Papanikolaou, 1978a; 1978b). It is comprised of a 2000m thick sequence of marbles with interlayers of schists and quartzites, metapelites along with metabasites and serpentinite lenses near the base of the nappe. The schists are mostly composed of muscovite, chlorite, quartz, and calcite, and rarely amphibole and epidote. The marbles are fine-grained to medium-grained and usually transition to cipolines. The schist in the upper horizons of the unit constitutes a metamorphic "wild flysch" with blocks of meta-ophiolites and other lithologies (Papanikolaou, 1978a; 1978b). The tectonically overlaying "Ochi" nappe is situated in the southernmost part of Euboea and has at least a 2500m thickness. The unit is mainly composed of metavolcanic, metabolites, meta hornfels, calcareous schists, quartzite interlayers, quartz-feldspar schists, and gneiss. Scarce lenses of mafic and ultramafic meta-igneous rocks are found in Ochi nappe, but mainly along the tectonic contact with the underlying Styra nappe. The contact of the two nappes is an ENE-directed shear zone rather than a discrete fault surface (Xypolias et al., 2010; Ring et al., 2007). This unit has been associated by Papanikolaou with the Makrotantalon Unit in northern Andros Island, where there have been found marble horizons with Permian fossils (Papanikolaou, 1976; 1978a; 1978b). The unit underwent blueschist-facies metamorphism at 18kbars and 550ºC. Afterward, a retrograde greenschist-facies metamorphism followed at 4-9kbars and 450-550ºC during the exhumation of the unit. The beginning of the metamorphism was dated in the Upper Cretaceous around 105-75 Ma, which was followed by the blueschist-facies metamorphism in Upper Eocene (ca 45-35 Ma) and finally, the retrograde greenschists-facies metamorphism around 25-20Ma (Bröcker & Franz, 1998; 2006; Zeffren et al., 2005). However, to this day, the unit's position in the tectonostratigraphic terranes is a matter of debate. Some researchers propose that the Ochi unit represents the ophiolitic mélange of the Cycladic Blueschist Unit (CBU) (Papanikolaou, 1978a; 1978b; 1987; Ring et al., 2007; Shaked et al., 2000), while others consider it as part of the Pelagonian Zone (Blake et al., 1981; Bonneau, 1982; Dürr, 1986; Huet et al., 2015) or the Upper Unit of the ACM metamorphic core complex (Katzir et al., 2000).

3 Mineralization

The southern Euboea is a part of the Attic-Cycladic-Pelagonian ore belt, which includes base- and precious-metal skarn, intrusion-related, and epithermal mineralization deposits. Most specifically, the Karystos area consists of the metamorphic formations of Northern Cyclades nappe and the overlying Makrotantalon – Ochi nappe, as mentioned earlier. The two types of mineralization in southern Euboea are mixed sulfide and manganese ores.

3.1 Mixed sulfides mineralization

The mixed sulfides mineralization located in the Kallianou area (Fig.1) has been exploited mainly for its golden-silver-rich ore since ancient times (Voudouris et al., 2011). The indicated size of the Kallianou deposit is estimated to be 500,000 tonnes at an average grade of 2-2.4% Pb, 0.7% Zn, 0.5-0.8% Cu, 35-60 g/t Ag and 5 g/t Au (Alexouli-Livaditi, 1978; Katsikatsos, 1978). According to Alexouli-Livaditi (1978), Theofilopoulos and Vakondios (1982), Perlikos (1988) and Vavelidis and Michailidis (1990), the mineralization in the Kallianou area covers an area of about 50 Km^2, north of Karystos. The host rock of the sulfides is the metapelites (mica schists) and the marbles of the Styra nappe. The mineralization occurs either within monomictic tectonic breccias in the hanging–wall marble unit along the contact with the schists or as meter-thick quartz veins that crosscut the foliation of the footwall schists (Voudouris et al., 2011). The quartz veins that are enriched in mixed sulfides ore contain up to 52 g/t Au and 242 g/t Ag (Alexouli-Livaditi, 1978). These veins have a general NW direction with a 30-70º NE dip (Theofilopoulos and Vakondios, 1982). Breccia in the marble unit consists of angular fragments of the host rock cemented mainly by quartz, chlorite, albite, and carbonate minerals. Galleries, shafts, and dumps of rock waste are found in the area, suggesting intense mining activity since antiquity.

Metallic mineral facies of the ore include pyrite, arsenopyrite, löllingite, argentite, electrum, native silver, gold, various Ag-Cu tellurides, etc. (Alexouli-Livaditi, 1978; Vavelidis and Michailidis, 1990; Voudouris and Spry, 2008). Pyrite, galena, and chalcopyrite are the most common metallic minerals. Chalcopyrite postdates pyrite andreplaces pyrite along with galena. Sphalerite participates as a minor phase and is closely related to chalcopyrite (Alexouli-Livaditi, 1978). The latter one is often found as inclusions in the former (Varelidis and Michailidis, 1990). It is notable that Ag does not replace Pb in the crystal lattice of galena, but it is present as an inclusion of Ag-bearing sulfotellurids. The main gangue minerals of the ore-rich veins include quartz and calcite, while the wall rock alteration consists of chlorite, muscovite, albite, and calcite (Voudouris et al., 2011). The veins postdate the ductile deformation associated with the HP/LT metamorphism of the Miocene. As for the mechanism responsible for the formation of the deposit, two theories have been proposed. The first one proposes that the hydrothermal fluids have originated from a granitoid intrusion during the cooldown (Vavelidis and

Michailidis, 1990; Alexouli-Livaditi, 1978). The second one argues for the introduction of metals during retrograde greenschists-facies metamorphism (Theofilopoulos and Vakondios, 1982; Perlikos 1989).

According to Sakharova et al. (1981), Au hydrothermal deposits are formed at temperatures ranging between 50° and 250°C (Vavelidis and Michailidis, 1990). According to Voudouris et al. (2011), the maximum temperature for the formation of the Kallianou quartz veins was considered to be about 300°C. This temperature estimate is based on the study of Nüchter and Stöckhert (2007), who proposed that microfabrics in the discordant quartz veins in the metamorphic rocks of the broad Kallianou area indicate deformation around 300°C, at a depth just below the brittle-ductile transition. Similar temperatures (290-310°C) were estimated by chlorite geothermometry for the formation of quartz veins hosted within retrograde metamorphic rocks of the CBU unit in central Euboea Island (Voudouris et al., 2008). Furthermore, the fahlore and polybasite assemblages' composition suggests that they were formed at temperatures below 200°C in the Kallianou area.

3.2 Manganese mineralization

The manganese occurrences in the broad Karystos area are located near the village of Stoupeoi and on the beach of St. Demetrius. These occurrences are overlying (tectonically) the mixed sulfides mineralization. Furthermore, while the mixed sulfides ore is confined in an area close to the hypothetical igneous intrusion, the manganese ores are widespread even at distances of several kilometers in the northern direction (Perlikos, 1989).

The manganese occurrences can be classified into two groups:

- The first group is hosted into quartzites (Andronopoulos, 1962). The ore is scattered in three separate quartzite horizons, which are located in the middle and the upper sections of the quartz-mica schists. These horizons stretch from an area north of the village of Aetos to the villages of Frygana and Pano Kampos. They are discontinuous and can be described as a disseminated mineralization of manganese lenses, which have undergone small-scale exploitation in the past (Dimou et al., 1997).
- The second group of manganese ores is found in quartzitic-micaceous schists and occurs in scattered areas north of village Aetos and up to the ravine of St. Demetrius and the Stoupeoi village. These occurrences are stratified with ore bands alternating with gangue.

The occurrences of the two groups are probably related stratigraphically, as suggested by neighboring occurrences of the two ore groups north of Aetos village in the Panagia and Tsiftiliki locations (Perlikos, 1989). The primary minerals of the ore are braunite and hausmanite, while secondary minerals such as pyrolusite, holandite, and piemontite were described (Andronopoulos, 1962; Perlikos, 1988).

Other types of mineralization. According to Latsoudis and Triantaphyllis (1997), who carried out a detailed geological mapping in the area of southern Euboea, mineralizations of iron-manganese and iron-copper also exist.

4 Iron metallurgy in antiquity

The Iron Age started in the second millennium BC. The forging of man-made iron was sporadic at the beginning, but gradually, the production increased to meet the demands for weapons around 1200-1100 BC. The greater ductility of iron swords in comparison with tin and led bronzes gave them a significant advantage, as they could withstand more blows without breaking (Tylecote, 1992). As a result, the need for improved weaponry created the knowledge of ironworking. The technology of ironworking is divided into two sections: smelting and hot forging. The melting point of pure iron is at 1538°C, and this temperature was unachievable by early smiths up until the 19th century AD, with the invention of the blast furnace. Thus, all early wrought iron was produced in a solid state by chemical reduction of iron ore to solid iron at about 1200ºC, using charcoal as a reducing agent (Tylecote, 1992).

According to Tylecote (1987), in antiquity, two types of furnaces were used for iron smelting: the bowl furnace and the shaft furnace. In the bowl furnace, the iron ore, along with coke, is placed in a hole in the ground, which is coated by loam. Then, fresh air was pumped through tuyere in the bowl furnace. The air reacted with the hot coke to form CO. Thus, the iron ore was provided with a continuous supply of CO, which was progressively reducing the ore to metallic iron (Vaxevanopoulos, 2017).

The shaft furnace was developed as the technology of ironworking was improving and became dominant until the discovery of the blast furnace. It consisted of a vertical stone structure, usually above a pit. The structure was cylindrical and had a coating of loam in its interior. Coke mixed with iron ore was supplied from the top of the furnace structure (Papadopoulos and Nerantzis, 2012). In the upper layers of the shaft furnace, the iron minerals (e.g. $FeCO_3$) are broken down at temperatures around 500ºC. In the lower layers, reducing conditions were developed at 750ºC, where the produced CO participated in the reduction of iron oxides (Vaxevanopoulos, 2017), according to the following equation:

$$FeO + CO \rightarrow Fe + CO_2$$

The reduced iron was removed as lumps called “bloom”, which was a mixture of solid iron, slag and pieces of unburnt charcoal. In order to extract the iron from the slags, the lumps were broken down and the iron fragments were separated with hot hammering at a temperature of 1200ºC approximately (Zianni, 2012).

4.1 Metallurgical slags

The undesired impurities of the ore, alongside fluxes, remnants of fuel, and ceramics from the walls of the furnace or the tuyere and some iron remnants, were merged and created slags. Since most of the slag components had a lower melting point than iron, the slags were in a liquid or semi-liquid state in the furnace. As a result, they were concentrated in the bottom of the pit and exited the shaft furnace through a hole into the surrounding area. In antiquity, the slags were left in situ once the metal was collected because their transportation would be costly and pointless. Therefore, the existence of slags is an indicator of metallurgical activity in the area. Depending on the quantity of the ore used, slags could form heaps or be scattered lumps in the broader area of the furnace. Their existence is important because they often are the sole evidence of the metallurgical activities in ancient Greece (Saiti, 2017).

4.2 Archampolis

During antiquity, the Ravine of Archampolis was a settlement related to extensive ironworking (Panagopoulou, 1994; Dimou et al., 1997). Dating of the findings uncovered by excavations suggest that the area was inhabited during the 5th to 1st century BC, but there is evidence of a Geometric period settlement that is yet to be uncovered or was already destroyed by the 5th century BC. The settlement was under the influence of the city of Karystos during the classic period, as revealed by two bronze coins of Karystos and three of the Euboean League, of which Karystos was an active member.

5 Materials and methods

5.1 Materials

The slag samples studied (Fig.2) were collected by the broad area of Archampolis in the southern part of Euboea Island. The slags are found on the northern side of Archampolis Gulf at the outlet of the gorge and occupy an area of about 200 m^2. The slope displays a great inclination (35-45º) and is affected by strong winds, a basic element for the process of smelting. The slags have a dark brown, black, or bluish color and are found approximately 800 m away from the archaeological excavations area (Dimou et al., 1997). No stratigraphic sequence in the slag deposition area was observed, so sampling was conducted at random points. For the present paper, 9 slag samples were selected for analysis, representing different textural features, named ARPL1 to ARPL9 (Fig.2).

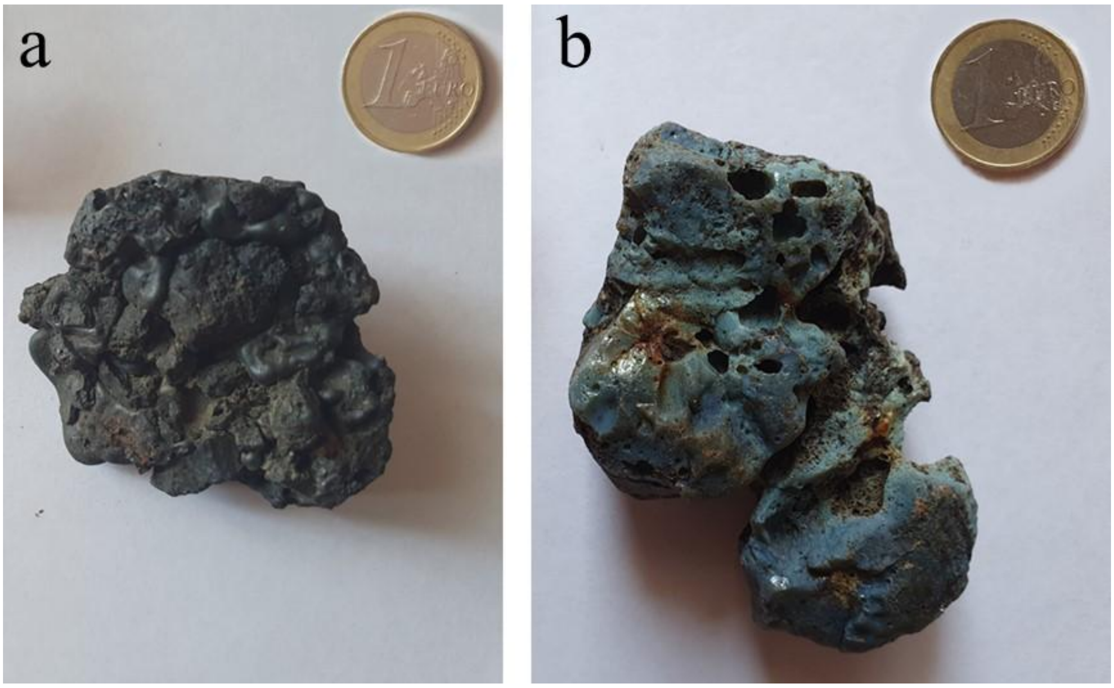

Fig 2: Representative samples of Archampolis slags. (a) Ferrous slag (ARPL-1) and (b) glassy slag (ARPL-8)

5.2 Analytical methods

The methods used for the determination of mineralogical phases were X-ray diffraction (PXRD) and electron Microprobe Analysis (SEM-EDS), while the elemental composition of the samples was determined by X-ray Fluorescence (XRF) technique. The XRD analysis was conducted by TITAN S.A. using the D8 ADVANCE Diffractometer model of Bruker Corp. The evaluation of the results was conducted with EVA v5.2 software, a part of the DiffacPlus package of Bruker Corp, in a Windows environment. The XRF analysis was conducted in TITAN S.A. R&D labs located in Eleusis, using the Bruker 58 TIGER spectrometer. The SEM-EDS analysis was conducted in the lab of the Mineralogy and Petrology Department of the Faculty of Geology and Geoenvironment, NKUA, using a JEOL JSM-5600 scanning electron microscope equipped with an EDS micro-probe type Oxford Link ISIS 300. Operating conditions were 20kV and 0.5 nA with a beam diameter of 3μm (CuKa X-ray line).

6 Results

6.1 XRD patterns

All samples analyzed by the XRD method. The mineralogical analysis revealed that the main component of the slags is wüstite (FeO), followed by fayalite, quartz, and bustamite ($CaMnSi_2O_6$). All the other minerals occur in smaller amounts or only in certain samples (Table 1). In addition to crystalline mineral phases, the presence of amorphous silica glass was deduced in all samples from the hump between 20-

26° on the XRD patterns. The most noticeable humps were detected in samples ARPL6 and ARPL9, indicating higher concentrations of glassy matrix.

Table 1: XRD mineral analysis of the Archampolis slags*

SAMPLES	WUSTITE	FAYALITE	BUSTAMITE	QUARTZ	ALBITE	ANORTHITE	CALCITE	TEPHROITE	MAGHEMITE	GOETHITE	DOLOMITE	HEMATITE	MAGNETITE	GARNET	PYROXENE	LIME	MELILITE	MICA/ILLITE	CHALCOPYRITE	HORNBLENDE	CORUNDUM
ARPL1	MJ	MD		TR			TR	MJ						TR		TR			TR		
ARPL2	TR		MJ	MD			TR														
ARPL3	MJ	MD		MD	TR		TR									TR					
ARPL4				MD	MJ	MJ	MD						TR					TR		TR	
ARPL5	MJ	MD		MD	TR		MD						TR			TR					
ARPL6			MJ	MJ	TR		MD										TR				
ARPL7	MJ			MD					MJ	MD			MD		TR		TR				TR
ARPL8			MJ	MD	TR		MJ				MJ	TR									
ARPL9			MJ	MJ	MD		MD					TR		TR	MD		TR				

*: Explanatory notes: MJ = major component, MD = medium component, TR= minor/trace component

6.2 XRF analysis

XRF analysis was used to determine the elemental composition of samples ARPL1 –ARPL9. Major elements are presented as oxides and trace elements as parts per million (ppm) in Tables 2a and 2b. It is noted that in the XRF analysis, the total iron concentration is referred to as Fe_2O_{3t}. However, this does not mean that the samples contain exclusively Fe^{+3}. In fact, as the XRD patterns show, all samples contain mostly Fe^{+2} with traces of Fe^{+3}.

Table 2a: XRF analysis for major elements oxides, Archampolis slags

%	ARPL-1	ARPL-2	ARPL-3	ARPL-4	ARPL-5	ARPL-6	ARPL-7	ARPL-8	ARPL-9
SiO_2	9,8	46,28	12,47	50,92	5,73	47,28	50,77	48,84	46,2
Al_2O_3	2,26	6,94	2,77	14,96	1,37	7,76	8,04	8,01	7,51
Fe_2O_{3t}	77,53	6,06	73,55	12,12	88,82	2,98	2,93	2,89	2,64
CaO	4,42	11,19	4,06	6,46	1,66	11,75	15,65	15,61	11,01
MgO	0,62	2,58	0,49	4,75	0,17	3,97	2,4	2,45	2,96
SO_3	0,19	0,31	0,21	0,16	0,22	0,34	0,32	0,32	0,41
Na_2O	0,19	0,48	0,27	5,11	–	0,58	0,46	0,47	0,66
K_2O	0,32	2,72	0,28	0,55	0,11	2,96	3,1	3,09	2,68
TiO_2	0,14	0,31	0,2	2,11	0,08	0,34	0,35	0,35	0,33
MnO	5,97	22,51	4,68	0,56	2,57	22,21	16,07	16,08	26,01
P_2O_5	0,58	0,05	0,54	0,37	0,31	0,02	0,04	0,04	0,03
LOI				1,28				0,74	
SUM	101,83	99,43	101,52	99,35	101,04	100,19	100,13	100,91	100,44

Table 2b: XRF analysis for trace elements, Archampolis slags

Elements (ppm)	ARPL-1	ARPL-2	ARPL-3	ARPL-4	ARPL-5	ARPL-6	ARPL-7	ARPL-8	ARPL-9
V	71	56,9	207	266	28,9	21,1	10,2	19,8	21
Cr	208	347	54,2	51,5	114	280	61,9	245	318
Co	0	0	16,2	30,3	0	0	0	0	0
Ni	21,3	10,3	117	8,5	37,2	9	123	13,7	18
Cu	259	21,5	25,6	105	360	43	2117	27,8	12,1
Zn	32,1	7,9	9,1	163	9,8	16	33,8	4,3	5,9
Ga	14,7	14,1	0,7	22,9	9,5	11,1	6,6	9,4	14,6
Ge	0,7	0,7	9,9	0,7	0,7	0,7	0,7	0,7	0,7
As	8,2	1,2	11,9	3,1	7,5	10,5	1036	3	0,7
Br	0	0,1	0	0,2	0	0,1	13,1	0,1	0,1
Se	11,6	8	0	2,9	10,9	8,5	5,2	9	7,4
Rb	0	37,5	80,6	8,1	2,5	40,1	30,3	52	39,1
Sr	86,2	595	9,7	141	19,5	560	35,9	506	569
Y	10,5	60,4	22,1	28,2	3,5	82,6	0	54,1	73,7
Zr	21,1	59,6	2,5	123	15,9	65,4	19,8	65	65,3
Nb	3,1	3,4	2	14,3	2,5	3,3	0,6	2,1	2,3
Mo	4,3	1,6	1,4	1,8	3,8	0,9	12,8	0,5	0,3
Ag	0,6	2	0,1	0,8	1	6,4	1,2	2,4	8,3
Cd	0,3	0,5	2	0,3	0,5	0	1,1	0	0,1
Sn	1,8	0	7,2	1,5	1,4	0	10,1	0,3	0
Sb	8,8	0,3	2,7	0,3	10,4	0,7	52,6	1,2	1,5
I	2,8	0	3,6	0,6	2,5	0	2,5	0,8	0
Te	0,4	0	1,3	0,6	0,1	0	2,2	0,8	0,9
Cs	3,4	3,7	645	3,8	5,1	3,4	3,2	3,1	2,8
Ba	867	1578	16,2	99	335	5552	179	1717	7250
La	11,5	46,2	7,9	26	8,4	53,9	7,5	44,7	39,1
Sm	8	12,1	22,9	7,6	5,9	13,2	7,7	11	9,6
Ce	20,3	72,2	24	55,6	14,6	81,4	16,7	68,4	68,4
Nd	31,2	70,6	120	32,2	10,8	129	12,7	67,5	136
Yb	4,9	0	3,7	0	39,1	0,6	0	0	26,8
Hf	5,5	11	56,4	0	0	9,9	0	11,9	12,9
W	65,7	30,8	0,7	22,7	76,6	34,3	61,2	33,1	39,2
TI	2028	437	47,6	20,8	925	192	193	89	198
Pb	47,1	0	0	224	42,1	0,8	158	2,1	1,2
Bi	0	0	0	0	0	0	0	0	0
Th	0	3,8	9,9	0	0	5,3	0	1,2	1

7 Discussion

The Cyclades area, of which southern Euboea is a part, belongs geologically to the Attic-Cycladic Massif and was affected by two orogenic episodes: one in the Late Jurassic-Early Cretaceous and one in Late

Eocene-Oligocene. During the Middle-Late Miocene, the Anatolian microplate, by moving westwards, started to push the Aegean area southwards. The result of these movements was to speed up the subduction velocity, creating a back-arc extension regime in the ACM. Under these conditions, the exhumation of the metamorphic core complex and igneous intrusions were favored. One such intrusion is hypothesized to have created the Fe-Pb-Cu-Zn mixed sulfides mineralization in southern Euboea and Andros islands, the center of which is located in the Kallianou area. The discovery of slag heaps near the ancient settlements of Archampolis and in northern Andros (Ipsili, Palaiopolis)suggests that the abundance of ferrous deposits drove a rapid development of ironworking in the Aegean Sea.

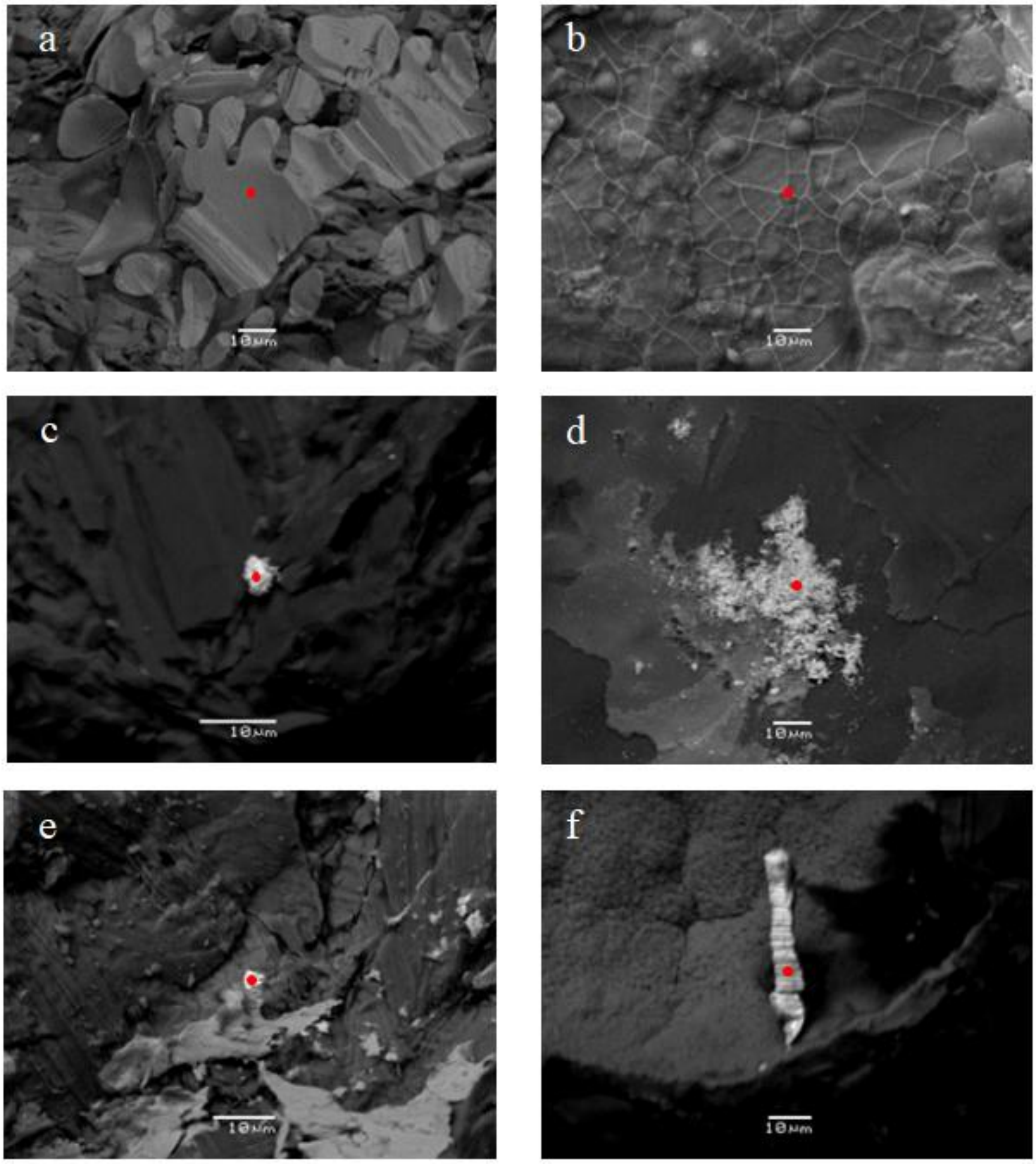

Fig 3: Granules of (a) wüstite, (b) Mn-rich fayalite, (c, d) prills of galena and cerussite, (e) cuprite-cassiterite and (f) cassiterite, marked by the red do*t*

Before examining the origin of the initial material used to extract the iron, the melting condition in the furnace must be understood. However, the various melting points of the artificial minerals and the glassy phase created in the furnace complicate this task, especially if flux agents were used, such as manganese oxides. As was mentioned earlier, charcoal was used to reduce the ore, which produced CO. The reduction of iron, however, was not usually achieved in one stage but rather in several ones. As a result, magnetite was formed below 300ºC and wüstite between 300-1000ºC as intermediate products (Tylecote 1992). Furthermore, in temperatures ranging between 1000 and 1200ºC, wüstite reacts with SiO_2 to form fayalite. Sheikh et al. (2010) studied ferrous slags from the 4th century BC in India and concluded that the furnace in which they were produced was working at 1250-1300ºC, given the fact that fayalite has a melting point of 1205ºC and the wüstite-fayalite eutectic point is at 1177ºC.

The presence of the series of calcareous olivines of monticellite-kirschstenite, where monticellite ($CaMgSiO_4$) is the manganese member and kirschstenite is the ferrous end-member of the series, is significant to determine the smelting temperatures. Mukhopadhyay and Lindsley (1983), while studying mixtures of fayalite-kirschstenite, discovered that the Ca-olivines were formed at 1165-1170ºC, while fayalite formed at 1100º C, under CO-CO_2 atmosphere. Correspondingly, Sharp and Mittwed (2011), by examining fayalite-kirschstenite-rich slags, found that the intermediate glassy phase was formed at temperatures of 1100-1200º C, which is also shown in the FeO-SiO_2-Al_2O_3 ternary diagram. A similar pattern was observed while analyzing the ferrous slags of Andros Island. When plotted in the ternary diagram SiO_2 – FeO (+MnO + CaO) – Al_2O_3, the slags occupy an area between pure $FeSiO_4$ and optimum 1 point, which signifies the maximum concentration of SiO_2 in the melt for fayalite to form (Stamatakis, 2018).

In both samples from Archampolis and Andros the MnO could not be reduced in the furnace, so instead reacts with SiO_2 to form Mn-Fe-Ca-silicates, which make up the glassy matrix. As a result, in Andros slags, crystallization starts with metallic iron, followed successively by wüstite, mineral phases which are formed from the reaction of FeO with SiO_2 (fayalite, bustamite, tephroite, kirschstenite), and finally glass of melilite composition (Stamatakis, 2018). On the contrary, in Archampolis samples, the glass is composed almost exclusively of bustamite, fayalite, and tephroite, depending on the concentration of manganese in the sample. Kirschstenite was not detected, but in one sample, the magnesium end-member of the series, monticellite ($CaMgSiO_4$), was found. The fact that Fe does not form Ca-silicate minerals on its own, but prefers to substitute the Mn in bustamite is probably caused by the high concentration in MnO of the samples, which was maybe used as a flux agent. Also notable is the absence of the melilite group minerals, with the exception of samples ARPL6 and ARPL9. In ARPL6, åkermanite ($Ca_2MgSi_2O_7$) was detected, while in ARPL9, the composition of the melilite was $Ca_{5,95}Na_{2,05}[Si_2O_7]_2$, according to the XRD analysis. This phenomenon is probably due to the low concentrations of Na_2O and Al_2O_3 in the samples, which are usually trapped in the albite crystal lattice in the rock formations of the study area and, henceforth, not available in the melt.

According to the XRF analysis, the samples can be classified into two categories, regarding their chemical composition:

1. Fe-rich samples, with $Fe_2O_{3t} > 70\%$
2. Silica-rich samples with $SiO_2 > 45\%$

7.1 Fe-rich samples

Fe-rich samples constitute residual iron (II) oxide, which was not fully reduced to metallic iron (Fig 2a). This group includes the samples ARPL1, ARPL3 and ARPL5. They are made up mostly of wüstite (FeO), which is found in spheroid to botryoid granules sunk in a fayalitic matrix (Fig.3a, b). SEM-EDS analysis revealed that fayalite is of the manganese variety, detected mostly in ARPL1 and ARPL3 samples. Moreover, in sample ARPL1, where the maximum concentration of MnO (5.97%) for this group was detected, the glassy matrix is dominated by tephroite, the manganese end-member of the olivine group. The lowest concentration of MnO (2.57%) is found in the ARPL5 sample (Table 2a), while the ARPL3 contains 4.68% MnO, which results in the formation of the intermediate member of fayalite-tephroite series, knebelite $(Fe, Mn)_2SiO_4$. These results are in accordance with the findings of Dimou et al. (1997), who measured 4-8% content of MnO in fayalites of the Archampolis slags.

The maximum concentration of Mn in wüstite granules was detected in the ARPL1 sample (3.9% MnO). According to the XRD patterns (Table 1) and the SEM-EDS analysis, the Fe-rich slag samples also contain the following trace minerals:

- ARPL1: Spessartine, a-quartz, lime (CaO), calcite, rutile
- ARPL3: a-quartz, calcite, lime (CaO), albite
- ARPL5: a-quartz, calcite, anhydrite, ilmenite, lime (CaO), albite, magnetite, siderite, brownmillerite [$Ca_2(Al, Fe)_2O_5$]

Concerning the mechanism of ancient shaft furnaces described beforehand, the presence of iron minerals such as magnetite and siderite can be attributed to a partial reduction of iron ore. Oxides like rutile (TiO_2) and ilmenite ($FeTiO_3$) could be primary or authigenic, formed due to the reducing conditions inside the furnace. The presence of calcite and lime can possibly be sourced from the marbles, pipelines, and calcareous schists hosting the mineralization. When heated to 1200ºC, the calcite was transformed to lime. A part of the lime could be trapped inside the wüstite clumps, while the rest reacted with the CO_2 of the atmosphere and reverted to calcite. Another possible source of these phases could be chunks of refractory coating (loam) trapped within the slags. The presence of chalcopyrite in the ARPL1 sample is an indication that the source of the ore was probably the mixed sulfides mineralization located in the area and, more specifically, the oxidized parts of it. Furthermore, in samples ARPL3 and ARPL5, two baryte crystals, a gangue mineral accompanying hydrothermal mineralizations, were observed in SEM. Their presence further supports the aforementioned theory about the source of the iron ore. Anhydrite crystals are also present in the samples. Minerals like spessartine and brownmillerite could have been formed during the cooling of the glassy matrix. The quartz could either have formed also by the crystallization of glass or preexist as part of the source material since it is known that the mixed sulfides in southern Euboea are found inside quartz veins.

7.2 Silica-rich (glassy) samples

In this group belong the samples ARPL2, ARPL4, ARPL6, ARPL7, ARPL8 (Fig. 2b) and ARPL9. Among them, ARPL4 and ARPL7 stand out due to the drastic divergence of their mineral composition in comparison with the rest of the group. ARPL4 is composed mainly of minerals of the plagioclase group (albite, anorthite) and secondarily by a-quartz, calcite, magnetite, illite, hornblende, and muscovite (Table 1). The sample is likely a semi-melted host rock (schist) that contained the ore. As Dimou et al. (1997) have pointed out, muscovite and hornblende are characteristic minerals of the metamorphic rocks of the basement rocks in the studied area. The XRD pattern of ARPL7 shows mainly iron phases, though the XRF analysis (Table 2a) showed concentrations of only 2.9% Fe_2O_3t, 16.07% MnO, and 50.77% SiO_2. Sample analysis showed the presence of mineral facies such as wüstite, maghemite (g-Fe_2O_3), goethite, a-quartz, grossular, halloysite, monticellite, åkermanite, spinel, corundum, magnesite, jadeite, lepidocrocite and a substantial amount of glassy matrix (given the hump and kurtosis of the XRD pattern). It may represent a transition zone between the wüstite-fayalite phase at the bottom of the furnace and the manganese glassy phase, which, according to Bachmann (1980), is formed in the upper layers of the furnace when the ore contains a substantial percentage of manganese. The rest of this group samples are glassy microporous slags, which have macroscopically a bluish hue. As observed by Dimou et al. (1997), the glass has undergone partial devitrification, though the extent of the phenomenon is not uniform in all samples. The maximum concentration of glassy matrix appears to be in samples ARPL6 and ARPL9, followed by ARPL8 and ARPL2. The concentration of MnO ranges between 26% (ARPL9) and 16% (ARPL8). According to Dimou et al. (1997), the microliths formed during the recrystallization are of bustamite composition ($CaMnSi_2O_6$), which is confirmed in this paper. Apart from bustamite, according to XRD patterns (Table 1), the glassy slags contain the following minerals:

- ARPL2: a-quartz, wüstite, calcite
- ARPL6: a-quarts, calcite, åkermanite, langbeinite $K_2Mg_2(SO_4)_3$, albite
- ARPL8: dolomite, calcite, a-quartz, christobalite, hematite, albite, siderite
- ARPL9: a-quartz, calcite, albite, melilite, diopside, hematite, grossular

Minerals such as quartz, cristobalite, langbeinite, grossular and siderite were formed by recrystallization of glass, while the samples also contain small quantities of iron ore that were not completely reduced (wüstite, hematite). As in ferrous slags, the presence of calcite is attributed to coating chunks that were stripped off from the furnace's wall or alternatively to the host rock, while the albite probably remains as a relic mineral of the host rock of the mineralization. Finally, notable is the presence of many members of the melilite mineral group (melilite, åkermanite) and the pyroxene group (diopside). According to Bachmann (1982), melilite is formed when the ratio of MeO (metal oxides) to SiO_2 reaches 1.5:1 in the furnace, while pyroxenes when the ratio drops to 1:1. In conclusion, it is deduced that the sample ARPL9 is the most depleted in metal oxides, which is confirmed by XRD analysis, for all metals except for Mn.

7.3 Other metals in the slags

By SEM-EDS microprobe analysis, galena and cerussite granules (Fig.3c, d) were detected in samples ARPL4 and ARPL6 and Cu-As (Fig.3e) granules in ARPL7. Moreover, as it is shown in Table 2b, unusually elevated concentrations of thallium were observed in samples ARPL1 (2028 ppm) and ARPL5 (925 ppm), even though no thallium minerals were detected, as it probably entered in the lattice of neocrystallized Fe-rich minerals. Thallium is known to be present in high concentrations at hydrothermal environments below 200°C, in relation to sulfides (Sobott, 1995) and especially pyrite, as a substitution of Fe in the crystal lattice (Lopez-Arce et al., 2017). These findings are in accordance with the theory proposed by Voudouris et al. (2011), who hypothesized that the mixed sulfides deposition in the Kallianou area took place at 300-200°C. All evidence suggests that the primary iron mineralization was constituted by mixed sulfides while being a part of distant occurrences of the hydrothermal Kallianou system. Afterward, the ore was oxidized, resulting in the leaching of the more labile elements and the enrichment of iron in the form of Fe-oxyhydroxides. (Voudouris et al., 2011; Tombros et al., 2021). Possible sources of the raw primary ore could be the region of the southern Euboea (Kallianou and surroundings), and/or the neighboring Cyclades islands. Similar iron deposits derived from the alteration of mixed sulfides have been found in Andros, at the sites Paleopolis and Aghios Petros, where the iron ore contains residual pyrite, chalcopyrite, and a gold grain of 50 μm (Perlikos, 1988; Vasilatos, 1990; Strati, 2019). Also, high concentrations of Cu were detected in three samples (259 ppm in ARPL1, 360 ppm in ARPL5, and 2117 ppm in ARPL7), as well as 1036 ppm As in ARPL7. Furthermore, no high concentrations of Cr or Co were found in any sample (maximum 347 and 30 ppm, respectively).

To conclude this paper's findings, we must report that during the SEM-EDS analysis, a tin grain was found in ARPL5 and a Cu-Sn grain in the ARPL8 sample (Fig.3f). Given the fact that none of the samples showed Sn concentration above 10 ppm, it is rather improbable that the tin grains were part of the primary mineralization. Maybe the source of these grains was the various tools used to load the furnace with the ore-charcoal mix. In that case, this would be an indication of dating these slags in the Early Iron Age, where iron was still a luxury item used for jewelry and weapons. This indirect dating would be close to the oldest dating Keller (1984, 1985) proposed as the beginning of the settlement in the 7th century BC.

8 Conclusions

By combining all analytical results, it was concluded that metallurgy was applied for iron extraction. The original feeding material was most likely an oxidized polymetallic ore. Geochemically, it turned out that certain slag samples are enriched in Cu, As, Pb, and Tl. Thallium is known to be present in high concentrations at hydrothermal environments below 200°C, in relation to sulfides and especially pyrite, as a substitution of Fe in the crystal lattice. These findings are in accordance with the theory proposed by Voudouris et al. (2011), who estimate that the mixed sulfides deposition in the Kallianou area took place at 300-200°C. All these observations are indicative of a possible origin of the initial ferric ore from the oxidization of the mixed sulfide ore, which is located in the area of south Euboea Island. However, the neighboring island of Andros could also be an additional source of iron ores for the Archampolis metallurgical works.

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Characterization of mortars from the Vartalis Watermill in Cyprus

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Abstract. Traditional watermills for grain production are found in many places across the world. However, despite being an integral part of rural agriculture throughout history, these structures have received relatively little attention compared to other monuments and traditional buildings. Hence, studies of their building materials, including mortars, remain scarce. This paper focuses on the assessment of four mortar samples received from the Vartalis watermill in Cyprus. The study is part of a wider project focusing on the building materials (especially mortars) of a number of watermills around Nicosia and Cyprus. Two of the four mortar samples investigated were extracted from the aqueduct leading to the water tower, while the remaining two were obtained from the water tower of the watermill. In both cases, the mortars were in direct contact with water whilst the water tower was operative. Therefore, the assessment involved an insight into their consistency and hydraulic properties. Macroscopic observations and laboratory analytical experimental techniques, which included powder X-Ray Diffraction (XRD) analysis on the binder/aggregate fractions separately and Thermogravimetric and Differential Thermal Analysis (TG-DTA) on the bulk samples, were employed for the detailed study and characterization of the mortars. The results showed that all four mortar samples were consistent, with densely packed river sand as aggregate material and the occasional presence of lime lumps and coal. They also revealed the presence of calcite and crushed ceramic in the binder fraction, as well as quartz and plagioclase (albite) in the aggregate fraction. Notably, the CO_2/H_2O ratio of the samples ranged between 1.2 and 3, suggesting that these may be classified as strongly hydraulic lime mortars.

Keywords: Lime mortars, Watermills, XRD, TG-DTA.

1 Introduction

Hydraulic mortars consisting of aerated lime and fired clay brick powder were used in the past in structures where protection from water and humidity was required [1]. In fact, the utilization of crushed brick-lime mortars in Cyprus traces back to the Late Bronze Age. The use of crushed brick, an artificial pozzolanic additive, in prehistoric mortar production technology in Cyprus has been attributed to the absence of natural pozzolans on the island [2, 3]. Crushed brick-lime mortars have been identified in various water-related structures across Cyprus to date; these include water channels, baths, workshops, and watermills [4, 5].

Cypriot watermills have been an integral part of the island's traditional rural life, economy, and cultural heritage. There are over 650 watermills scattered across the island; most of these have been in use until the middle of the 20th century [6]. However, during the British Colonial period, technological innovations led to the industrialization of the local society. This inevitably led to the decline of Cypriot watermills. Notably, while in 1919, 400 watermills operated simultaneously alongside windmills, animal-driven flour mills, and steam mills on the island, during the 1930s, traditional watermills decreased in number while steam mills gradually increased. Eventually, in the 1950s, traditional watermills were replaced with engine-driven mills [7]. Nowadays, most of the watermills in Cyprus are abandoned.

A number of studies on Cypriot watermills have been attempted lately [8]. Nevertheless, studies of their building materials, including mortars, still remain scarce [5]. This paper focuses on the assessment

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of four representative mortar samples received from the Vartalis watermill located in the village of Agios Ioannis in Nicosia district (Cyprus). The aim of the investigation is the characterization of the aforementioned samples and the potential identification of any natural or artificial pozzolanic additives.

2 The watermill of Vartalis

The watermill of Vartalis is situated within the administrative boundaries of Klirou, Malounta and Agios Ioannis villages, on the west bank of the Akaki River, in Nicosia district (Cyprus – Sheet/Plan: 29/ 47E2 - Parcel No.: 282) (Fig. 1) [9]. It was constructed either in 1841 or 1856 and remained operative until World War II. In 1979, it was declared an Ancient Monument.

The mill (Fig. 2) is well preserved and retains the aqueduct, the water tower with its pit, the main room with the grinding mechanism, the underground room which housed the waterwheel, and traces of an auxiliary room. It is built of local limestones and river pebbles, while the interior surfaces of the aqueduct and the water tower are plastered.

Fig. 1. Map of Cyprus showing the location of the Vartalis watermill.

Fig. 2. Aerial view of the Vartalis watermill, showing the sampling locations.

3 Materials and Methodology

Four mortar samples were extracted from the preserved remains of the Vartalis watermill (see Fig. 2) using a hammer and chisel. Two of these samples are classified as jointing mortars and were extracted from the aqueduct (AGIM 1-3) and the water tower (AGIM 1-6), while the remaining two are classified as plasters and were collected from the interior of the walls of the aqueduct (AGIM 1-4) and the water tower (AGIM 1-1).

The samples were first observed macroscopically, both on-site and in the lab, using a stereomicroscope. Their binder was then separated from the aggregates, following cycles of sonication and sieving through a 63 μm sieve. This helped determine the binder/aggregate (B/A) ratio of each sample, whilst it also provided individual samples for some of the analyses that followed.

Simultaneous Differential Thermal Analysis (DTA) and Thermogravimetry (TG) on each sample were then carried out with a Shimadzu DTG – 60H analyzer, using specimens of mass 20-70 mg. The bulk samples were placed in alumina crucibles and the analyses were conducted under atmospheric air, from room temperature to 1200°C, at a heating rate of 5°C/min.

In addition, powder X-Ray Diffraction (XRD) analysis on the binder and aggregate fraction of each sample was performed separately, using a Bruker D8 Advance system with Cu K_{α} radiation ($\lambda = 0.15406$ nm) at 40 kV and 40 mA. The analyses were carried out with continual rotation of the sample and a scanning speed of 2°/min, within the 2-70° 2θ angle range. The International Centre for Diffraction Data (ICDD) PDF 4 database was used for the qualitative identification of the constituent mineral phases.

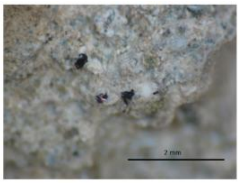
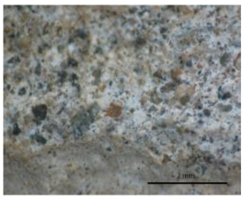
4 Results and Discussion

4.1 Macroscopic and microscopic observations

Preliminary macroscopic observations of the bulk specimens showed that all four samples were made of the same type of raw materials (see Table 1). Most of the samples appeared to be light grey or grey in color. The mortars extracted from the water tower were harder and more compact compared to those extracted from the aqueduct. The two mortars extracted from the interior walls of the aqueduct and the water tower were characterized by smooth external surfaces. None of the samples showed evidence of the presence of layers; all samples could be described as homogenous.

Further observations under the stereomicroscope revealed that the mortar samples were consistent with densely packed river sand as aggregate material; the latter ranged from ca. 0.2 to 2 mm in grain size and comprised various colors and shapes (see Table 1). In all samples, mainly subangular to rounded aggregate particles with grey and dark brown colors were identified, while the color of the binder was mostly whitish, suggesting a calcitic origin. Moreover, within the binder matrix of some samples, lime lumps measuring up to 2 mm were observed (see Table 1), the presence of which is common in historic lime mortars, indicating an incomplete calcination process [3]. It is noteworthy that lime lumps were identified only in the samples extracted from the water tower of the mill (AGIM 1-1 and AGIM 1-6). Sample AGIM 1-1 further showed evidence of the presence of some subangular and extremely fine reddish clay inclusions with grains < 1 mm. In sample AGIM 1-3, traces of coal were observed.

Table 1. Macroscopic and microscopic characteristics of the mortar samples collected from the Vartalis watermill.

Sample	Sampling location	Photo (in hand)	Photo (stereomicroscope)
AGIM 1-1	Water tower – Plaster		
AGIM 1-3	Aqueduct – Plaster		
AGIM 1-4	Aqueduct – Plaster		

AGIM 1-6	Water tower - Jointing mortar		

4.2 Binder/aggregate ratios

The binder/aggregate ratios of the four mortar samples hereby studied ranged from 1:2 to 1:3. The B/A ratio of 1:3 is the most common one cited in the literature [10, 11] and aligns with the ancient technological "standards" concerning crushed brick-lime mortars, as outlined by Vitruvius [11].

4.3 Thermal analyses

The thermal analysis results confirmed that the mortar samples under study may be classified as strongly hydraulic. The graphs obtained during these analyses (Fig. 3) correspond to similar graphs found in the literature for hydraulic lime mortars [12].

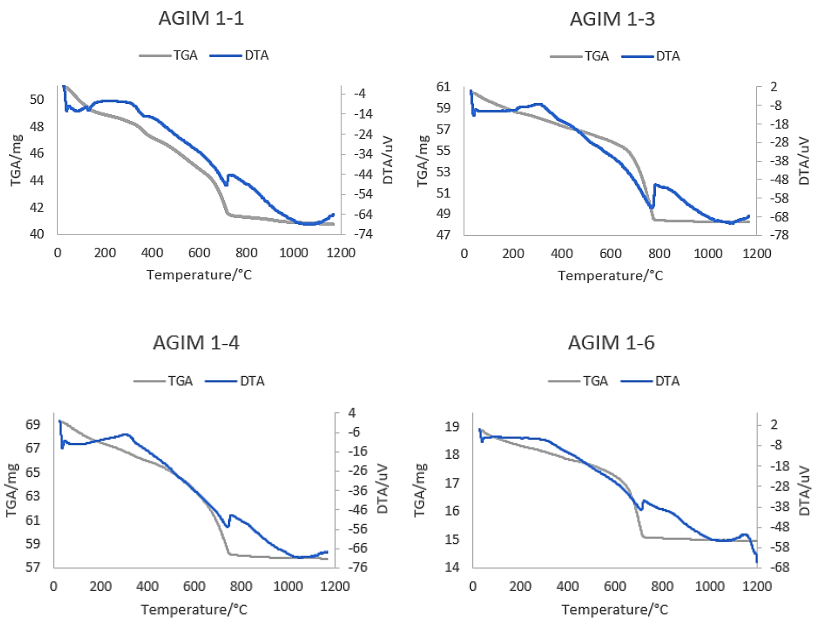


Fig. 3. DTA/TGA curves of the mortar samples under study.

In the graphs above, the first endothermic peak shown in the DTA curves, occurring between 40–60°C, is attributed to the loss of absorbed water from the mortars [13]. The second peak, between 120-200°C, which is more prominent in samples AGIM 1-1 and AGIM 1-3, corresponds to the loss of chemically bound water from hydrated salts, such as gypsum ($CaSO_4 \cdot 2H_2O$) [14]. The presence of gypsum may indicate mortar deterioration arising from reaction with atmospheric pollutants, or it might have been intentionally added to the mortar mixture [15, 16]. The limited amount observed in the analyzed samples suggests that gypsum is rather incidental, possibly due to environmental pollution. The exothermic peak at ca. 300°C suggests the loss of organic material [17].

Weight loss between 200 and 600°C is attributed to the release of chemically bound water from hydraulic compounds, such as calcium silicate hydrates and calcium aluminate hydrates [1, 12, 18]. These hydraulic products usually form following a reaction between lime and ceramic fragments [19]. Between 350 and 400°C, a reaction was detected in sample AGIM 1-1; similarly, two imperceptible reactions between 450 and 550°C were observed in sample AGIM 1-3. Both aforementioned reactions indicate the presence of portlandite [20, 21, 22].

The loss in weight occurring > 600°C is associated with the release of CO_2 due to the decomposition of carbonate minerals (calcite and/or dolomite) [15, 18, 23]. Usually, the thermal decomposition of carbonate minerals begins at temperatures > 600 to 650°C and continues until 750 to 850°C [15]. In the samples analyzed in this study, the carbonate decomposition reaction occurred between 700-800°C. Endothermic reactions within these temperatures (see DTA curves in Fig. 3) confirm the calcitic origin of the binder of the mortars. The mass loss at ca. 750°C may also indicate the loss of CO_2 due to the use of re-carbonated lime within certain cementitious materials, in which the original limestone contained specific clay minerals [18]. Calcite decomposition at temperatures < 850°C further suggests the use of impurities, such as magnesian lime or clays [23].

Through thermal analysis, the degree of hydraulicity of the mortars can be determined. This is defined as the ratio between the amount of CO_2 lost and the amount of H_2O linked to hydraulic compounds. A higher CO_2/H_2O ratio corresponds to less hydraulic mortars [24, 25, 26]. The calculated values of the ratio CO_2/H_2O of the mortars hereby examined are reported in Table 2. These ranged between 1.2 and 3, suggesting that the mortars under study may be classified as strongly hydraulic [15, 23].

Table 2. Water and CO_2 mass loss calculated from thermal analyses and hydraulicity ratios.

	H_2O Loss (%)			CO_2 Loss (%)	
Sample	<120°C	120°C-200°C	200°C-600°C	>600°C	CO_2/H_2O
AGIM 1-1	2.7	1.3	6.5	8.0	1.2
AGIM 1-3	1.6	1.2	4.5	11.6	2.6
AGIM 1-4	1.5	0.5	4.1	10.6	2.6
AGIM 1-6	1.9	1.1	4.5	13.4	3.0

4.4 X-Ray Diffraction

The mineralogical composition of the binder and aggregate fractions of the four mortars hereby studied is shown in Fig. 4.

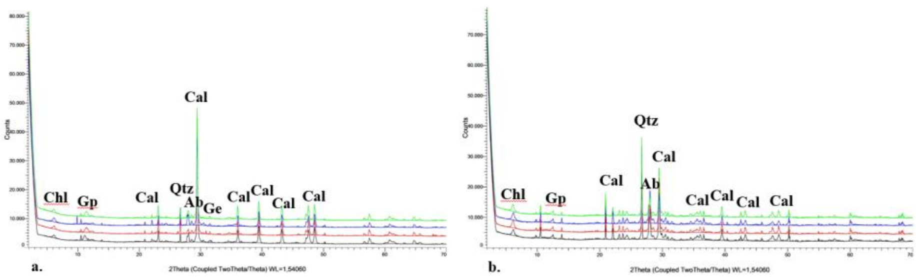


Fig. 4. Powder XRD patterns of the binders (a) and aggregates (b) of the mortars under study (some minor peaks have not been identified for clarity).
(Chl: chlorite, Gp: gypsum, Cal: calcite, Qtz: quartz, Ab: albite, Ge: gehlenite).

The binders of all samples mostly comprised of calcium carbonate ($CaCO_3$), confirming the calcitic matrix of the mortars (Fig. 4a). It is presumed that the calcite originated from local limestones, which were also used in the construction of the mill. The source of these limestones might be a quarry in Mitsero village, located near the mill, where reef limestones from the Koronia Member of the Pakhna geological formation are extracted [27].

In minor amounts, albitic plagioclase, along with quartz and amphibole, was detected in all binder samples. It is assumed that plagioclase and quartz are mainly derived from crushed brick [1]. The use of the latter is also supported by the presence of gehlenite within the binder fraction of all samples; this is characteristic of natural hydraulic lime burnt at temperatures < 1200°C or ceramics fired within the temperature range of 800 to 1060°C [2, 28].

Some traces of hydraulic compounds, such as portlandite, were also detected in all binder samples. Portlandite can form by slaking free lime or through the hydration of hydraulic phases. Portlandite reacts with CO_2 from the air to form calcite through carbonation. However, due to the dense structure of hydraulic mortars, part of the portlandite at the interior of a mortar may not be converted into calcite, as moisture and CO_2 cannot entirely penetrate the interior [28]. Portlandite might also be present in the samples due to the decarbonization of lime; this might be associated with certain environmental conditions, such as the humid environment of the mill [12].

Hydrocalumite was also observed in the binders of AGIM 1-1, AGIM 1-3 and AGIM 1-6. Its presence suggests the use of impure limestone and/or partially dolomitized limestones in lime production [29]. Mixing lime and dolomite with fly ash slurries results in the formation of hydrocalumite [14]. The presence of hydrocalumite in the mortars hereby studied can, therefore, be an indication that these were produced by combining lime and ashes. In sample AGIM 1-3, coal was also detected through macroscopic observations; this can justify the presence of hydrocalumite. The coal could either be a residue from the burning of limestones or could have been intentionally added to the mixture to provide hydraulic characteristics to the mortar.

Quartz, calcite, and plagioclase (albite) were the predominant phases in the aggregate fraction of all samples (Fig. 4b). Quartz is a commonly occurring mineral found in the lime mortars of many sites in Cyprus [4] and in hydraulic lime mortars from Cypriot watermills [3, 5]. Generally, quartz is associated with numerous rock types (igneous, sedimentary, and metamorphic). Therefore, in the case of the mortars under study, their origin in the river sand used might be related to the erosion of a great variety of rock types. Minor amounts of calcite and actinolite were also present in the aggregate fraction of the mortars. Last but not least, phyllosilicate minerals, such as chlorite and montmorillonite, were observed in all samples. The presence of the minerals albite, actinolite, and chlorite indicates that the sand contained an amount of material originating from lithologies of the Troodos ophiolite complex, which dominates the central part of Cyprus [27].

5 Conclusions

In this paper, four mortar samples obtained from the Vartalis watermill in Cyprus were examined. The study involved an insight into their consistency and hydraulic properties. Macroscopic and microscopic observations, along with laboratory analytical experimental techniques, such as XRD on the binder and aggregate fractions separately, as well as TG-DTA on the bulk samples, were utilized for their characterization.

The observations and analyses revealed that all four mortar samples exhibited consistency, with densely packed river sand as aggregate material and the occasional presence of lime lumps and coal. The CO_2/H_2O ratio of the samples ranged between 1.2 and 3, suggesting that these may be classified as strongly hydraulic lime mortars.

XRD analysis revealed the presence of calcite and crushed ceramic, used as artificial pozzolan, in the binder fraction and quartz and plagioclase (albite) in the aggregate fraction. The use of crushed ceramics used was likely intentional, considering their ability to provide hydraulic properties to the mortars. Furthermore, XRD analysis indicated that the river sand used contained mineral phases originating from eroded lithologies of the Troodos ophiolite. Therefore, it is evident that the raw materials utilized in the production of the mortars could be linked to the immediate environment of the watermill, as well as to the geological conditions of the wider area.

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Pre-industrial construction techniques, using industrial materials, in Greek urban vernacular architecture: the peculiar heritage of a transitional period (from 19th to 20th century)

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Abstract. In late 19th century Greece, newly introduced industrial materials are found to be used in small-scale vernacular constructions, following a quasi-autonomous path, detached from respective construction technologies of the time. This detachment can be understood in practical, financial and cultural terms, as well as in terms of symbolic order. In this context, this paper analyses a series of construction details in several cases of urban vernacular architecture, that make use of industrial materials that usually substitute traditional ones, in order to classify them and understand their contribution to the transition from traditional construction materials and techniques to an industrialized construction world. The analysis follows a comparative study, including field, relevant literature and personal archives research, photographs, graphic representations and descriptions, in order to make a contribution to the study of these peculiar architectural heritage samples.

Keywords: Vernacular architecture, 19th century architecture, Industrial, preindustrial construction, Modern Greece architecture history.

1. Introduction

From the end of the 18th century, along with the rapid industrial development, the building industry entered a period of innovation, with an increasing variety of new industrial building materials - i.e. wrought iron, cast iron, steel and later, Portland cement and structural steel bars to produce reinforced concrete - entering the markets and gradually replacing natural building materials (mainly stone and wood).

In countries subjacent to the first waves of industrialisation, in an environment of rapid urbanisation, the construction material industry responded to the demand for large scale constructions, requiring innovative technologies to be implemented massively, safely and at a low cost. New materials were developed during an excessive industrial growth resulting from scientific progress and the consequent development of new construction technologies, refined by pioneering architects and engineers as J.-G. Soufflot and J.-B. Rondelet (Panthéon of Paris), H. Labrouste (National Library of France, Sainte Geneviève Library), E.-E. Viollet-le-Duc (Castle of Pregny project etc.) [ ], J. Paxton (Crystal Palace) [ ], G. Eiffel [ ], J. Bogardus (New York cast-iron factory) [ ], F. Coignet and F. Hennebique (reinforced concrete) [ ]. Nowadays, this category of historic structures and the variety of construction methods related to them have been recognised and analysed in depth, promoting as well several protection and reuse technologies and techniques, as proven by the richness of relevant literature [ ].

However, the transition to the new era was accomplished as new building materials and construction technologies were spread to the periphery of industrial growth, regulated by local socio-economic conditions. In late 19th century Greece, new industrial building materials are often used just to replace pre-industrial materials, following traditional construction methods, instead of being a part of a newly introduced innovative building technology. Such examples are more than frequent in heritage buildings built after 1880, yet they are not adequately studied.

The objective of this paper is to highlight and analyse the case of these peculiar architectural heritage samples and underline the need for the creation of a historic and technical record about this part of Greek architectural construction history. Collecting and organizing relevant knowledge could facilitate the protection and reuse of such constructions.

Regarding the method followed, this study is comprised of (a) an in-depth relevant literature review, including urban history, building architectural techniques, technology and materials construction records and history and relevant Greek legislation, (b) a comparative field survey, by taking notes, photos and creating sketches of constructions' details, and (c) the survey and retrieval of relevant information from our personal and professional archives. Making use of the above, we developed a study plan that directly addressed our research goals.

2. Analysis

2.1 Innovative construction technologies, new materials and vernacular architectural production

In late 19th century Greece, innovative technologies and new industrial building materials were implemented in two ways: (i) Through high quality and costly constructions (mostly large-scale buildings and luxury residences), elaborated by architects and engineers, that made use of new materials and applied innovative construction technologies [ ] and (ii) In small-scale mainly residential constructions.

However, in Greece, a small and poor country of European semi-periphery where steel products were imported until the 1930's [ ], large-scale constructions were rare as not of primary demand. Moreover, the lack of housing development policy kept housing construction as a small-scale and private activity, in line with the small scale of the vast majority of urban land properties [ ].

This applied even in Athens that, although lacking remarkable industrial growth, was to become the country's dominant urban centre. As the capital of the new state, its population grew rapidly, creating a high demand for new constructions and attracting a significant number of builders, masters of traditional techniques mainly from the Aegean islands [ ]. New building materials were imported and were disposed in Athens as well as in other urban centres with adequate transport access. Athens was subjected to a rapid urbanization, with the land divided in small properties, distributed to the lower middle strata and actively involving building craftsmen to its development, as entrepreneurs [ ]. Furthermore, according to the vague legal framework applied from 1828 to 1923, no structural study was required in order for a building permit to be issued, concerning common housing projects [ ], while several buildings were constructed without any permit at all.

In this respect, the majority of small-scale residential buildings, up to the 1920's (and further), could be classified as of vernacular architecture. According to J.M.F. Pardo "Vernacular architecture can be defined as a type of regional construction influenced by geography, available materials, climate, traditions and culture that is produced by non-experts through knowledge transmitted and enriched from one generation to the next" [ ]. Moreover, for both the international charters for the protection of architectural heritage [,] the concept of "vernacular architecture" broadens to include, where appropriate, any kind of widespread, everyday "architecture without architects" expressing local conditions, resources and cultures [ ].

It is in this context, from late 19th century, that new building materials [ ] were often used as substitutes for traditional ones of the pre-industrial era, according to traditional construction methods. New materials were embedded into vernacular constructions empirically, without prior theoretical knowledge and as such, did not fulfil their specifications. Consequently, such structures belong to a particular typology and have their own pathology, in need to be recognised and documented.

2.2 Objective, cultural and symbolic influences on vernacular architecture's choices

Luxury residential and large-scale/multi-storey special buildings, where new construction technologies were applied and new materials were used, as well as relevant technical publications [ ] were providing examples and information about construction innovation to vernacular architecture builders. However, an examination of new building technologies from late 19th to the first decades of 20th century [ ] does not reveal any notable influence on vernacular architecture construction methods, other than the occasional use of new materials. E.g. there are no cases of substitution for complicated timber structures' with wrought iron or steel ones, like metal truss structure roofs, to replace timber ones, or metal frame walls, with brick infill, to replace traditional timber frame walls, with stone or brick infill.

Practical and financial issues [ ] may be important reasons for this: the use of new materials could improve the structure's strength, decrease on-site works, while maintaining traditional construction procedures [ ]; besides, imported, wrought iron and steel structural elements [,] were hardly affordable, so their use - especially in vernacular constructions - was as limited as their budgets.

Besides, the conventional use of new materials did not produce a new architectural language in Greece [ ] - or elsewhere [ ]. Historicism as the dominant spectrum of architectural languages, until early 20th century, remained well established as a major influence on architectural design, even in common and vernacular structures, leading architects and builders to hide new materials behind traditional material coatings or appropriately shape them in order to imitate historic architectural forms [ ]. In fact, the way new materials were embedded in vernacular architecture construction was perfectly in line with historicism and did not actually affect construction procedures. Building activity stayed attuned to neoclassicism, dominant in Greece [ ] at that time, which later evolved to a “neoclassical eclecticism”.

2.3 Vernacular building techniques by industrial materials: a typology record

In this context, from late 19th century and on and mainly in urban vernacular Greek architecture, several new materials replaced traditional ones (see tables 1, 2).

Prefabricated cast-iron balcony railings and cantilever corbels became popular thanks to their rich sculptural patterns and widely replaced hand-made wrought iron elements and their modest geometrical form. Since 1870, local production of such parts [ ] made possible their wide application, by making them affordable. As A. Sowa states [ ], cast-iron parts promoted the popularisation of neoclassicism.

Wrought iron or steel beams used in the construction of roof, floor and cantilever (balcony) slabs, replaced timber beams. In some cases, railway tracks were used instead of structural beams. That application is another example of pure empirical/experimental construction processes in Greek vernacular architecture. Flooring remained traditional, using timber planks mainly on interior floors, or slate stone slabs mainly on rooftop slabs and balconies. In stone or brick masonry, wrought iron or steel beams, were also frequently used as lintels, bridging wall openings, replacing timber lintels or in order to straighten slightly arched openings. Transversal bridging, between metal lintels, was achieved with slate slabs or solid bricks. In a similar way, timber bond beams in bearing walls were replaced with steel.

During 1920’s, two new construction materials were increasingly spreading: reinforced concrete and lime-cement mortar, for stone or brick wall construction and their coating. Reinforced concrete, a technology rather than a material, was primarily used replacing (a) floor and roof slabs supported by stone or brick walls and (b) cantilevers (balconies). A rather rare application of concrete is in the construction of a horizontal slab of densely arranged concrete beams, lightly reinforced, casted between rows of common clay bricks (~20cm long), that are eventually integrated in the slab.

In cantilevers' construction, marble or metal corbels and marble/timber/metal sheet slabs were replaced by reinforced concrete elements (two or more corbels embedded/anchored in the bearing wall, supporting a reinforced concrete slab). Concrete balcony corbels’ formation often followed neoclassical or eclecticist style. A rural version of similar reinforced concrete cantilevers appeared after WWII, when the timber balconies of thousands of houses of Greek villages had to be reconstructed after being burned due to occupation forces retaliations.

From the 1930’s and onwards, engineers and architects became increasingly involved in the production of the urban built environment, through multi-storey apartment building construction, using reinforced concrete. However, construction remained small-scale, as it was generally carried out on the same small properties [ ], construction crews remained small-scale craftsmen groups in labour-intensive enterprises, more or less retaining traditional construction techniques, with the exception of the transition to reinforced concrete load-bearing technology.

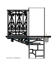
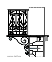
The prevalence of “artificiel” coating (chipped cement plaster) in multi-storey apartment buildings is another example of the condition discussed. “Artificiel” is about a cement-based mortar, worked out with a traditional technique of stone craftsmanship, in order to reproduce the texture of chipped stone in buildings’ façades. It was initially used to imitate the roughness of uncoated stone wall surfaces in late historicist building façades, but was gradually established as the standard façades’ treatment for multi-storey residential buildings and survived for as long as traditional stone craftsmen still worked for the building industry (until 1970’s).

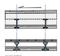
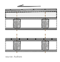
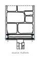
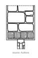
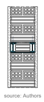
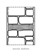
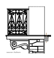
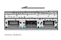
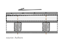
Table 1: Traditional construction techniques that use new materials from late 19th to mid-20th century and their correspondence with the traditional ones they replaced.

	Period (estimation)	Construction type	Construction with new materials	Relevant traditional construction
Cast iron parts	1890’s-1910’s	Cantilevers (open balconies)	Cantilevers supported by cast iron corbels (support beams) with ornaments. Bridging (flooring) with one-piece thin marble slabs, timber planks or sheet metal.	Cantilevers supported by wrought iron corbels (support beams). Bridging (flooring) with timber planks.

	1890's-1910's	Balcony railings	Cast iron railings or mixed construction railings, including cast iron railing parts (posts, ornaments) and wrought iron parts.	Wrought iron railings forming decorative patterns.
Steel parts	1890's-1920's	Floor slabs	Floor slabs supported by railway track beams or "I" shape steel beams. Bridging with schist stone pavement slabs. Flooring with cement tiles.	Floor slabs supported by timber beams. Bridging (flooring) with timber planks (one or two crossed layers).
	1890's-1920's	Rooftop slabs	Rooftop slabs supported by railway track beams or "I" shape steel beams. Bridging with schist stone pavement slabs. Final cover with thick earth layer and stone slabs or cement tiles.	Rooftop slabs supported by timber beams. Bridging (flooring) with planks or schist stone pavement slabs. Final cover with thick earth layer and stone pavement slabs or clay.
	1900's-1920's	Cantilevers (open or enclosed balconies)	Cantilever supported by railway track beams, or "I" shape steel beams, as extensions of internal floor structure. Bridging with schist stone pavement slabs. Flooring with cement tiles.	Cantilever supported by timber beams as extensions of internal floor structure. Bridging (flooring) with timber planks.
	1900's-1930's	Lintels in wall openings	Lintels of "I" shape steel beams in the wall sides, bridged with schist pavement slabs or bricks.	Arched lintels in stone walls. Lintel horizontal levelling with mortar or timber lintels. Horizontal straight lintels made with timber beams in the wall sides, bridged with schist pavement slabs or timber planks.
	1900's-1930's	Bond beams in bearing walls	"I" shape steel bond beams in bearing walls' both sides, bridged with schist pavement slabs or bricks.	Bond beams in the in the bearing walls, made by schist pavement slabs, or bricks, or timber beams in the wall sides, bridged with timber sticks.
Reinforced concrete	1920's-1950's	Cantilevers (open balconies)	Cantilevers supported by reinforced concrete corbels (support beams) fixed in the bearing walls of the building. Bridging (flooring) with concrete slab, often as extension to the interior slab (where exists).	Cantilevers supported by marble or stone corbels (support beams) fixed in the bearing walls. Bridging (flooring) with one-piece thick marble slab.
	1920's-1930's	Rooftop or floor slabs	Slabs constructed of a dense arrangement of thin reinforced concrete beams, bridged with transversely placed perforated bricks.	Rooftop slabs supported by timber beams. Bridging (flooring) with planks or schist stone pavement slabs.
Cement plaster	1930's-1980's	Building façades	Façades design with "*artificiel*" (chipped cement plaster) that imitates the texture of chipped stone.	Chipped stone bearing walls' façades.

Table 2: Graphic and photographic representation of Traditional construction techniques that use new materials from late 19th - mid-20th century and their correspondence with the traditional structures they replaced.

	Period	Constr. type	Construction with new materials		Relevant traditional construction	
Cast iron parts	1890's-1910's	Cantilevers (balconies)				

	1890's-1910's	Balcony railings				
Steel parts	1890's-1920's	Floor and rooftop slabs				
	1900's-1920's	Cantilevers (open or enclosed balconies)				
	1900's-1930's	Lintels in wall openings				
	1900's-1930's	Bond beams in bearing walls				
Reinforced concrete	1920's-1950's	Cantilevers (open balconies)				
	1920's-1930's	Rooftop or floor slabs				

3. Conclusions and discussion

In late 19th century in Greece, the spread of new industrial building materials was largely due to their use in vernacular architecture, replacing traditional pre-industrial ones, rather than being properly introduced along with new construction technologies. In this context, prefabricated cast-iron balcony railings and cantilever corbels replaced wrought iron elements, steel beams replaced timber beams in roof, floor and cantilever slab construction, as well as lintels in wall openings and masonry bond beams. A bit later, reinforced concrete floor and roof slabs replaced cantilevers' corbels and slabs and chipped cement plaster appeared in façades.

This study, identifying, analysing and classifying a number of relevant construction details of this peculiar architectural heritage, attempts to promote the need for further recognition and research, in order for (a) the creation of a historic and technical record about this path in Greek architectural history and, eventually, (b) to contribute to the accumulation of relevant knowledge that could encourage the protection and reuse of such constructions.

Research concerning this particular category of architectural constructions deserves to be enhanced and broadly extended into issues of recognition, description, pathology and intervention methods, in order to support positive and scientifically correct interventions [ ].

This study could also promote a discussion about today's building production socio-economic and cultural aspects in Greece, as well as in countries developing in a similar context. Factors such as urban land fragmentation into small scale properties and interdependent small scale, work-intensive craftsmanship, construction system do not favour innovation, but tend to remain attached to traditional construction procedures: e.g. there is always an aspect of reluctance on behalf of many craftsmen, who resist innovations, as they are considered unreliable, especially when there is a lack of know-how. Apparently, a rationalised reconciliation of traditional and scientific knowledge in every aspect of buildings whether it is about construction, conservation, restoration, rehabilitation, reuse, is necessary, in order to obtain sustainable ways to produce and treat the build environment.

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Architectural neo-classicism was perceived as an anti-lending: ancient Greece had passed on classicism to the West, and then, in 19^{th} century the West was returning the loan to Greece.

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Restoration Study of late Ottoman Terzakis House in Nafplion

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Abstract. The position of the "Terzakis house" in the town of Nafplion supports scientific findings that is probably a converted pre-revolutionary building, according to Ottoman construction and morphological standards[5]. On the Ground Floor in the western space, a HEA 200 metal beam will be supported under the floor wall with beam support with cross intermediate elements. All the interior walls of the main floor are reconstructed as light construction with visible coating as the existing ones, and according to the static proposal. Reconstruction of doors and windows of the west courtyard. The flooring of all areas of the Floor will be done with a double wooden element. It is planned to reconstruct a wall of light structure at the western boundary of the hall. To improve the static, a reconstructed section of a wall of a built structure corresponds to the surviving traces on the ground floor. Maintenance and repainting of floor and ground floor openings and the addition of double-glazing are needed. Repair and reinforcement in the SW corner of the building due to the (arbitrary) foundation here of a column of an adjacent building! The attic is very critical for the reconstruction of roof support elements of the small flat roof and of the surfaces of the construction. A fully reconstructed wall of lightweight structure at the roof boundary was also proposed. It is planned to reconstruct all parts of the wall at the staircase. Light walls defining the eastern zone will be aligned for static reasons. For the roof completion of its western edge and its protruding underlying wooden cover.

Keywords: Roof reconstruction, light structure wall, static improvement, alignement

1 Generalities

1.1 General Details - Description

The so-called Terzakis building is located in the middle of the street of the same name in the core of the city of Nafplio (Napoli di Romania) inside the former Venetian walls. A characteristic feature of the street in question is that it leads -transversely- from the usually busy coastal zone in IN Ag. Spyridon, where the first Governor of the Greek State Ioannis Kapodistrias was assassinated..

It is also noted that on the same route from the coastal zone, there is the Folklore Foundation of Peloponnese as well as the War Museum - Nafplio Annex, which is housed in the first building of the Evelpidon Military School. These two are together with the great historical site of I.N. Saint Spyridon.

It was the residence of the lawyer by training, writer, and essayist Angelos Terzakis.

Unfortunately, from the relevant research in the given time frame of the present study, it was not possible to find a historical depiction of the building during the 19th century. However, the bending construction of a wooden wall (split wall) can be seen in the corner, as is also the case in the SE corner of the Terzakis building.

The building is located approximately in the middle of the northern side of the building block there, i.e. on the southern side of Terzaki Street.

From the contrast of the historical maps (Fig 1 a and b) with the present-day zoning, it is documented that it is located on a main historical transverse road from the sea gate of the 2nd Venetian period of the Lower city to the area between the eastern outer fortifications and the eastern wall of the Upper city (Akronaflia)

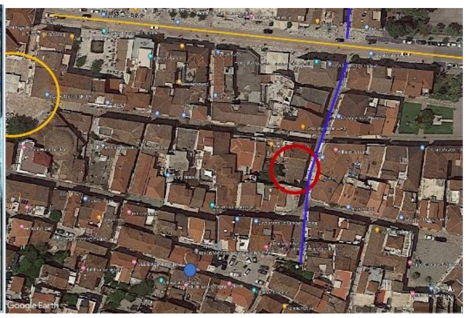


Fig 1a. Historical map of Nafplion after the new blocks (in South) and in red mark the position of Terzaki mansion [1] **Fig 1b** "Terzaki" mansion at Nafplion traditional town grid red circle (the blue cycle indicates the site of Kapodistrias murder! The yellow line indicates the position of the early Venetian *South* coastal wall. Yellow arc indicates the area of Nafplion central square!

1.2 Brief Initial Description

The "Terzaki building" is built in a continuous dense building system on the now homonymous street. It consists of a Ground Floor with shop uses (now?), while the First Floor has a residential function. The attic obviously served auxiliary uses of the residence, while its small (flat) roof is probably an element of post-revolutionary remodeling. A small courtyard to the west had access from the ground floor, and a sun porch was later installed in it. However, for more details about the spaces, see below.
Until the recent purchase of it by the Ministry of Culture by Mr. G. Didaskalos, it was owned by the heirs of Kalkounos, together with the corner property to the south border – a 3-storey flat-roofed building

2 Ground Floor Description and Pathology

2.1 Description

There is a large oblong space on the north side without communication with the rest of the section, with masonry walls, and access from the east side with glass windows partially restored. The wide area of the rest of the ground floor consists of the central part and the elongated southern part which has been fully integrated with the central part by the removal (1950's?) of the stone partition but with openings (?) in the wall.
[4] The linear staircase to the floor is also included in this section.

There is also a crudely constructed oblong room tangential to the SW corner - not maintainable - which probably functioned as a latrine (??) of the ground floor

The courtyard uncovered area in the western part of the plot is currently filled with a lot of building materials from the familiar building or the neighbors.

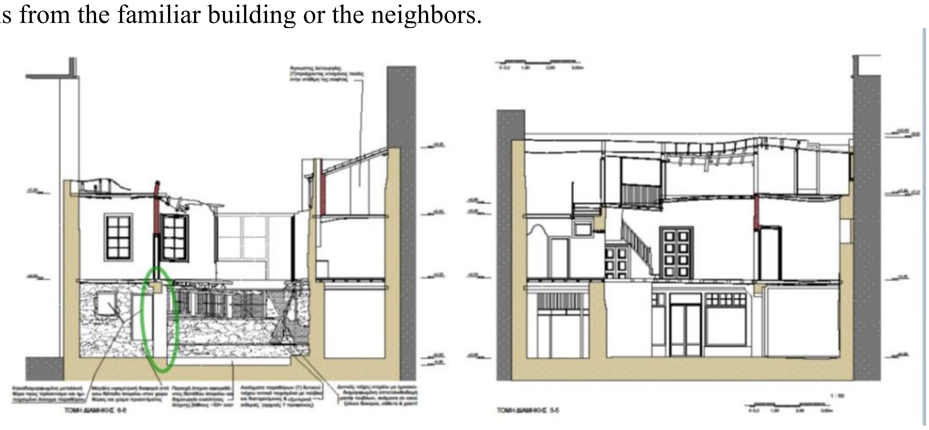


Fig 2. Longitudinal Sections of Terzaki, showing Ground floor, 1st floor, and Attic floor (B)
(the green ellipse, on where the newer reinforced concrete beam and pillars had been put)

2.2 Pathology

Important is the ill-formed wall of the north boundary to the property of Kalkounou to the south. The adjacent area of the courtyard area is full of ruins from the western part of the building and lots of rubble. Possible by initial floor at ±0.00 ??

The floor of the extension area is also earthen but unformed (probably with embankments). But the **B** (phase?) wall of the extension is also poorly formed with unskilled light construction, while the area west of it is completely unformed. The metal door to the annex and the half-walled opening of the window there are badly designed.

The western wall of the building is semi-poorly shaped brickwork of massive bricks between bad wooden beams, vertical & crosswise. Probably the same structure continued above. The openings of the windows (?) of the west wall are locally bricked and retain external ironwork (original ? apparently). There is a big difference in height from the ground floor to the door area and the construction ground! In addition, in the western central area of the ground floor, there is an artificially removed area of the floor, creating a cavity!? shallow depth ~ 30+ m.

The North-South internal wall to the south now has newer (pre-war or immediately post-war) concrete beams with a connection insert that apparently replaced an original load-bearing wall there. Support of the newer concrete beams apparently replaced most of the stone-built (?) wall there.

At the eastern boundary of the precinct, there is an artificially shaped metal glass window opening with a local widening of its original built boundary without possible skylights, with iron bars above. The central double (original?) entrance door is semi-well-preserved, as are the fixtures on either side of the case, as well as the wooden door to the floor, painted light gray. High skylights everywhere with iron bars and wooden cornices. Correspondingly, they also apply to the eastern opening of the **B** (phase?) oblong space, which is very difficult to access. In the middle of it there is a partition of a light structure made of metal (?) elements (artless), while the retreat of the wall to the S is possible for a future opening to the central space!

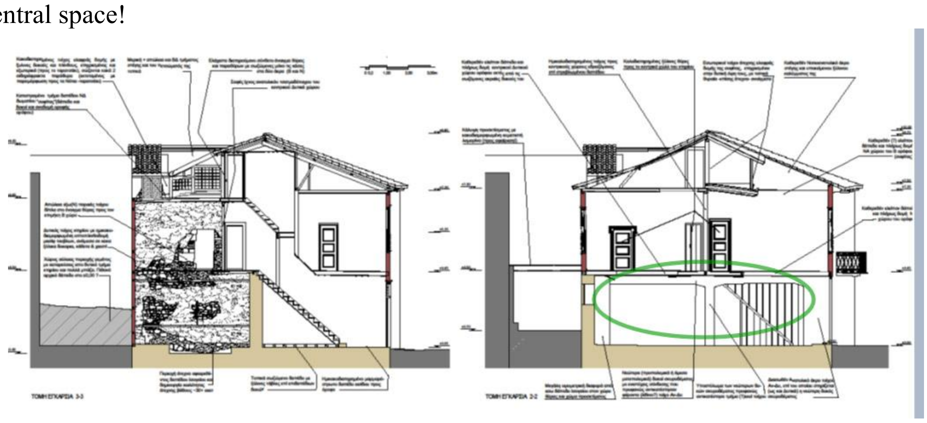


Fig 3 Tansverse Sections of Terzaki, showing Ground floor, 1st floor, and Attic floor (B) (the green ellipse, on where the newer reinforced concrete beam and pillars had been put, to expand ! ground floor shops area !!!)

3 First Floor Description and Pathology

3.1 Description

The listing, in this case, does not show the original structure of the building as estimated by the Architectural study, and the spaces are listed as they could potentially be provided after the restoration.

- The Central zone of the floor consists of a central "corridor - hall" and two rooms on either side (East and West). The one to the East leads to a balcony and the West to a completely destroyed exterior (or loggia? sunroom?) In the central corridor goes the staircase from the Ground Floor and it starts to the Attic (2nd floor) higher up.
- The North zone of the level in question has a room of main use in the NE, a middle space of small rooms next to it, one of which is a toilet and a laundry and kitchen array in the NW part. These spaces communicate with each other and with the aforementioned central corridor.

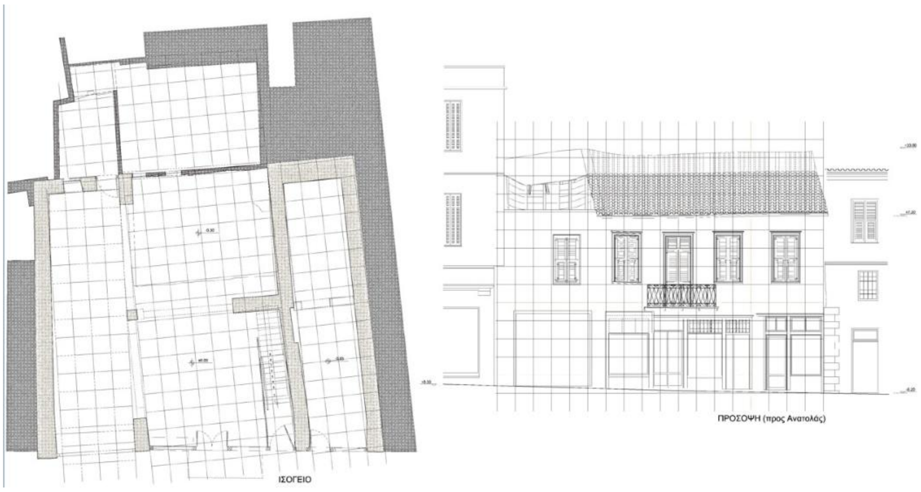


Fig 4. Metrological Analysis–Study according to Ottoman cubit *(zira)* of 75,8 cm valid in the late 18th century [5] © G. Antoniou

- The south zone consists of two rooms that communicate with the central corridor and each other. They used to have three windows to the South (it seems that there were on the ground floor)

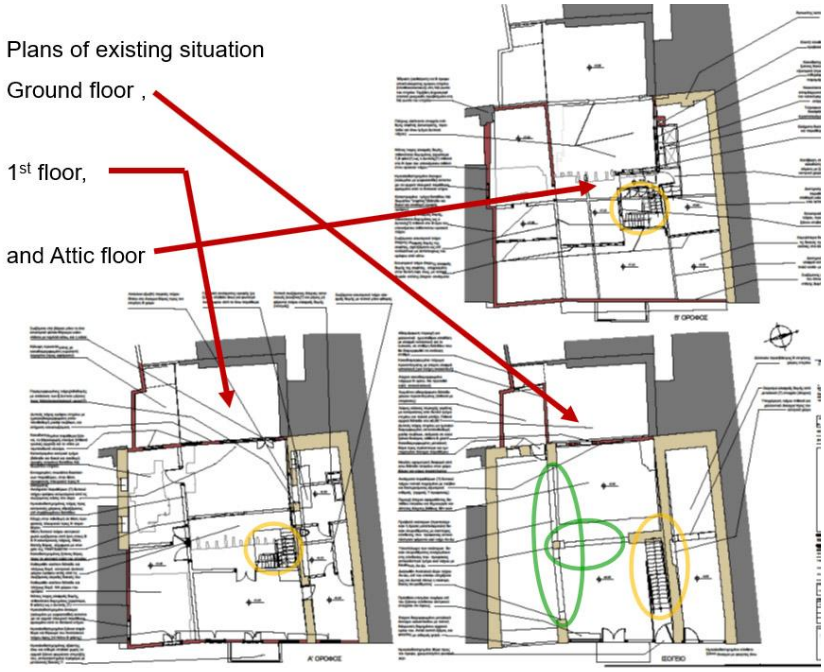


Fig 5 Plans of existing situation Ground floor , 1st floor, and Attic floor

3.2 Pathology

Starting again from the SW, the addition is covered with badly formed corrugated sheet metal! The west floor wall is ~ as level as the structure! The wooden windows are badly preserved, the northern one without blinds (probably originally louvered) and the southern one with paneled blinds! The window openings (?) of the west story wall are estimated from the surviving casements at the end. Only the one(!!) internal leaf-door window with a panel below is preserved in the north and the neighboring casement!

In the SW area, there are 2 niches in the stonework in place of an obvious lateral window to the S. The central part of the SW room of the building is damaged (floor and beams and ground floor ceiling structure are missing). The wall to the central areas is half-preserved but rests on a warped floor. Well-preserved wooden doors of the D area to the central area & hall of the building

The position of the (now missing) west wall of the central hall is defined by traces on the N & N interior walls. The position of the double door is according to data from the Service of Newer Monuments of Peloponnese and West Greece

A Removed - *missing* the floor and complete structure of the central Western floor area except for its preserved end beams, but also completely the counterpart of the SE room, the southern wall of the light structure, probably built (? later, phase B) as the Western (?). It has a semi-well-preserved opening (covered with plasterboard) which corresponds to an original side window, blocked by the adjacent building.

Half-preserved are the wooden windows and door of the Eastern wall (the South B phase?). It is in a semi-well-preserved condition, both the outer (upper) and the iron parapet, but without its original wooden supports, roughly replaced with metal cross-section upright P beams!.

The stone wall towards the central areas is deformed, with a deviation of 2/3 of its Western part to the South!. There is a loss of the outer (N) side of the wall next to the clear door opening to the elongated B space!

On the roof, there is an opening (with a wooden upper parapet) for lighting the space from the upper attic windows. In the elongated (eventually) B floor area, there are locally preserved unskilled constructions (kitchen?) and part of a (now) non-load-bearing wall of a light structure (a fragment). In addition, there are preserved internal walls of a light WC structure and a storage room, with only localized damage. Their doors are well preserved!

4 Attic (second floor) Description and Pathology

4.1 Description

In the North zone, there is an elongated northern space at a lower level with an elongated light opening for the kitchen on the floor below. The NorthEast end is not in use (it is within the Structural Element and ceiling suspension beams of the Floor). The central space (kind type of hall) next to the staircase also has access to the other parts of the attic (and the roof light is visible there)

The small (earlier–mid 19th?). terrace (which is completely missing!) was in continuation of the width of the stairwell space. The semi-used space to the east of the central one - towards Terzaki Street -facade- is essentially inside structural elements of the roof

The three spaces that make up the South zone are distinguished in the largest SW and in the rest of the part that had normal use. The only part with a ceiling was separated from its SouthEast part (and here effectively inside the roof's Structural Element) by a crude wooden wall. These used to have openings to the South, which are now walled up due to the adjacent three-story building. -The central part of the attic is a small 'isolation' hall.

4.2 Pathology

The placement (arbitrarily!) on the B floor (attic) of a single building column (brick construction) in the SW corner of the Terzakis building creates great static cracking problems in the SW corner of the building!

The South wall of the light structure was probably built (later?, B phase?) as the West(?), estimated at the S limit of the underlying stone boundary wall. The semi-well-preserved opening (covered with plasterboard) corresponds to an original side window, now blocked by the adjacent building. There is a damaged part of the SW floor of the "loft" room (floor and beams and floor ceiling structure)!

In the center of the N space, the surviving internal walls of the attic light structure are mostly related to those of the floor below. However, the internal walls of the light, unskilled structure of the attic towards the Eastern zone, have their western face plastered, with local doorways - also unskilled - openings.

What is preserved is the eastern wall in its upper part, where the load-bearing beams of the roof are located. The wall is structured with micro-bricks and a lot of mortar! Lower shaped is the NE floor with visible beams of the floor ceiling, as corresponding images on the other two higher floors to the S. It is separated from the N (central?) part by a ~60+ cm. and a lot of mortar

The composite opening of a door and 3 windows is partially preserved with only the lower fixed glazing bars and the wooden door also preserved, while the 3 opening elements above are missing.

From the arrival area of the staircase, there is a descent to the lower level (+6.40) with a well-preserved wooden staircase guarded by a wooden parapet with access to the central space of the attic through a paneled wooden door as well.

Minimally preserved is the complex opening of door and windows to the terrace, with only the casings at its two ends (B and N) preserved.

The wall of a light structure with wooden beams and plinths is poorly preserved, plastered on the outside (toward the terrace), 2 iron-barred windows are poorly preserved (also partially extended with distortion towards the South - terrace). Behind (B) is a newly constructed (?) tubular gutter for the removal of debris collected from the now-destroyed tile roof battlement. He probably put it on the roof! . Built brick (newer?) chimney, projected independently in the space of the floor (but eventually also of the attic)

5 Proposed Intervention Works

5.1 Ground Floor – Intervention Proposals

Various interventions are suggested. Beginning with ND, we have:

Configuration of space for a canteen and proper construction of space for canteen service elements (sink, refrigerator, stoves, etc.) Configuration of background and movement level in the canteen and construction of 2 steps for access to the courtyard area. (±0.00) (see & Pr04 k Pr03). Configuration to the west of the low, covered space (~1.60) for semi-outdoor storage for the canteen at ±0.00 floor level with light construction.

The addition of 2 steps (2X17) is planned for access to the new enlarged door level and also to the canteen. The northern and southern parts of the canteen are made with a light metal structure and lightweight concrete on the roof on a trapezoidal sheet, with the addition of T131 reinforcement.

It is also proposed that the boundaries of the stonework openings there (ND) be repaired and the door and window/ironwork remodeled. More centrally, the reconstruction of the west courtyard wall (as on the Ground Floor) of light construction and reinforcements with tilting internal windows at a high level is proposed. Of the 4, 3, with the second from N to be represented colored (inside-out) as metal reinforcement, will be built internally with hollow beams and a cross configuration (see Static study).

In the western area, support for a metal beam HEA 200 will be placed under the floor wall with beam support with *X-shaped* intermediate elements (see static member)

For the entire floor of the ground floor, a configuration is planned with wooden longboards glued to a background of strong cement mortar with a gap of 8 cm for EM, on the Gross concrete placed on a layer of plaster for anti-moisture protection (see Pr06). In the elongated southern area, the construction of two WCs (men – women) is planned from walls with YTONG 7.5 million thick, with special glue, sanded, plastered, and painted.

Underneath the newest beton beams, additional wall thicknesses are planned with elements of plasterboard walls, 15 cm thick, with an internal galvanized metal frame. Between them, 22 million of space for storage, leaving access openings in the ground floor exhibition. Also, IT facilities for the future configuration of visitor entry control.

At the Eastern border, an entrance element with a fixed opening to the N will be formed, with a similar morphology to the preserved element at the N end of the long narrow space. Vertical HEA 200 probes will be inserted into the entire east wall (with horizontal elements high, see static study), they will not be covered with plasterboard around the visible parts.

Overall, on the East wall, repair and maintenance of existing doors and openings are proposed, as well as the addition of double glazing as well as the maintenance and repainting of the entrance door to the floor. In the elongated B space, a reconstructed transverse wall is planned in place of the light old one, with an opening and with YTONG elements 15cm & white thin coating.

Finally, in the NW corner of the central space, there will be a starting area for an elevator for the disabled to the Floor with a protective glass parapet of 2m! A layer of thin square semi-solid ceramic plates is suggested.

5.2 First Floor – Intervention Proposals

All internal walls of the floor are reconstructed as light construction with visible plastering as existing, and according to the static study

Configuration of upper canteen space level will be configured with thin square plates 30x30 and a thin garbiloid image on the roof-roof configuration mentioned on the ground floor.

Most important element!! Repair and reinforcement in the SW corner of the Terzakis building due to its (arbitrary) location on the second floor of a pillar of a neighboring building!

It is planned to reconstruct the exterior of the courtyard according to the surviving elements on the west wall cover it with a double wooden element of 2 cm (static), and build a simple wooden parapet of a mild gray color ~RAL 1012

Reconstruction of doors and windows of the west courtyard wall (light construction) according to surviving and imprinted elements and reconstruction of both dark ones with jambs (the surviving SW paneled repair) to the southernmost. Color ~ RAL1012

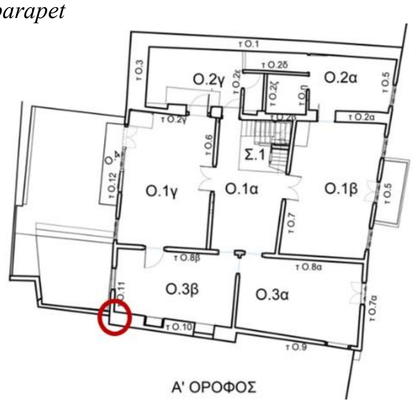
The central window (of the double section) will be represented in color internally and with simple nailing of its spiers externally.

The flooring of all floor areas will be made with a double wooden element that is 2 cm thick (see static study) on the floor beams. A reconstructed wall of a light structure is planned on the western boundary of the hall, with the reconstruction of its door in accordance with the same one as the East.

To improve stability, a reconstructed wall section (longitudinal at the southern end of the B area) of a masonry structure is planned in correspondence with the surviving traces on the ground floor counterpart.

Vertical HEA 200 surveying of the east wall (with horizontal elements high up, see static study) and covering the visible parts with plasterboard elements. (see reference to Ground Floor)

Maintenance and repainting (RAL1013 or 1012) of floor openings (and locally ground floor, see Ground Floor) and addition of double glazing. There will also be maintenance, repair & additions of wooden beams below, and recoloring (~ RAL1012, etc.) of exterior elements. Matt floor wood polishing at *Wooden parapet*



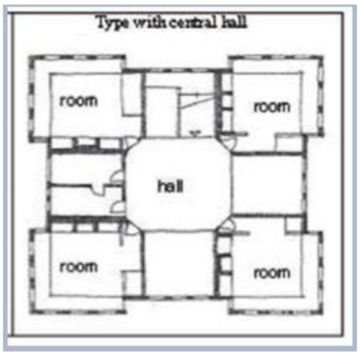


Fig. 6a Repair -reinforcement in SW corner (red cycle) in all floors due to the (arbitrary) placement of a pillar of a neighbor building! **6b** The formation of the 1st floor proves the relation with Ottoman similar layouts.

5.3 Second Floor – Intervention Proposals

Most important element!! Repair and reinforcement in the SW corner of the Terzakis building due to the (arbitrary) placement of a pillar of a similar building here!

Reconstruction of roof support elements and configuration of its surface as plans of Sections (P03) and Details (P06). There will also be a completely reconstructed light structure wall at the edge of the roof with a visible white coating on the outside (see Pr03 Pr04 & Pr06) Structure as provided in the static study.

The walls to the light structure terrace will be rebuilt with the reconstruction of their openings as a relative section (see Pr04& Pr5& Pr06 & statics)

It is also planned to reconstruct all the sections of the wall (staircase borders) according to the surviving elements in the wooden parts (&opening glazing in the opposite window to the south).

A newly constructed telephone service desk will be located in the central area of the attic. Center and CCTV surveillance unit (see PC). Also newly built small WC at the attic level in the small room to the N.

Further repair & strengthening of the eastern wall (upper zone) and reconstruction of the southern section in conjunction with the installation of attic floor beams. In addition, the floor configuration of attic spaces with a single wooden element 2 cm thick (see static study)

According to the same study, the light walls that define the eastern zone will be aligned for static reasons (P02 and Static study)

All the internal walls & of the attic (2nd floor) are reconstructed as a light construction with visible coating as existing, and according to the static study

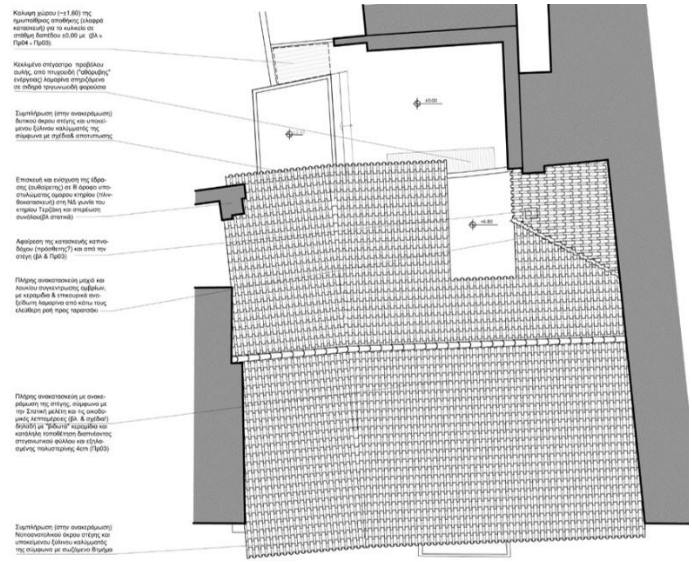


Fig 7. A full reconstruction with retiling of the roof planned, according to the Static study and the construction details i.e. with "screwed" tiles and proper placement of a breathable waterproofing sheet and 4cm extruded polystyrene

5.4 Roof Reconstruction - Proposals

A full reconstruction with retiling of the roof is planned, according to 7 of the Static study and the construction details (see & plans!) i.e. with "screwed" tiles and proper placement of a breathable waterproofing sheet and 4cm extruded polystyrene (P03 and P06)

Completion (in the brickwork) of the western edge of the roof and its underlying wooden covering according to drawings & impressions.

Completion (in the brickwork) of the Southeast end of the roof and its underlying wooden covering according to the preserved Northern part.

Complete reconstruction of rain gutters and hatches in the N NW section (see Pr02), with tiles & auxiliary stainless-steel sheet below them and free flow to the terrace

In addition, the sloped cantilever roof of the yard, made of pleated ("silent" energy) sheet metal supported on iron triangular trusses (P03), is mentioned

6 Conclusions - Evaluation

All the proposed interventions were made, taking into account the particularity of the building and the need to preserve its image as a preserved monument [2]. Also, all possible proposals were made to improve the energy footprint of the monument [3] by improving its thermal insulation capacity but also by integrating the strongest Electromechanical components, taking into account the provisions of the feasibility study for the integration of exhibition arrangements in the monument both on the ground floor and on the floor (of a different subject?) two exhibitions?

That probably elements of the building can be changed locally and on a very small scale due to the future Museological-Museographical study which is necessary,

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The Vasari Corridor of the Uffizi in Florence
New monitoring systems for sustainable restoration

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I. EXTENDED ABSTRACT

The corridor designed by Giorgio Vasari to join the palaces of Palazzo Vecchio and Pitti, passing over the Arno, has recently undergone a important restoration, which will allow it to reopen to the public. One of the most significant architectures in Florence, as an integral part of the Uffizi, it was built in 1565 for the wedding of Francesco I de' Medici and Giovanna d'Asburgo. (1) The building has been the subject of numerous studies, especially on its historical aspects, and its history is known from its construction to its various transformations. Over the centuries, the building has undergone major transformations and alterations, in addition to the bombings of the Second World War, the flood of the 1960s and the Georgofili bombing, which compromised at least part of its original character. (2)

The transformations undergone during the second half of the 20th century, which until now had not been sufficiently investigated, were clarified during studies carried out by the Research Unit of the Department of Architecture of the University of Florence. Recent restoration work has opened up the possibility of further study of the corridor, through a process of continuous verification between the documentary sources, the materiality of the building and the theoretical positions of those who intervene and have intervened. (3)

The information and documents collected were organised in a digital database linked with its georeferenced digital twin. The database organised not only the historical documentation, but also the materials relating to the most recent restoration work, and in particular files recording the methodologies, techniques and materials used in the restoration itself.

The investigation of Vasari's corridor is therefore not a simple recording of material documents, but a critical acquisition of physical and paper documents organised in a digital tool that will be the basis not only for future restoration work, which respects the parameters of sustainability, but also for monitoring the building itself. Moreover, the knowledge phase has long since lost its role as a 'preliminary moment', as is now clear thanks also to the various disciplinary debates, to extend throughout the duration of the restoration site and well beyond with the verification and monitoring actions. (4)

The meticulous study work in the archives was combined with the laser scanner survey to create a georeferenced digital twin, which would allow the corridor's movements to be monitored over time and, through an alert system, preventative action to be taken. The work conducted emphasises once again how the historical-critical reading of the building, not only of the archival and documentary sources, as well as the iconographic testimonies and their complex historiography, but also of the material and structural aspects, (5) represents a delicate step when it is transformed first into a project and then into restoration site choices. The problem of how to structure an investigation aimed at bringing out clearly the physiognomy, the nature, the materiality, the characteristics of the building (in this case of an iconic work such as the Vasarian corridor), not without declaring any gaps and changes that may have emerged during the cognitive journey, is far from simple and, even today, represents a largely underestimated problem. (6)

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[3] In March 2021, many newspapers, magazines and web pages reported on the start of the restoration works entrusted to the company Fratelli Navarra on a project by the Uffizi Galleries and the Soprintendenza Archeologia Belle Arti e Paesaggio for the metropolitan city of Florence and the provinces of Pistoia and Prato. At the same time as work began, the Department of Architecture of the University of Florence signed a research agreement, coordinated by the writer, aimed at drawing up "preliminary studies for the documentation of the restoration and site activities for scientific purposes".

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Investigating color on Archaic architecture: “Athena” from the Gigantomachy pediment of the Temple of Apollo at Delphi

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I.EXTENDED ABSTRACT

The Gigantomachy on the West Pediment of the Late Archaic Temple of Apollo at Delphi represents a significant work of early Greek architectural sculpture. Crafted from poros stone covered with plaster and paint, the surviving figures from the West pediment are notably different in material from those on the East pediment, which are made of marble. The extant fragments include a partially preserved standing male figure, potentially Apollo or Dionysos, dressed in a robe and animal skin; a fighting female figure identified as Athena, dressed in a chiton and moving left; and a prone, nude male figure in a three-quarter view with an extended leg, likely representing the serpent-footed giant Enkelados, as referenced by the chorus in Euripides' *Ion*.

This study focuses on documenting and analyzing the polychromy of Athena. Non-destructive methods and imaging techniques have revealed remnants of rich, colorful decorations on the plaster surfaces covering the stone figures. These methods include handheld/portable X-ray fluorescence spectrometry for elemental analysis, visible-induced luminescence (VIL), and various ground-based remote multispectral imaging techniques such as visible wavelength spectral imaging (400-900 nm), high-resolution spectral imaging (hyperspectral analysis Remote VIS/NIR Hyperspectral Prisms 400-1000 nm), and laser-induced fluorescence spectroscopy.

The pigments identified thus far include Egyptian blue, natural blue and green copper-based pigments, and ochre-based reds and yellows applied on a white calcitic ground. These findings offer significant evidence for a more accurate evaluation of Archaic polychromy in Greek architecture within its specific archaeological context. Further investigation into the Gigantomachy is expected to enhance our understanding of the chromatic techniques employed by Archaic artists and the application of polychromy on poros stone sculpture.

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Part III

Thematic Area 2 - Digital Techniques and Information Management for Cultural Heritage

Contribution of 3D Bedrock Formation to the Restoration of the Ancient Theater of Dodoni, Greece

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Abstract. The study focuses on developing and implementing a methodology for restoring and reconstructing the ancient theater in Dodoni, Greece, using advanced digital technologies. The research employed photogrammetry to create detailed three-dimensional documentation and diagnosis of the conservation status of two kerkides at the theater. The Dodoni Theater, a significant historical monument, faces numerous preservation challenges, including the need for extensive documentation of its architectural members. The project aimed to preserve cultural heritage by producing a detailed digital 3D replica of the theater's bedrock, which supports both the accuracy of restoration efforts and the understanding of the monument’s original construction logic. The study included creating 3D models of kerkis 9A before restoration, revealing essential geometrical and structural details. These models were crucial for the accurate repositioning and identification of displaced members of the theater. The study’s framework enhanced research efficiency by integrating digital repositioning and identification techniques, thereby minimizing errors during the restoration process. The overall methodology proposed in the study significantly improves the restoration quality and process efficiency for monumental architectural heritage like the Dodoni Theater. The digital models and workflow processes developed are intended to assist future conservation efforts, providing a foundation for precise restoration and preservation of similar historical sites.

Keywords: Digital Reposition, 3D Digitization, Building Analysis, Ancient Theatre, Close-Range Photogrammetry, 3D Model, Digital Cultural Heritage

1 Introduction – The theatre of Dodoni – challenges and open issues

The Dodoni Theatre is a monumental structure associated with the reign of Pyrrhus. The orchestra forms a complete circle, with the thymele positioned at the center. The koilon has a capacity of approximately 15,000 spectators and is divided into nine kerkis (**Fig. 1**). Two concentric pathways, known as diazomes, vertically divide the koilon into three sections. The configuration of the ancient theater, as it appeared until 2009, is the result of restoration work completed in a relatively short period during the 1960s [1] (**Fig. 2**). This restoration enabled the theater to host performances of ancient drama in the summer of 1960. The projects completed in 1960 were executed in a short timeframe without the necessary documentation. This lack of documentation led to improper placement of architectural elements, geometric deviations, and the loss of components due to wear, as well as limited information regarding the monument's original condition. Furthermore, the pathology of the stone material, combined with environmental conditions, has contributed to the dissolution and loss of material, alterations due to wear, and misinterpretations. Consequently, an additional challenge to the quest for authenticity has emerged for contemporary scholars.

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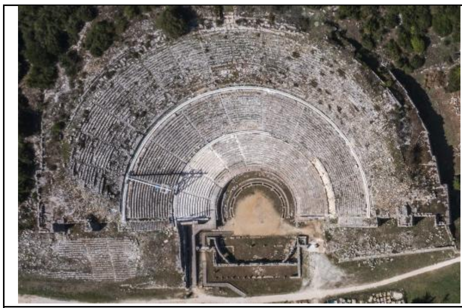


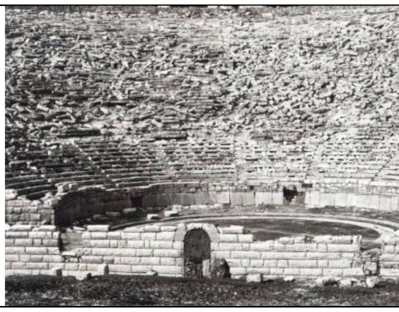


Fig. 1. Location of the archaeological site (Ephorate of Antiquities of Ioannina).

Fig. 2. Restoration works 1960's (Ephorate of Antiquities of Ioannina).

In the 2000s, an important multidisciplinary study was conducted on the topography and architecture of the koilon, the static analysis of the retaining walls, and the conservation of materials. This research culminated in an examination of the two eastern lower kerkis and their corresponding retaining wall [2, 3]. The use of a point cloud during this phase of the study greatly enhanced the estimation of the koilon's geometry and the restoration of the two eastern kerkis.

The restoration of the lower zone seven kerkis was completed in 2022 through a staged development process, which included the approval and implementation of studies for each stand. Over the past decade, the studies conducted by the Ephorate of Archaeology of Ioannina have focused on preserving the material, recovering lost authenticity, and achieving the morphological restoration of the monument.

For this purpose, the potential of digital technology was harnessed through a combination of methodological tools, with a primary focus on authentic members related to the time period of the monument prior to 1960. [4, 5].

Among the major challenges in documentation are: a) the issue of original geometry, b) the positioning of original members, c) the authenticity of fittings for neighboring members, and d) the identification of fragmented parts belonging to the same member. The restoration methodology begins with an on-site investigation of the architectural members in their original location, followed by their removal and transport to the construction site, where comprehensive measurements are conducted prior to maintenance work. Field testing and the development of final restoration plans are subsequently carried out. This process demands significant effort and meticulous organization to safely transport a large number of members, each averaging approximately 1,000 kg. During the cleaning of kerkis 9A, stepped rock was uncovered (**Fig. 3**). Its surface exhibits vertical and horizontal formations, indicating direct contact with the architectural members of the koilon (footstools, steps, edolia).

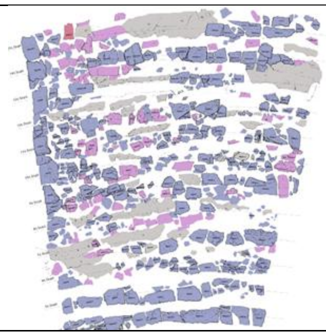


Fig. 3. The bedrock of kerkis 9A (Authors)

Fig. 4. Bedrock in gray color. Pathway plates in blue color (6)

These formations provide essential information for the construction logic of the monument, and their study is a fundamental requirement for the accurate geometric restoration of the koilon (**Fig. 3**). From the restoration work conducted thus far, a significant number of members in the lower zone, particularly those in kerkis 9, are constructed on formed bedrock [6] (**Fig. 4**). The bedrock remained clean and visible for only six months, which facilitated a comprehensive application of three-dimensional (3D) documentation techniques.

1.1 Research Aims – Objectives

The Dodoni Theater presents significant restoration challenges, primarily due to the complex and detailed documentation required for its architectural members. Among these challenges is the need to accurately determine and reposition the original placement of the edolia (seats and footrests), which is crucial for preserving the theater's historical integrity. To address these challenges, we propose a comprehensive methodological framework that employs advanced 3D digital acquisition and modeling technologies specifically tailored to the theater's unique architectural features.

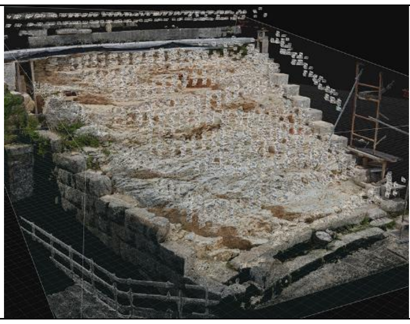
The primary objective of this framework is to digitally support the restoration of the kerkis by employing advanced 3D documentation techniques. By revealing and meticulously documenting the exposed rock relief in three dimensions, we aim to enhance ongoing efforts to document and restore the theater's architectural members. This digital approach provides a detailed and accurate record of the state of the kerkis 9A, which is vital for guiding future restoration work. The second objective is to accurately document the positions of the edolia and to plan their precise repositioning in a more efficient and systematic manner. To achieve this, we developed a methodology that combines the digital study of the rock surfaces with an analysis of their relationship to the architectural members, such as the edolia. This approach involves integrating close-range photogrammetric capture, creating detailed 3D models, and applying digital assessments to match and verify authentic joints between components. This enhanced workflow serves as an essential tool for the restoration team, providing the capability to explore various digital repositioning scenarios and make informed decisions throughout the restoration process. By offering a reliable and precise digital reference, this methodology significantly improves the efficiency and accuracy of restoration planning. Overall, the proposed framework not only addresses the immediate challenges of restoration but also establishes a new standard for the use of digital tools in the preservation of complex cultural heritage monuments.

2 Relevant Approaches

Numerous studies focus on the application of laser scanning, 3D imaging, and modeling methodologies, which are essential for documenting and reconstructing archaeological monuments, particularly ancient theaters [7, 8]. Concurrently, 3D digitization through photogrammetry significantly enhances our understanding of these structures by ensuring the accurate restoration of both surface and volumetric features, thereby aiding in the visualization and highlighting of many ancient theaters [9, 10, 11]. The digital capture of architectural and decorative elements facilitates a comprehensive understanding and precise reconstruction of replicas, which is vital for completing restorations [12, 13]. However, to our knowledge, the existing literature does not include comprehensive 3D surveys of the kerkis' bedrock. Examining the rock relief and conducting a detailed study could provide valuable documentation regarding the original formation of the kerkis structure and, consequently, its theater. In the Dodoni theater, we have a unique opportunity to digitally survey the rock relief in detail.

3 Data Acquisition – Processing – Editing

In the context of the restoration of the koilon, significant emphasis was placed on the acquisition and documentation of the exposed bedrock. The carvings in the natural rock of the slope provided valuable insights into the geometry of the theater. However, they also raised questions regarding the initial placement of the edolia and the necessity for their precise repositioning. This section focuses on the digital capture, processing, and creation of 3D models of the bedrock of K9A kerkis, as well as other members within the same kerkis of the ancient theater of Dodoni. Close-range photogrammetry was employed as the primary tool for documentation due to its rapid image acquisition and high accuracy. A photogrammetric methodology was developed, and three-dimensional models of Kerkis 9A were created prior to any restoration work (**Fig. 5**) in collaboration with the staff of the archaeological site of Dodoni. The process involved photographing the bedrock surface and three consecutive steps: B9A07, B9A08, and B9A09, along with an edolion, K9A18 (**Fig. 6**), which is in contact with the middle step B9A08 on its left side.



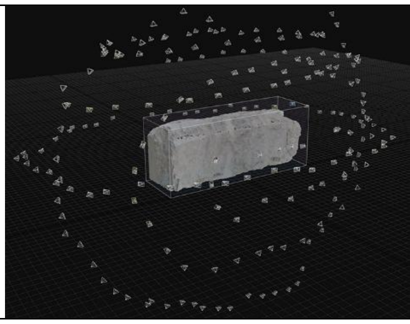


Fig. 5. Parallel lines on the rock, photos (Authors)	**Fig. 6.** Edolion photos (Authors)

The entire bedrock was documented in its full magnitude through perimeter photography, utilizing parallel lines that followed the slope levels of the rock wherever the slope relief permitted. All sides of the steps and edolion were photographed to facilitate a comprehensive photogrammetric reconstruction (material collection-processing by M. Tenechtsi, graduate student, Department of Conservation of Antiquities and Works of Art, University of West Attica). The data were then processed using two different software programs ContextCapture© (archaeological site of Dodoni) and RealityCapture© (academic license), for creating the 3D reconstructions. Open-source software, Meshlab, was subsequently employed for post-processing and exporting the final product, which includes individual 3D renderings of each object. The resulting models were further processed to extract the final output, which encompasses the 3D geometry and color information of each object separately.

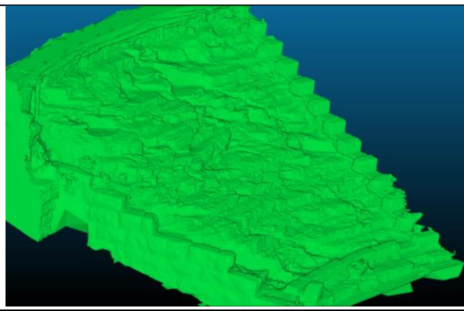
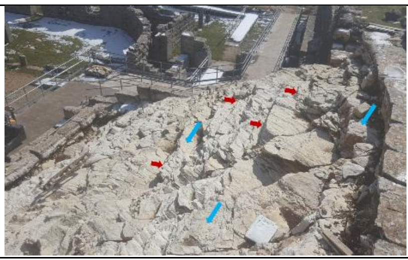


Fig. 7. K9A Orthographic view (Authors)	**Fig. 8.** K9A Isometric view (Authors)

A georeferenced 3D drawing was created for editing and aligning with other footprints to accurately orient and scale 3D models to their real-world dimensions (**Fig. 7**, **Fig. 8**).

4 Digital Repositioning Processes - Results

During the cleaning of the bedrock at kerkis 9A, a stepped rock formation was uncovered. The carvings in the natural rock of the slope, which emerged for the first time, provided valuable insights into the geometry and natural drainage of the theater. However, they also raised questions regarding the initial placement of the edolia and the necessity for their precise repositioning. The ancient formations on the surface of the natural rock revealed significant details about the original geometry of the theater and the edolia. Analyzing the surface of the rock, we observe that it features both horizontal and vertical formations, which were designed to accommodate the main members of the theater, including footstools, edolia, and steps (**Fig. 9**; **Fig. 10**).



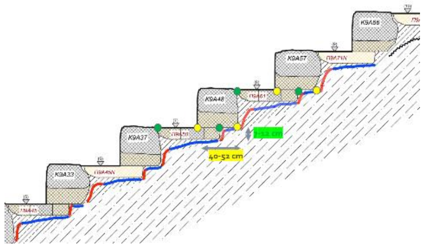
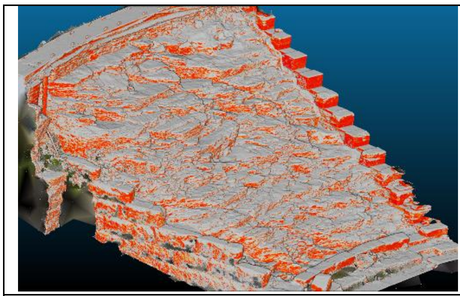


Fig. 9. Areas of carvings – vertical / horizontal (Authors)

Fig. 10. rock section Horizontal-vertical formations (blue-red). Edolion bearing lines (yellow) (Authors) (6)

The digital analysis of 3D data, utilizing point cloud analysis tools in CloudCompare (an open-source software), enables the identification of areas exhibiting both vertical (**Fig. 11**) and horizontal (**Fig. 12**) formations within the bedrock volume. Specifically, the horizontal carvings were primarily created to facilitate the direct seating of slabs during the construction of the corridors and the steps in the stair areas. The vertical carvings are associated with the backs of the slabs as well as the edolia. The specific mode of rock formation provides compelling evidence for the constructional logic of the theater and serves as a fundamental basis for the accurate geometrical restoration of the koilon.



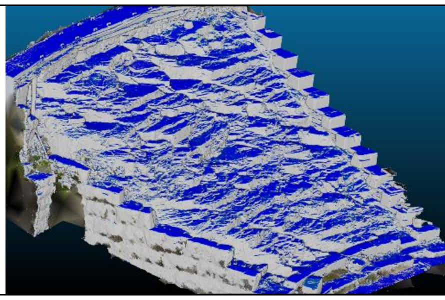
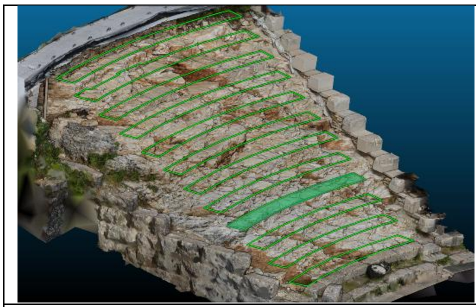


Fig. 11. Areas with vertical formations (Authors)

Fig. 12. Areas with horizontal formations (Authors)

A previous study conducted to update data and compare it with the quasi-original geometry of the monument [14] provides georeferenced 3D elevation planes, which are associated with the estimated end levels of the corridors situated above the 3D relief. Each closed line represents the estimated elevation of the corridors, which corresponds to the seating level of the edolion (**Fig.** ***13***). The elevations were derived from the geometric study of the koilon, specifically from the front line (plate edge) to the estimated width of the back line. The estimation of the heights, as well as the curvature of each level, resulted from the koilon's geometric analysis [14]. The inner curve toward the orchestra aligns with the front edge of the slabs, while the width of each level corresponds to the average width of the corridor slabs following their detailed mapping. Consequently, the georeferenced edolion levels for each edolia row are represented on the 3D relief model (**Fig. 14**). Each closed line indicates the elevation of the corridor plane, which also corresponds to the seating level of the edolion in the respective row. The internal curve toward the orchestra is identical to the front surface of the edolia, while the width of each level corresponds to the average width of the edolia after their thorough documentation.



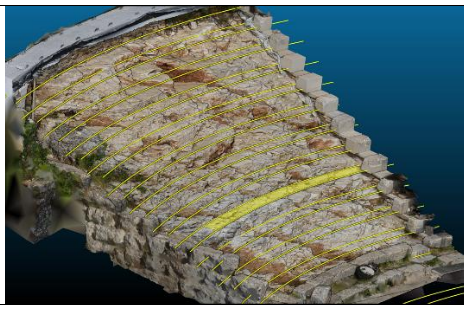


Fig. 13. Corridors levels. Front line: plate edge. Back line width estimate. (Authors)

Fig. 14. Edolia lines. Front line: Edolion edge Back line width estimate. (Authors)

The next step involves comparing the levels of upper georeferenced slabs and assessing the relationship between the edolia and the bedrock relief across the bearing area for each kerkis row. We analyze the data for the 7th row of edolia in kerkis 9A (**Fig. 15**). The estimated absolute elevation of the upper surface of the corridor is 632.29 m. The thickness of the corridor slabs, as determined by precise measurements of the stripped slabs, ranges from 7 to 12 cm. We delineate in the 3D relief the area with elevations ranging from 632.22 m (corresponding to -7 cm) to 632.17 m (corresponding to -12 cm). This area represents the direct bearing surface for the plates' various thicknesses of the plates. Utilizing the scalar field feature of CloudCompare software, we illustrate the elevation differences from 632.22 m (at -7 cm) to 632.17 m (at -12 cm). Areas depicted in red are closer to the reference level of the corridor surface, while areas shown in blue are further away (**Fig. 16**).

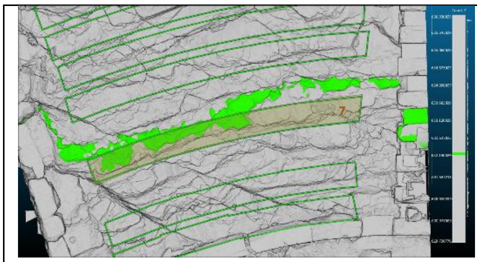


Fig. 15. Area delineation. Elevations from -7cm to -12cm. (Authors)

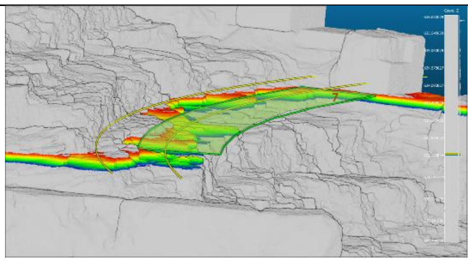


Fig. 16. Elevation's color gradation -7cm to -12 cm. (Authors)

In this manner, we visualize the topography of the rock in the vicinity of the reference plane. Subsequently, we correlate the rock topography with the width of the reference plane, which represents the average width of the corridor slabs.

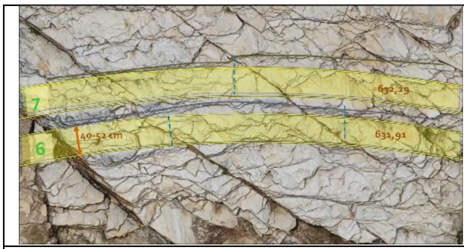


Fig. 17. Edolia bearing rows 6th and 7th. (Authors)

Fig. 18. Edolion bearing lines row 5th (yellow lines). (Authors)

In this manner, we have established the following confirmed facts: a) the level estimation of each row is validated with high confidence; b) minor corrections are implemented in the event of deviations from the initial estimate; c) misplaced runway slabs are managed more effectively based on their thickness and the contour of their bottom surface; d) misplaced corridor slabs are managed more effectively according to their width (ranging from 40 to 55 cm); e) joints between adjacent plates are identified (indicating changes in level and width); f) an accurate assessment is conducted regarding the preparation of the substrate for the repositioning of the slabs. Subsequently, we perform a similar workflow for the edolia of each row. (**Fig. 18**).

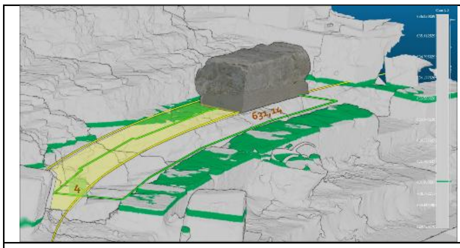


Fig. 19. 3D reconstructed edolion's digitally reposition to its estimated position in the 3D relief. (Authors)

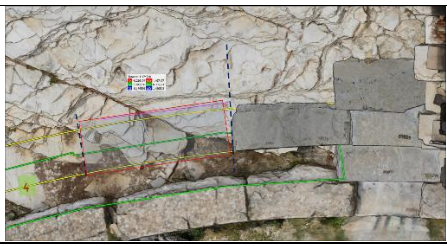


Fig. 20. plan view of edolion placement K9a18, with adjacent member boundary (Authors)

In the case of the 4th row of edolia, we place the georeferenced edolion plane—estimated to have an elevation of 631.14 m and a width corresponding to the mean edolion width—onto the 3D relief (**Fig. 19**). We then delineate the area with elevations ranging from +0 cm (632.14 m) to -5 cm (632.09 m) to identify points where the edolion directly interacts with the rock relief. Subsequently, we correlate the vertical carvings in the bedrock with the width of the reference plane, which represents the average width of the rows of edolia. This approach allows for better management of misplaced edolia by associating the features of the rock relief with their geometric characteristics. Additionally, we can digitally reposition the 3D reconstructed edolion to its estimated location within the 3D relief (**Fig. 19**). The guide for the placement of the edolion is based on the specific row edolion level (**Fig. 20**). Consequently, we can define precise sections that validate both the accuracy of the placement and the geometry of the edolion in relation to its proximity to the bedrock (**Fig. 21**). This method helps to prevent errors during the restoration process.

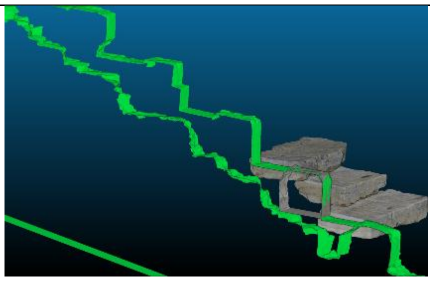


Fig. 21. 3D digital section (Authors)	**Fig. 22.** Orthographic view ((Ephorate of Antiquities of Ioannina)

Finally, it is possible to digitally position contiguous members (for example, steps B9A07-08-09 and an adjacent edolion, as they were arranged during the restoration of kerkis 9A) (**Fig. 20**; **Fig. 21**). In this instance, in addition to verifying the contact surfaces of the members in relation to the rock, the original contact surfaces between the contacting members are also documented (**Fig. 21**).

5 Discussion – Conclusions

The approaches outlined in this study aim to enhance the capabilities of restoration teams during the restoration study phase, particularly by improving the documentation and identification of the original positions of each architectural component. The primary goals are to maximize efficiency by optimizing the movement of the actual architectural members (e.g., edolia) and to minimize errors during the repositioning and restoration processes. The integration of a 3D digital restoration workflow into the ongoing koilon restoration process significantly enhances the precision of restoration efforts, enabling the accurate reorganization of architectural members by identifying their original positions and authentic connections (**Fig. 22**). This approach not only streamlines research and restoration processes but also establishes a reliable digital reference, which is crucial for preserving the integrity of complex cultural heritage monuments, such as the Dodoni Theater. By setting a new standard for the use of digital tools in restoration, this framework effectively addresses the challenges associated with these intricate projects.

One of the key strengths of the proposed framework is its emphasis on detailed documentation of the theater both before and after the removal of its architectural components. High-quality 3D models are created for each member, capturing their precise condition and geometry, thereby providing an invaluable digital record. This comprehensive documentation extends to areas of the monument that lie below the visible surface, such as foundational rock formations, which are often the most enduring members and offer critical insights into original construction techniques. By incorporating these frequently overlooked elements, the framework ensures a thorough and accurate reference that supports long-term preservation and restoration.

The framework's capability to digitize and document the geometry and topography of the monument provides crucial evidence of the original positions of ancient architectural members in the koilon. This digital record is vital for managing misplaced components, offering precise data that facilitates accurate identification and comparison of members within their intended locations. Consequently, this process enhances the reattachment of displaced components, ultimately improving the accuracy and efficiency of restoration efforts. Furthermore, the digital documentation of the bedrock has enabled more precise application studies in a virtual environment, creating a comprehensive future reference archive of the kerkis. This archive ensures that the data remains accessible for ongoing and future restoration projects, thereby supporting continued research and preservation activities.

Overall, the framework developed in this study not only advances the documentation and restoration of monumental structures, such as the Dodoni Theater but also establishes a new benchmark for the integration of digital tools in cultural heritage preservation. The results demonstrate that a comprehensive digital approach can significantly enhance both the processes and outcomes of restoration efforts, providing a robust and sustainable solution for the preservation of complex historical sites.

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Rope access monitoring and data management of the monumental complex in Piazza dei Miracoli in Pisa

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Abstract. Over the past few years, Opera della Primaziale Pisana has perfected a plan for periodic monitoring of the monuments in the monumental complex of Cathedral Square in Pisa. The monitoring is carried out by a group of OPA conservators specialized in rope access restoration works. The operators lower themselves from the monuments with ropes and safety harnesses to check the state of preservation of all the architectural elements.
This operational choice allows restorers to supervise architectural surfaces in their complexity without scaffolding or mobile elevating work platforms, prioritizing visitor safety. A specific inspection procedure is planned for each monument according to its complexity and features. All surfaces are visually and tactually examined, and critical issues are documented with photos. The data are reported in technical sheets, customized by AFI (Associazione Fabbricerie Italiane), that estimate the state of damage. Since 2020, this systematic approach has been integrated with a GIS (Geographic Information System) for more efficient data management and accessibility. This project simplifies maintenance planning and minimizes emergency interventions by implementing preventive maintenance procedures. Periodic inspection would save resources and be more efficient in preservation compared to sporadic restoration work.

Keywords: Rope access monitoring, Periodical maintenance planning, Piazza dei Miracoli.

1 Introduction

The importance and necessity of monitoring operations are now established issue in conservation practices, strongly connected to the concept of “preventive restoration”.

Preventive restoration focuses on the sustainable management and long-term conservation of artworks by “protecting, eliminating risks, and ensuring favourable conditions"[1] to prevent alterations to the material of the artworks. This means that the main consideration of conservative operation should not be the direct intervention in the material but rather ensuring stability in its environment and physical surroundings.

Prioritising preventive action instead of an occasional or emergency restoration work has become a fundamental part of conservation practice, especially for large monumental complexes like Piazza dei Miracoli Square.

In recent years, Opera della Primaziale Pisana (OPA) has implemented a specific method for monitoring stone surfaces based on the guidelines of the Associazione Fabbricerie Italiane (AFI), an association of major Italian cathedrals of which OPA is an active member.

AFI was founded in Pisa in June 2005, and is a non-profit association that brings together the most important institutes involved in the preservation of cathedrals, monuments, and related museums in Italy. It includes some of the most important Italian Cathedrals such as Veneranda Fabbrica del Duomo of Milan, Procuratoria di San Marco of Venice, Opera di Santa Maria del Fiore of Florence, Opera della Primaziale Pisana, Opera Metropolitana del Duomo of Siena, etc.

Over time, it activated constructive relationships with the Ministry of Internal Affairs, the Ministry of Labour and Social Policies and the Italian Episcopal Conference to clarify the legal nature of the Fabbricerie.

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In September 2017, a Technical Working Table was set up, composed of engineers and architects from the Fabbricerie, with the specific aim of embarking on a common path and setting up a systematic calendar of opportunities for comparison in order to systemise experiences and specific operations in the field of restoration and conservation interventions.

AFI Working Table focused on preventive action following the tragic accident that took place at the Basilica of Santa Croce in Florence, where a Spanish tourist visiting the Basilica died because of an accidental falling stone fragment from the architecture.

In 2019, the AFI Working Table defined a document outlining criteria and operational methods for managing and scheduling periodic inspections of all the high-located architectural elements and their deterioration, which may pose a danger to public and private safety [2].

The focus of the Monitoring Working Table was the definition of a Code for Scheduled Maintenance, which each Fabbriceria must have in relation to its economic and financial resources.

Inspection procedures were designed by the AFI technical table with the aim of obtaining a unique criterion for reading and interpreting the gravity of the phenomena for each Italian Cathedral. The operative methodology has been structured and perfected considering the complexity of working on historic buildings and the safety of the large number of visitors present in the square. It consists of an initial analytical part, which defines the health status of each monument, and a planning phase, which aims to define intervention strategies to halt the ongoing deterioration.

2 Rope access monitoring and 'AFI Inspection Sheets'

In addition to ordinary structural and conservative monitoring systems, carried out by technical staff in cooperation with the University of Pisa and various research institutions, rope access work has been introduced for monitoring issues.

The operators lower themselves from the monuments with ropes and safety harnesses to check the state of preservation of all the architectural elements.

This type of access to monument surfaces would save time and resources for the company because it would eliminate the cost and time required to set up scaffolding and the cost of hiring specific equipment, such as forklift trucks and suspended platforms.

OPA provided a rope access work training course for a group of employees, mainly restorers and technicians, who have thus become specialized in rope restoration works.

In this way, in-house conservators, through periodic visual inspections directly conduct the monitoring of architectural surfaces. The purpose of the inspection is to assess the state of preservation, identify critical issues, and contribute to the maintenance planning process. To record the observations made during the inspections, it is necessary to use an accurate architectural survey of the object of investigation, such as orthophotos, 3D surveys, and architectonic plans.

The architectural survey is an essential knowledge tool that allows the identification and location of the building's components, the dimensional and morphological features of the monument, the mapping of decay and intervention areas, and the control of the evolution of deterioration over time [3].

Fig. 1-2 The conservator is mapping critical areas on the architectural survey while suspended by ropes.

The monument is divided into 'Architectural Spaces,' made up of architectural and decorative elements called 'Components.' All the components are identified by an alphanumeric code that indicates the architectural characteristics and the position of the element within the entire monument. This code became a kind of Identity Card to which different types of documents are virtually attached: graphic representations, photographs, and descriptive sheets.

The visual inspection phase is carried out by a team of at least two conservators and planned as scrupulously as possible to optimize the space that can be inspected for each rappel, in order to minimize horizontal displacements that could be dangerous for the operator's safety. The inspection starts from the top of the monument and progressively proceeds following the vertical course of the rappel.

The position of the rope access and the number of the rappels are defined according to the morphology of the monument, the types of anchorage available, and the equipment required for working at height. All these considerations must be taken into account during the design phase.

As each monument has its own geometry, thus requiring specific procedures, a site inspection is conducted to organize the work and structure the technical aspects.

The first step is to check the accessibility of each area and create temporary lifelines where they are not present. Anchor points are then identified, and ropes are attached for the rappel down from these points. This moment is essential to ensure their structural suitability to withstand the load to which they are subjected.

According to the geometry of the architecture and possible anchors, each monument is divided into macro sections where the same rope access procedure can be repeated.

Some application examples are described below:

The Leaning Tower is a monument morphologically formed by a cylinder of overlapping rings. Each ring corresponds to an order and is composed of a stone loggia with marble columns, capitals, arches, and cross vaults.

The way to access the last two orders is easy, but in the lower orders, it's necessary to install temporary lifelines. The anchor points that can be used are the pillars of the bell cell or the columns of the lower loggias.

The biggest problems with this monument are first the slope of the surfaces and then the presence of circular lodges built from three-dimensional elements. Because of the slope, a series of additional vertical lifelines are fixed along the inclined side, to which the restorers anchor themselves to follow the incline of the tower.

Three-dimensional components, such as capitals and columns, require inspection from all four sides and therefore a large movement space; consequently, a lanyard system, anchored around the columns, is used to allow inspection from each side.

In the case of the Baptistery building, the procedure is different. The monument consists of three exterior architectural orders where architectural components are not aligned, especially between the 3rd order and the orders below. Therefore, it's necessary to carry out two different rope access procedures.

The first includes the dome and the 3rd order, and the anchorage used is the cylindrical brick element at the top of the dome. The second procedure involves the 2nd and the 1st order, where the anchorages used are the columns of the mullioned windows of the 3rd order. This differentiation is also necessary to avoid the obstacles constituted by the geometry of the building, such as the walkway on the 3rd order, which represents a protrusion of the architecture.

In the first procedure, each rappel horizontally covers a segment of the dome and a span of the 3rd order. In the second procedure, each rappel covers two spans of the 2nd order and one of the 1st order.

During the inspection, the operator proceeds to fill out the 'AFI Inspection Sheets,' which define the parameters that characterize the state of preservation of architectural 'Spaces' and 'Components' and establish the extension of the damage, in particular, the presence of any decay and the risk of elements falling.

To estimate the condition of a single ‘Space’ is considered the ratio between the number of degraded ‘Components’ out of the total number.

The AFI sheets estimate the state of damage and the consequent Alert Level (AL) value through a calculation system. Damage evaluation is classified into 5 levels (from 0 to 5), as shown in the following table [2].

Table 1. Alert level (AL) description.

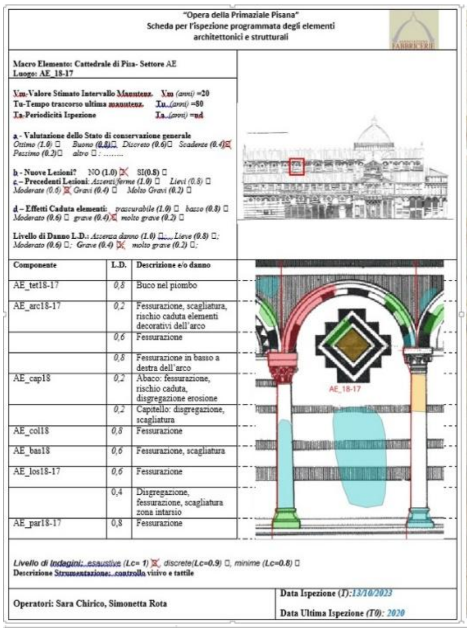
AL	Damage degree	Description
0	No damage	Elements and surfaces are in good condition
1	Light damage	First evidence of damage of limited extent
2	Moderate damage	Damage in the initial phase of development with disruption of limited extent
3	Severe damage	Marked evidence of damage in the intermediate phase of development
4	Very severe damage	Damage with parts on the verge of collapse
5	Collapse	Finds the detachment of a ‘Component’

AFI sheets AL values contents in their topic the state of conservation of each single area, frequency of maintenance and inspection, and the deterioration speed. This process may identify the main critical issues, define the date of the next inspection, and plan the conservation program for the entire monument.

During the monitoring activities, a photographic campaign has been carried out in order to document the different degradations and then digitized them within information systems. The interventions that have been defined are divided into two main classes: *Quick maintenance* activities and more *Comprehensive restoration works*.

Quick maintenance can be carried out in conjunction with inspections, for example: removal of biodeteriogens and vegetation; installation of bird deterrents; checking the condition of the lead roof by welding joints; repositioning the displaced tiles to restore the correct overlap and seal cracks to prevent rainwater infiltration; cleaning the gutters by removing any deposits and other operations.

In urgent situations, such as the presence of detached elements, immediate action can be taken by stabilizing them through anchoring or consolidation or removing them if necessary for safety.



"Opera della Primaziale Pisana"
Scheda per l'ispezione programmata degli elementi architettonici e strutturali

Macro Elemento: Cattedrale di Pisa- Settore AE
Luogo: AE_18-17

Vm-Valore Stimato Intervallo Manutenz. Vm (anni) =20
Tu-Tempo trascorso ultima manutenz. Tu (anni) =80
Ta-Periodicità Ispezione Ta (anni) =nd

a - Valutazione dello Stato di conservazione generale
Ottimo (1.0) ☐ *Buono (0.8)*☐ *Discreto (0.6)*☐ *Scadente (0.4)*☒
Pessimo (0.2)☐ *altro* ☐ : ....

b - Nuove Lesioni? NO (1.0) ☒ SI(0.8) ☐
c – Precedenti Lesioni: *Assenti/ferme (1.0)* ☐ *Lievi (0.8)* ☐
Moderate (0.6) ☒ *Gravi (0.4)* ☐ *Molto Gravi (0.2)* ☐

d – Effetti Caduta elementi: *trascurabile (1.0)* ☐ *basso (0.8)* ☐
Moderato (0.6) ☐ *grave (0.4)*☒ *molto grave (0.2)* ☐

Livello di Danno L.D.: *Assenza danno (1.0)* ☐; *Lieve (0.8)* ☐;
Moderato (0.6) ☐; *Grave (0.4)* ☒ *molto grave (0.2)* ☐;

Componente	L.D.	Descrizione e/o danno
AE_tet18-17	0,8	Buco nel piombo
AE_arc18-17	0,2	Fessurazione, scagliatura, rischio caduta elementi decorativi dell'arco
	0,6	Fessurazione
	0,8	Fessurazione in basso a destra dell'arco
AE_cap18	0,2	Abaco: fessurazione, rischio caduta, disgregazione erosione
	0,2	Capitello: disgregazione, scagliatura
AE_col18	0,8	Fessurazione
AE_bas18	0,6	Fessurazione, scagliatura
AE_los18-17	0,6	Fessurazione
	0,4	Disgregazione, fessurazione, scagliatura zona intarsio
AE_par18-17	0,8	Fessurazione

Livello di Indagini: esaustive (Lc= 1) ☒, *discrete(Lc=0.9)* ☐, *minime (Lc=0.8)* ☐
Descrizione Strumentazione: controllo visivo e tattile

Operatori: Sara Chirico, Simonetta Rota
Data Ispezione (*T*): *13/10/2023*
Data Ultima Ispezione (*T0*): *2020*

Opera della Primaziale Pisana

Ispezione Programmata degli elementi Architettonici e strutturali.

Macro Elemento: Cattedrale di Pisa- Settore AE Componente: AE_18-17 Data 13/10/2023

Ta= Periodicità Ispezione (anni)	Ta=1 ☐ Ta=2 ☐ Ta=3 ☐ Ta=4 ☐ altro ☐	Ta =	ND
a - Valutazione dello Stato di conservazione generale:	Ottimo (1.0) ☐ Buono (0.8)☐ Discreto (0.6)☐ Scadente (0.4)☐ Pessimo (0.2)☐	a =	0,4
b- Nuove Lesioni?	NO (1) ☐ SI(0.8)☐	b =	1
c- Precedenti Lesioni	Assenti/Ferme (1.0) ☐ Lievi (0.8) ☐ Moderate (0.6) ☐ Gravi (0.4) ☐ Molto Gravi (0.2) ☐	c =	0,6
d – Effetti Caduta elementi (Fattore di Perdita)	trascurabile (1.0) ☐ basso (0.8) ☐ Moderato (0.6) ☐ Grave (0.4) ☐ Molto Grave (0.2) ☐	d =	0,4
e - Nuove Lesioni-Livello di danno L.D.	Assenza danno (1.0) ☐ Lieve (0.8) ☐ Moderato (0.6) ☐ Grave (0.4) ☐ Molto Grave (0.2) ☐	LD=	0,4
Vm = Valore Stimato Intervallo Manutenzione	Vm=Valore stimato Intervallo Manutenzione (anni)	Vm =	20
Tu = Tempo trascorso dall' Ultima manutenzione	Tu= Tempo trascorso dall' Ultima manutenzione (anni)	Tu =	80
Lc = Livello delle Indagini; Strumentazione	esaustive (1.0) ☐ discrete(0.9) ☐ minime (0.8) ☐	Lc =	1
T= Data di ispezione	Data Ispezione (T)	T =	2023,8
T0 = Data Ultima precedente Ispezione	Data Ultima precedente Ispezione (T0)	T0 =	2020,5
Ft = Fattore Tempistica Ispezione	$DT = T - T_0 \Rightarrow Ft = fattore\ Tempistica\ Ispezione = [e^{(\frac{DT-Ta}{DT})}]$	*Ft* =	1,00
Fm = fattore Tempistica Manutenzione	$Fm = fattore\ Tempistica\ Manutenzione = [e^{(\frac{Tu-Vm}{Tu})}]$	*Fm*	*2,12*
Se = Stato di Esercizio	$Se = Stato\ esercizio = [(a + b \cdot c + e)/3] \cdot L_c \cdot \frac{d}{F_t \cdot F_m}$	*Se* =	*0,09*
LA= Livello di Allerta	*LA = Livello di Allerta (LA1, ..., LA5)*	*LA* =	*LA_5*
Ta= Nuova Periodicità di Ispezione (anni)	*Nuova periodicità di Ispezione (Anni)*	*Ta* =	*1,0*
T= Data prossima ispezione (Anni)	*data Prossima Ispezione*	*T*	*2024,8*

I livelli di Allerta (con gradazione di colori) sono attribuiti in base allo stato di esercizio Se. N.B.Con livello LA_5 (Rosso) il periodo di ispezione si riduce a 0.5*Ta

75% < Se	LA_1
45% < Se ≤ 75%	LA_2
20% < Se ≤ 45%	LA_3
10% < Se < 20%	LA_4
Se < 10%	LA_5

Fig. 3 Example of an AFI data sheet of Cathedral's monitoring.

For Comprehensive restoration work, it may be necessary to install scaffolding in the affected areas and modify the frequency of interventions according to the AL recorded, and thus modify the maintenance operations in order to contain the ongoing degradation.

Through this "Modus Operandi," a series of interventions are scheduled in the near future for the Leaning Tower and the Baptistry: the consolidation of the capitals and the treatment of biological patinas; both works will be carried out entirely by rope.

3 GIS data management

The data collected are organized in a GIS (Geographic Information System), which allows identifying the component's location. The peculiarity of the GIS system is to integrate the representation of metric data with the alphanumeric information that characterizes the heritage from a conservation point of view. GIS stores, manages, and visualizes data with spatial identification and links the graphic representation with the informative data in a virtual folder [4]. So, the information about the single monument such as scientific analysis, photos, inspection sheets, documentation of the condition, and restoration work, could be collected in a virtual folder and consultable by all OPA technicians.

The GIS system geo-references data showing the survey geometries, graphical mapping of the state of conservation, in particular the location and type of deterioration of 'Components', and the correspondence of alert levels (AL) for each 'Space'.

Attribute tables are defined to place all information collected during inspections within different fields. The result is a layer of knowledge that characterizes the constituent elements of the object, from which it is possible to obtain graphical maps with different colors and symbols relating to the type of data to be highlighted.

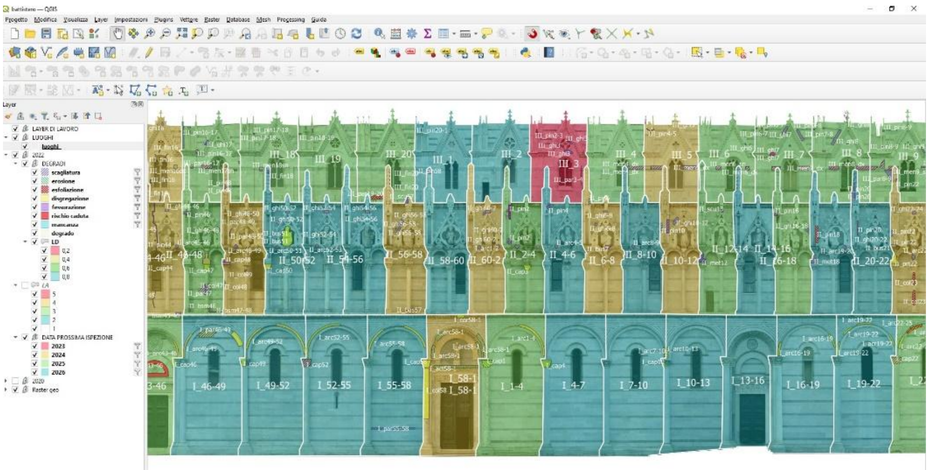


Fig. 4 GIS data management of Baptistery data.

It must be considered that over time, the volume of information will increase considerably. The constant updating of data overlaps with the compilation phase, characterizing the cyclical nature of the conservation and maintenance process and increasing the knowledge of the monument [5].

The use of an Information System is essential for creating a folder of updatable and consultable data, which is fundamental for planning maintenance and understanding the evolution of deterioration processes over time so their evolution can be predicted. This will form the knowledge support for the conservation plan, which aims to minimize emergency interventions and focus on maintenance, replacing restoration with preventive conservation.

4 Conclusions

Drawing up a plan for the programmed conservation of architectural surfaces has been introduced from the perspective of promoting activities aimed at limiting the onset and progression of deterioration, promoting the idea of maintenance as a continuous process of care, rather than resorting to emergency restoration operations [6].

The choice of periodical inspection would definitely be more efficient in conservation issues as it can better mitigate deterioration phenomena, limit the future aggravation of the degradation process, and prevent the emergence of critical conditions. It would also save time and resources for the company because it would eliminate the cost and time required to set up a scaffold and the cost of hiring specific equipment, such as forklift trucks and suspended platforms.

This procedure used in recent years by the restorers of the Opera della Primaziale Pisana, which combines rope access monitoring and data management by AFI sheets and GIS processing, helps to increase maintenance. To improve the monitoring work instead of large-scale restoration works.

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Innovative applications of 3D printed elastomers in the restoration of Cultural Heritage

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Abstract. This study evaluates the application of innovative materials in 3D printing for the protection and conservation of cultural heritage, focusing on the intervention conducted on the environmental installation 'Spiette, 36' by artist Paolo Icaro at MAXXI, Rome. The main challenge of this artwork's conservation is related to its interaction with the museum's audience. Specifically, the presence of floor-placed elements necessitated a comprehensive approach to ensure their preservation. For this reason, with the artist and museum's support, a project was developed to create exhibition copies and digitally preserve the installation.
The project involved acquiring the shape through 3D scanning and generating its negative by processing the digital model. Extensive research was then conducted to select elastomers introduced to the market in recent years capable of emulating the performance of silicone rubbers for 3D printing molds. The study of these materials and printing techniques has provided valuable insights, laying the groundwork for potential applications of 3D printing elastomers in restoration.

Keywords: 3D printing, elastomers, production of molds, installation art, exhibition copy.

1 Challenges associated with environmental installations.

1.1 The artwork "Spiette, 36"

"Spiette, 36" is an environmental installation created by Paolo Icaro, a Turin-born artist who is still active internationally, recently acquired by MAXXI- National Museum of 21st Century Art, Rome. The artwork consists of thirty-six plaster tiles, each containing a fragment of mirror set at a particular angle. The mirror element serves as the mechanism for setting up the artwork and expressing the artist's intention: through a play of reflections, the tiles are progressively positioned in the environment, including walls, floors, and ceilings. As visitors explore the immersive environment of the artwork, they engage with a captivating interplay of reflections, actively shaping their experience.

Collaborating with the living artist: understanding the artwork and its conservation requirements. The study of the artwork was greatly enhanced by the invaluable contribution of the artist Paolo Icaro, who kindly welcomed us into his studio in Tavullia (Pesaro, PU, Italy) and showed us the entire production process of his work. Observing the artist's firsthand process of working with plaster allowed for a deep exploration of his artistic expression while also highlighting the fragilities of the material due to its execution technique.

In addition, through conversations with Paolo Icaro, we were able to explore themes related to the conservation of his work and potential preservation solutions. The fundamental aspects identified for preservation comprehend the ability to set up the installation elements throughout the environment, including the floor, and ensuring visitors can freely access and navigate the entire space without restrictions.

Fig. 1: (from left) “Spiette, 36”; Paolo Icaro in his studio; element no. 7 front and back.

1.2 Conservation issues and restoration intervention

The thirty-six elements of the artwork displayed uneven conservation conditions, closely influenced by their placement within the environment and, thus, the extent of interaction with the public. The tiles exhibited on the floor have inevitably experienced numerous episodes of accidental impacts and trampling by visitors. For this reason, they displayed numerous fractures, losses, and stains from residue material originating from shoe soles.

Throughout the restoration of the five elements, careful consideration was given to the delicate nature of the constituent material, focusing especially on minimizing mechanical stress and exposure to water. The cleaning process was carried out through a series of tests to identify the most effective system for maintaining the action at the gel-surface interface. Among the different systems, PVA-B (5% polyvinyl alcohol, 1% borax, also with the addition of 15% acetone) was selected [1]. For the reattachment of detached fragments, a solvent-soluble adhesive resin, Mowital B60HH (5%, 20% in ethanol), was selected to avoid the use of water [2]. The plastic reintegration, which the artist wanted to be mimetic, was carried out using a vinyl-acrylic-based plaster, the Red Devil One Time, which can be easily identified under UV light observation and is highly reversible through a ketone such as acetone.

2 Addressing conservation challenges of the exposed artwork through digitalization and 3D Printing

2.1 The development of a production system for exhibition copies

In addition to the restoration intervention, the project also includes the creation of a digital model of each of the thirty-six elements, with the aim of preserving the artwork and creating molds for exhibition copies. This practice is common in contemporary art conservation, especially for installations vulnerable to public damage [3]. The traditional technique of copying using casting materials is unsuitable due to the fragility of the artwork, as it requires direct contact with the original surface. To avoid this potentially damaging phase, the artist Paolo Icaro was offered the opportunity to utilize 3D technology, enabling precise surface detection and providing a versatile digital model with numerous practical applications. Using the digital model as a starting point, the restoration methodology usually requires the creation of an “intermediate” model to obtain the silicone mold. However, due to time and cost constraints, this method proves impractical for our project. An alternative would be to directly print the copy in plastic [4], but this does not meet our specific requirement for a copy made by gypsum and mirror. Therefore, the focus of our study shifted to the possibility of obtaining the negative form directly from the digital model through software processing, thereby enabling the printing of the mold. In this regard, market research was launched on the performance of available materials for 3D printing.

The project is organized into the following phases: acquisition through structured light 3D scanning of the original element; processing of the digital mold; 3D printing of the mold using the selected polymer; insertion of the mirror fragment and pouring of the plaster; demolding and finishing of the positive.

2.2 The aim: obtaining a flexible mold printed in 3D

To overcome the difficulties associated with using a rigid mold, we have selected several classes of 3D printing polymers with elastic behavior similar to silicone rubbers. These elastomers, with their elastic properties, are widely used for a variety of purposes in different fields, including medicine, engineering and fashion [5].

Printing elastomers, in fact, can provide a crucial contribution to the production of copies without coming into contact with the original material, allowing for the easy release of the positive, similar to traditional silicone molding.

Research for suitable materials The experiment compared three different elastomers using two different printing techniques: Fused deposition modeling (FDM) and Stereolithography (SLA).
Elastomeric resins for SLA printing. Numerous formulations of resins for SLA that mimic rubbers have recently been introduced to the market, offering varying degrees of elasticity. Among these, we have selected the American line Formlabs, which offers two elastomeric resins: Elastic 50A and Flexible 80A. The choice is motivated by the extensive documentation provided by Formlabs, including specific guides on printing and usage [6]. The first resin tested was the flexible 80A, methacrylate-based resin, which represents the stiffest elastomer in line with its shore hardness of 80A; it has been on the market since 2014, but its formulation was modified in 2020. The Elastic 50A resin, an Acrylate-based material introduced in 2019, boasts high elongation properties and constitutes the softest material in the line. Thanks to the SLA printing technology, both resins boast extremely high detail resolution, making them suitable for use in fields such as modeling, engineering, and healthcare.

Thermoplastic elastomers for FDM printing. The market has introduced the family of thermoplastic elastomers (TPEs). Within this class, the most common material is thermoplastic polyurethane (TPU), available commercially with a Shore A hardness ranging from 45 to 95. Its characteristics have made it one of the most studied 3D printing elastomers [7]: it is biocompatible, non-toxic, waterproof, and has high shape memory. Above all, it is known for its remarkable resistance to impacts, abrasions, and cuts, qualities that have made it one of the preferred materials to produce medical devices and smartphone covers. Among the TPU polymers on the market, we have selected Raise3D TPU95A.

3D Printing tests It is worth noting that printing technology plays a fundamental role in determining the final outcome of the object. Both technologies build the object layer by layer, but they leverage very different processes: while SLA constructs the object using a laser UV light that selectively hits a liquid resin, triggering its polymerization in layers, FDM works by melting and progressively depositing layers of a thermoplastic polymer [8]. For the experimental work, in order to compare work times and costs, we also printed test samples of rigid polymers (PLA and Tr250 acrylic-based resin from Phrozen). The TPU 95A and PLA were printed using the FDM printer Raise3D N2 Plus, while the Phrozen Tr250 resin and Formlabs' resins were used with the SLA printer Form 3B+. From each printed sample, gypsum positive models were obtained, and their results and potential were analyzed (Fig. 3).

Accelerated aging tests While printing materials such as PLA have been extensively studied and proven suitable for restoration purposes, the three elastic materials - Formlabs resins and TPU - are relatively new and lack the same specialized literature regarding their long-term behavior. For the purposes of the experimentation, it is indeed relevant to measure the plastic deformation of these elastomers under ambient conditions to observe their ability to maintain their original shape and to assess their suitability for repeated use over time. Cycles alternating between ten hours at low temperature (10°C) and high relative humidity (95% RH), followed by ten hours at high temperature (50°C) and low relative humidity (30% RH) were set up, for a total cycle duration of 24 hours (including 4h of transition) repeated twenty-seven times.

The measurement of deformation was obtained by overlapping the digital models obtained from the structured light 3D scanning of the samples using the GOM Atos Compact Scan 5M scanner, carried out before and after the aging cycles. This process was executed using Gom Inspect 2022 software for a direct comparison of the two three-dimensional geometries, providing quantitative measurements of deformations visible in false-color images (Fig. 4).

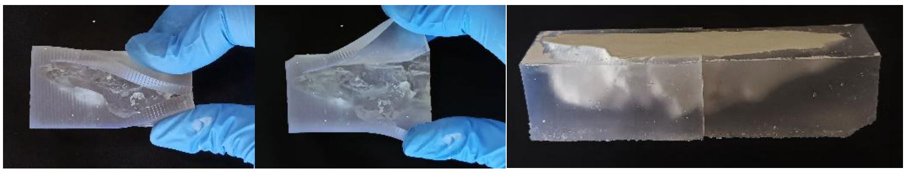


Fig. 2: (left) elastic deformation (right) transparency of Elastic 50A resin.

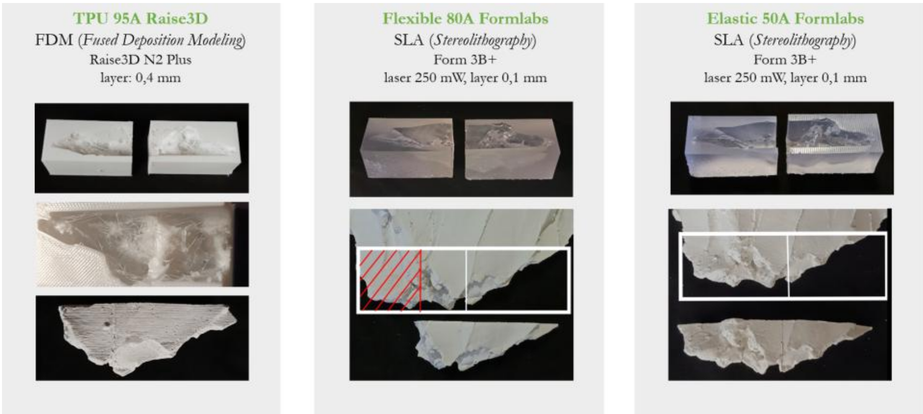


Fig. 3: Production process of the plaster sample starting from the elastic mold. In the first two cases, the sample broke due to hardness of TPU 95A and Flexible 80A.

3 Experimental Findings and Conclusions

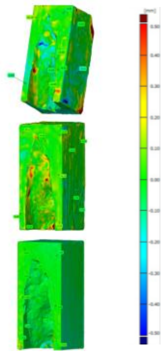
3.1 Considerations on the observed features of tested elastomers

The results of the examination conducted on the five materials were synthesized in a table (Tab.1), which includes the main aspects observed during the study: digital model processing time, printability, post-printing processing times, production costs, replicating surface details and morphological features, ease of use and ability to maintain their geometry over time.

The rigid polymers PLA and Tr250 are not the most effective options in terms of overall working time. In contrast, TPU offers advantages such as affordability in both material and printing methods, along with biocompatibility, non-toxicity, and adaptability to varying hardness levels. However, TPU printing requires significantly longer times and extensive testing. Furthermore, final processing is complex due to the need to address blemishes caused by printing stringing phenomena. On the other hand, the two Formlabs resins do not present the same disadvantages. The printed object does not need to undergo finishing processes as the printing SLA technique ensures high accuracy and precision in surface finish. In summary, in terms of production times, the two Formlabs resins represent the most efficient materials. Their disadvantage, instead, lies in the high costs.

Regarding the results of the aging cycle to which the three elastomers were subjected, measurements of plastic deformation showed the high ability of the three polymers to retain their shape (Fig. 4). The Elastic 50A showed a maximum deformation of +0.10 and -0.17 mm; the Flexible 80A resin of +0.15 and -0.08 mm. The TPU 95A specimen, on the other hand, with its maximum deformation of +0.06 and -0.06 mm, demonstrated a particular ability to withstand thermo-hygrometric stresses, partly due to its greater rigidity compared to the other two materials with lower Shore values.

Tab. evaluation of the five printing materials	PLA	Tr250	TPU 95A	Flexible 80A	Elastic 50A
Reduced digital model processing times	•	•	•••••	•••••	•••••
Easy of printing	•••••	••••	•	••••	••••
reduced post-printing processing times	•	•••••	•	•••••	•••••
Reduced production costs	•••••	••	•••••	•	•
Surface and morphological feature yield	•	•••••	••	•••••	•••••
Ease of use (positive demolding)	•	•	•••	•••	•••••
Ability to maintain its geometry over time.	-	-	•••••	••••	••••



Tab. 1: Final evaluations on the tested materials assigning a score to each one.
Figure 4: Overlay of digital models for measuring maximum deformation. In order: Elastic 50A, Flexible 80A, TPU 95A.

3.2 Evaluating the best material choice for Spiette, 36 and the production of exhibition copies.

Based on test results, we selected the Elastic 50A for printing the molds for the intervention on "Spiette, 36". It is indeed the material with the most pronounced elastic properties (50A shore) and the high detail resolution (SLA printing technique).

Practical Application of Elastic 50A Elastomer. Three elements of the installation were selected to represent the various cases based on shape (a corner piece) and surface characteristics (smooth or irregular elements).

Scanning 3D. The three elements were scanned in 3D using the GOM Atos Compact Scan 5M blue structured-light scanner, covering the mirror fragments.

Digital processing. The obtained digital model was imported and processed using the software Geomagic Wrap and Cinema 4D for mesh cleaning and digital mold generation from the object's surface. It was decided to maintain a mold thickness of 1 cm, similar to the silicone layer in traditional craftsmanship, in order to reduce production costs.

Printing 3D of the elastic mold. The printing process, as we have seen, was carried out using the desktop SLA printer Form 3B+ using a UV laser (405 nm). At the end of the process, the object undergoes washing with isopropyl alcohol, and the post-curing phase begins, which allows for the completion of resin residue cross-linking. Finally, the printing support structures are manually removed. In order to maintain the geometry of the elastic material unchanged during subsequent phases, a rigid external counterform was designed and printed in PLA.

Creation of the plaster copy. First, the mirror fragment was securely placed in its housing, and then the liquid plaster was poured into the mold. After the plaster had been set, the flexible cast containing the plaster positive was extracted from the rigid containment mold and delicately handled to allow the gradual removal of the copy.

On the surface of the replica, upon close observation, the thin lines of the layers are visible. We decided to preserve them as a recognizable feature of the replica compared to the original (Fig. 6).

Fig. 5: Elastic deformation of the printed Elastic 50A counterform of element no. 29.

Fig. 6: (from left) Demolding of the positive from the printed Elastic 50A mold; original element No. 29 and exhibition copy comparison; detail of the area characterized by printing layer lines on the copy.

Potential applications of printable elastomers in the Cultural Heritage field. This initial approach to the printable elastomers has showcased the potential of new 3D materials. In the case study presented Formlabs Elastic 50A resin emerges as particularly promising, offering a favorable combination of elasticity, detail accuracy, and surface quality, making it well-suited for our application of producing exhibition copies with minimal processing time.

However, the range of elastomers for 3D printing encompasses various materials with diverse performance characteristics and Shore hardness formulated for most printing techniques. Generally, these product classes boast advantages such as elastic deformation capability, exceptional resistance to impacts, abrasions and cuts, and in some instances, complete non-toxicity and biocompatibility (TPU). Above all, their printability allows for shaping as desired without direct contact with the artwork. These features suggest potential applications beyond mold production examined in this study. For example, due to their remarkably high resistance to external impacts compared to rigid materials, they can significantly contribute to the study of artwork protection during handling, transportation, and storage processes.

Ultimately, this research aims to open up possibilities for further research into material characterization and long-term durability to amplify our knowledge about the new polymers of 3D printing and how to use them for the conservation of cultural heritage.

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Using wikidata for managing cultural heritage information

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Abstract. The present study uses model wikidata elements as a basis and explores its dynamic formation into a cultural heritage information management tool within a museum. It aims at assessing the existing literature on the field, evaluate current practices, draw conclusions and weigh further uses within the museum environment. Literature search was centered on four axes: a) to provide a view of existing wikidata techniques and its relations to other wiki structures and databases, b) to describe existing projects within the museum environment and the use of wikidata for providing cultural information c) to locate works on the use of wikidata as a means for managing cultural information and, d) to explore if the pandemic COVID-19 has brought any changes on the use of wikidata. The literature review indicated that Wikidata have been and can be used as a:

i. common registry among cultural institutions for the description, semantic representation and visualization of artefacts, archival material as well as textual items
ii. basis for continuous augmentation of existing metadata by either the same or other metadata providers
iii. metadata pool for the production of a variety of coexisting or other informational derivatives
iv. means for encouraging global contributions independently of language, format or type of work
v. tool for implementing linked data
vi. broad base of information continuously expanding and updated that can serve for a variety of educational, entertaining and professional applications.
vii. means for gathering information independently of its origin, rights holder, country or type of institution thus offering a common platform for search, use and reuse of cultural information.

Keywords: Wikidata, Museums, Cultural heritage information, Metadata, Cultural information management

1 Scope and aims

The present study uses model wikidata elements as a basis and explores its dynamic formation into a cultural heritage information management tool within a museum. Large museums are faced with the problem of documenting the vast number of their collections, and in many cases, only a portion of their holdings are on display whilst the rest is in store. However, the information embedded in every museum object can be extracted, presented, and used by researchers and the public alike. The registration of these objects into museum catalogs is not only a means of securing their ownership but also a way of depicting the information they carry. The formation of such registries requires human labor and expertise along with historical, artistic, cultural, technical, or other specialized knowledge to augment the necessary metadata and give meaning to the artefact. Technology can be of help, and crowdsourcing technologies such as wiki-based ones offer valuable help and knowledge expansion mechanisms.

The present paper aims at assessing the existing literature on the field, evaluate current practices, draw conclusions and weigh further uses within the museum environment.

2 Methodology

The paper is a literature review. The literature search was centered on four axes: a. to provide a view of existing wikidata techniques and their relations to other wiki structures and databases, b. to describe existing projects within the museum environment and the use of wikidata for providing cultural information, c. to locate works on the use of wikidata as a means for managing cultural information and, d. to explore if the pandemic COVID-19 has brought any changes on the use of wikidata. Articles were grouped and then analyzed to understand the current situation and uses of wikidata techniques by information organizations for: a) complementing their existing standardized metadata, b) gathering information to be used for other activities such as the development of educational programs, c) a compilation of bibliographic resources, and d) other digital services such as digital museums and digital archival exhibitions.

In the digital world, the production of data is fast, in many cases automatic, and most of the time, it is done with no structure or any form of organization. (Gurstein, 2011) identifies seven elements necessary for people to use open data effectively, these being: "internet, computers and software, computer and software skills, content and formatting, interpretation, and sense-making, advocacy, and governance." If any of those elements is lacking, an organization, a community, a research discipline, or even a whole country will quickly be left behind. Data science is part of a wider information ecosystem, subject to government policies, social practices, and individual echoing through the system. This notion has served as a guide to the present literature review, and an evaluation of the resources examined has led to conclusions in regard to wiki data use and reuse for managing cultural information. Furthermore, potential uses were determined and proposed at the conclusion.

3 General framework

Wikidata (Wikidata, n.d.) started on October 2012 as an open, collaborative project. As stated by its name is run by Wikimedia (Abián, Guerra, Martínez-Romanos, & Trillo-Lado, 2018). (Wikidata Protection Policy, n.d.) Wikidata focuses on two elements: a. to provide a central storage space for the structured data of Wikimedia and Wikipedia and b. to attract and handle multi-language data thus expanding content and services to the global community. The creation of a central unit (knowledge base) of data for all Wikimedia projects offers the benefit of avoiding duplications, providing better control on the validity and structure of registered data whilst the multilingual capability broadens the queries as well as both the contributors and the end users. Today wikidata hosts more than 350 languages. One of their main characteristics is that they not only store data but relate it to their reference sources. This fact secures the validity of data in terms of their content. The continuous update of data creates a timeline, a history of the real content's development. For example, the gradual augmentation of a particular collection of a museum, or of an artist's production, etc do provide a timeline of their evolution through time. Every item (entry) in wikidata has a label, a description and a number of thematic terms along with qualifiers putting the term in context, properties and values, linked in statements that closely resemble an RDF triplet. References offer validity and additional information to the resource to complete the Wikidata item (Mora-Cantallops, Sánchez-Alonso, & García - Barriocanal, 2019).

Wikidata is linked to Wikipedia entries, thus offering additional information to the user and vice versa, enhancing the information deriving from the data with textual information nesting in Wikipedia (Albore, Malatesta, & Moliniè, 2021). The main use of Wikidata is linking to Wikimedia, the repository of photographs and digital images of artworks in which standardized descriptions and rich metadata offer their relation to textual information. The cross-validation of data and text entries augmented by images and media representations has created a world knowledge base (Roth, 2012).

In reality, wikidata (Wikidata Requests for Permission, n.d.) acts as a central data repository feeding information to Wikipedia and Wikimedia projects across multiple languages, thus eliminating duplications in different languages and in different Wikimedia applications. This way, an image, an article, or a map is supported by one or more relevant entries of data. Information is stored centrally in "one common data store from which any wiki project could retrieve data" (Ford & Iliadis, 2023).

The structure of data is standardized and follows schemas like Schema.org, which are designed to structure data derived from the natural language of websites and texts (Ford & Iliadis, 2023). Wikidata are retrievable through Google Search and various Search Engine Optimization tools, and their value is continuously increasing in retrieval procedures (Poddębniak, 2023); (Clark, Williams, & Rossmann, 2022).

Within this framework a series of articles have been located describing wikidata techniques and their uses in the museum environment. Furthermore, these techniques were assessed as to their capability of providing an information management tool for uses inside the museum as well as information exchange outcomes.

4 Literature Review

A good account of wikidata techniques and their uses is given by Mora-Cantallops *et al*. Their study (Mora-Cantallops, Sánchez-Alonso, & García - Barriocanal, 2019) focuses on articles entailing wiki data applications and the project itself. Research questions measure research activity since the project's introduction to assess its impact on a global basis, running across disciplines and languages. Then, they focused on topics aiming at pinpointing the wikidata use by discipline, area of interest, and the corresponding types of organizations. Apart from the use, the study also expanded in covering wikidata elements and structure and looked at the topics covered by wikidata itself to correlate it with the use and the further study of wikidata applications embedded in the relevant literature were also considered. Finally, the researchers looked at the leading institutions in wikidata research covering all elements such as production/contribution, standardization, search optimization, use, augmentation patterns, methods, etc. (Mora-Cantallops, Sánchez-Alonso, & García - Barriocanal, 2019). What has really come out of this is that wikidata research is on the rise as the concept and the importance of the wikidata knowledge base are attracting more interest due to its usefulness. Much of the research focuses on validity issues and the methods for securing the relevance of resources. (Piscopo, Phethean, & Simperl, What Makes a Good Collaborative Knowledge Graph: Group Composition and Quality in Wikidata, 2017) Their study explored the influence of users/contributors on wikidata quality. They considered both human users and bots and have set criteria such as topics and relevance, and in the case of human users, they examined elements such as affiliations, positions, fields of expertise, etc. They concluded that to gather high-quality wikidata, both human contribution and algorithmic input were of the essence. Human contribution acted as an expansion mechanism whilst algorithmic input offered much of the crosschecking, matching, as well as expansion. A more recent study by the same group evaluated the ontology of Wikidata (Piscopo & Simperl, Who models the world?: collaborative ontology creation and user roles in Wikidata, 2018), giving us a close look at the structure of topics and their interrelationships in terms of content. (Piscopo, Phethean, & Simperl, What Makes a Good Collaborative Knowledge Graph: Group Composition and Quality in Wikidata, 2017) characterized the wikidata ontology to be "large and messy, with numerous underpopulated classes and uneven depth". In this respect, the standardization and conformity of wikidata elements to one of the popular open standards such as DC or CIDOC CRM, would offer a solution to the above but, at the same time, might be restricting and somewhat limited to descriptive, structural and semantic information requiring further expansion in relation to administrative elements especially those securing the authority and validity of contributors, the editing and review processes along with a validation mechanism. At the same time, this practice would create an easier path for contributors supplying data directly from their catalogues and registries. The same holds for semantics.

Along the same lines and with particular interest to libraries mainly and archives can be found in the article by (Bacchi & Bergamin, 2018) who proposed the restructuring of the UNIMARC bibliographic records to be converted to the Wikidata data model. This will allow UNIMARC records to use the technical solutions and services of wikidata and wikidata to gain standardization practices. However, other standards, such as DC or MARC21 (the more widely used UNIMARC's counterpart), can offer better solutions and larger acceptance. As we can see, the standardization of wikidata elements to one of the existing bibliographic standards (UNIMARC) is already on the table and this shows the need for securing communication between wikidata and existing databases such as the bibliographic ones. However, many museums and archival collections have used other standards such as DC, EAD, etc. Past projects have shown the way of making existing catalogues and registries communicate. Europeana is a good example of that. However, wikidata's merits lie in rich information and augmented metadata and not in the simplification that Europeana's model (EDM) is built on. It does achieve communication but does not provide, at least at the first step, the full information depicted in the contributor's initial catalogues. In this respect, wikidata requires the exact opposite action: create a data store that data will be continuously augmented by different contributors, and this data store has no exclusive ownership or exclusive contributor. The idea of offering a variety of elements and leaving those to be filled based on availability is an idea but it is obvious that some mapping work or even crosswalks between standards can be of help.

Libraries, archives, and museums are key contributors to wikidata as they found an opportunity to store, link, and augment their metadata describing their collections. They are currently using wikidata as a "hub" of linked data, increasing and using knowledge stored there by other information institutions, complementing and cross-checking their sources, and presenting the "knowledge" embedded in their collections. The continuous cooperation of cultural institutions through the Wikidata platform has already given an enormous boost to hidden knowledge in artefacts and museum collections. One such example is given by (Chemello & Leva, 2018) presenting the partnership between the Fondazione BEIC (BibliotecaEuropea di Informazione e Cultura) and Wikimedia Italia.

Furthermore, the handling of semantics is of great importance. The article by *Bartalesi et al.*, dealing with textual items and their semantic values, was taken into account. (Bartalesi, Coro, Lenzi, Pagano, & Pratelli, 2023) dealt with the transformation of textual documents that contained geographic information into maps that actually tell a story. They used a semi-automatic workflow based on Natural Language Processing (NLP) and Semantic Web technologies. Their system used events associated with places and correlated wikidata entries along with multimedia information to create story maps. This process creates "a story map" that can be used as an educational, informational, and entertainment mediums. Story maps are presented in relevant web applications. Their semantic description follows the wikidata ontology based on subjects, predicates, and objects (Ford & Iliadis, 2023).

The global standardization of cultural heritage information is a challenge and an important agent of communication between cultural institutions and organizations. This is because the documentation is done using different metadata standards and different cataloging methods (Candela, Escobar, & Marco-Such, 2019). Nevertheless, a great effort is made by libraries to establish interoperability and aim at the homogenization of data across informational and cultural organizations. Linked data do offer the possibility of connecting resources with diverse descriptions and often conflicting metadata. This serves as a means to increase usage and ameliorate access to all types of resources. Library of Congress has been in the process of producing linked data to other institutions and, since 2019, has been linking its data to wikidata. Wikidata provides bibliographic information and resources, and LC, in turn, directs the user to the actual resources, to authority files, to hosting institutions, or even websites.

The success of the Library of Congress connection with wikidata is also attributed to the fact that more detailed bibliographic sources are provided through this connection. That is, relevant sources, established terms, terminologies, and even relevant websites according to the search of the users. All digital libraries and cultural organizations can follow this standard for developing, managing, and sharing cultural information (Ferriter, 2019). Other libraries, such as the National Library of Wales, have undertaken several wikidata projects focusing on the use of their existing metadata and the visualization tools provided by wikidata technologies. This is particularly useful for the presentation and use of cultural information through graphs, maps, tables, and other materials (Evans, 2021). Another example of this type of projects is the one undertaken by the National Library of the Netherlands. A digitized program regarding a diary of the 17th century, namely the "Album Amicorum of Jacob Heyblocq," contains some well-known figures that Jacob Heyblocq met during his lifetime. The book offers access to a series of figures serving as items within a collection and forms each one of them into a separate wikidata entity. In this respect, the resource is one, but the access points and wikidata items are multiple. The referencing, in this case, is creating a circle linking items embedded in a resource to other items, either independent or embedded in diverse collections. The interoperability and metadata sharing can work circularly and more efficiently not only by linking wikidata to collections but ideally by linking collections directly to the wikidata management system.

It becomes clear that the organization and management of knowledge can be supported by the technology and expertise of wikidata, creating a new information model. In this case, the Wikidata entity becomes the core item of information and can be used as a reference point, as an expanding knowledge element, and as part of any larger resource. The advantage of wikidata is that the entity is documented once, and this documentation can be continuously updated, referenced, complemented, and used by any institution or a simple user. The following diagram presents this information model based on wikidata techniques:

Diagram 1: Wikidata information model

It should be mentioned that the development of recent technologies combined with interoperability and linked data can enrich the catalogues of libraries and cultural organizations. All this innovation, in total, can help the users of cultural institutions to be served faster and more efficiently.

It is further pointed out that the future of wikidata projects will be the quick and easy navigation to information among cultural organizations. Knowledge sharing can be achieved through wikidata globally by reconfiguring the services provided, enriching the collections, and creating a circular information model as described above. Wikidata as means of managing cultural information will create a connected system in libraries, archives, galleries, and museums through the integration of more and more libraries and information services into wikidata (Perry, 2021).

Libraries have been adapting faster than many other institutions' wikidata technologies and are benefiting by their use. In their survey (Evenstein Sigalov & Nachmias, 2023), through qualitative research carried out with interviews, they present some wikidata projects that provide complex and multifaceted information. They also support information through modern technologies. The cases of libraries being involved, adapting, and using wikidata do offer an account of how the library community is seeing this new development and how ready it is to expand towards these new capabilities. Specifically:

a) The Bodleian Libraries (Bodleian Libraries. University of Oxford, n.d.) supported by Oxford University, tried to understand and promote wikimedia projects in the academic and research community. To realize this aspiration, library staff worked with the driving aim of making library collections visible in wikimedia projects https://www.bodleian.ox.ac.uk/

b) The Library of the University of Edinburgh (The University of Edinburgh, n.d.), Scotland supported the "witch-hunts" project. This program started in 2014, was an informative database for 16th−17th centuries Scottish Witch Hunts linked to wikidata. With the use of interactive methods, this project was an inspiration for the creation and support of future corresponding works https://www.ed.ac.uk/information-services/about/news/2019/interactive-witchcraft-map.

Along the same line, large museums did join similar projects in an effort to link their metadata to wikidata and gain interoperability. The best example of such a project is "The Portrait of Madam X," supported by the Metropolitan Museum of Art of the United States of America. This museum has a huge wealth of information and is internationally recognized. Specifically, in 2017 more than 350,000 works of art were added from the museum's metadata to wikidata, while in 2018 another 600,000 artworks were added enriching their collection at wikidata (Madame X (Madame Pierre Gautreau), n.d.) https://www.metmuseum.org/art/collection/search/12127. Also, the same museum created the "Met's Dashboard" and integrated it into wikidata (The Met Museum, n.d.) https://www.metmuseum.org/. Moreover, one more initiative of the Metropolitan Museum of Art was the project called "The Depiction Game," which was built with the support of artificial intelligence.

Academic institutions have joined the project efforts for research on wikidata capabilities. For example, the project sponsored by Tel Aviv University entitled "From Web 2.0 to Web 3.0, from Wikipedia to Wikidata". The project (A new academic course featuring Wikidata at Tel Aviv University, n.d.) coincided with the COVID pandemic, and its impact was increased by this fact (https://outreach.wikimedia.org/wiki/Education/News/October2018/A new_academic_course_featuring_Wikidata_at_Tel_Aviv_University)

Along the same line, Brazil's School of Journalism, inspired by the project of the Metropolitan Museum of Art, designed a tool that could create Wikipedia articles by using Wikidata. The same School used wikidata to find elements from other databases and specified information. Of great interest is the effort made by wikipedia volunteers to digitally capture the museum objects of the National Museum of Brazil, which was destroyed by fire in 2018.

The possibilities provided to the field of research and education by the semantic web are constantly being explored (Müller-Birn, Karran, Lehmann, & Luczak-Rösch, 2015). Based on the above, one can draw the conclusion that the academic and research community has shown great attention to the capabilities of wikidata, and libraries, museums, and archives have much to benefit from them. The early notion expressed by (Müller-Birn, Karran, Lehmann, & Luczak-Rösch, 2015) that the academic world has not fully understood the importance of wikidata technology is no longer the case. Universities and research institutions are rapidly exploring new directions, and relevant training courses have contributed to this evolution. The appearance of a training course (CIS-A2K/Events/Wiki Advanced Training/2018, 2018) already in 2018 hosted by Wikimedia (https://meta.wikimedia.org/wiki/CIS-A2K/Events/Advanced_Wikidata_Training_2018) is just an indication. Today, several universities do offer wikidata courses (Wikidata Basics, n.d.) as part of their curriculum (eg, the University of Edinburg https://thinking.is.ed.ac.uk/wikidata-basics/). Engaging with wikidata is a key element for the research community and cultural and governmental organizations (Evenstein Sigalov & Nachmias, 2023).

Finally, at the international level, it should be mentioned that during the COVID-19 pandemic, a worldwide disease monitoring portal using wikidata entities (with the participation of Brazil, Germany, and Australia) was created in several languages. From this portal, the user could obtain information related to the disease while the information is provided by various databases and information sources linked to wikidata. The construction of knowledge graphs the linking to the WikiGenome project provided much needed information (Turki, et al., 2022). The WikiGenome project is an open database for the research community powered by Wikidata.

Apart from that, museums made an effort to retain contact with their public during lockdowns, and this effort (Unesco Digital Library, n.d.) was implemented in the digital world (https://unesdoc.unesco.org/ark:/48223/pf0000373530). Digital museums, virtual exhibitions, and educational programs were the only means of staying connected with the public. Wikidata was, in many ways, the infrastructure for gathering, correlating, crosschecking, and providing ready information that would feed the educational programs, the virtual exhibitions, and the enhancement of digital museums themselves. As Wikidata is connected to Wikimedia Commons, graphic descriptions are automatically connected to textual information (Albore, Malatesta, & Molinié, 2021). This capability has made possible the creation of stories and educational games and has enhanced the informational content of virtual exhibitions. This has been stated in the "Survey on the Impact of the COVID-19 Situation on Museums in Europe" carried out by the Network of European Museum Organizations (NEMO). The survey presented the economic implications of the COVID-19 pandemic on museums. Recommendations of the survey do include the extensive use of tools such as wikidata for securing museums' impact in the digital world (NEMO, 2021).

Looking now at the projects taking place that have as their main scope the exploitation and use of wikidata technologies, one can observe a rigorous activity. The development of new technologies and their integration into information science has created excellent prospects for the dissemination of cultural information. The metadata of libraries, archives, and museums are an excellent feeder to wikidata and vice versa. In this way, cultural industries can provide knowledge through the Wikidata information management model quickly, reliably, and for free. Open Data is provided free of charge to all users and has a special feature that allows it to be created and constructed by all potentially interested parties for any purpose and in any place. (Open Definition, which the Open Knowledge Foundation created in 2005). According to the Open Knowledge Foundation this can be achieved with the corresponding legal and technological freedom. However, it is necessary to protect all works through intellectual responsibility and ownership. Technological support must allow for the free sharing of data (Albore, Malatesta, & Molinié, 2021).

The free sharing of data and cultural information is supported by many repositories and databases. The Data.europa.eu portal provides several open cultural projects. For example, The Miguel de Cervantes Virtual Library Foundation (Biblioteca Virtual Miguel de Cervantes, n.d.) which has in its catalogue more than 200,000 free-to-use records. (https://www.cervantesvirtual.com), the British Museum (The British Museum, n.d.) has one of the oldest and largest metadata search platforms. About 2,300,000 records out of a total of 4,000,000 objects are freely available to users; the Musee Saint - Raymond (Toulouse, France) (Musee Saint - Raymond Archeologie France, n.d.) should also be mentioned as it uses wikimedia platforms and wikidata projects https://saintraymond.toulouse.fr/, etc.

Accordingly, in the United States, notable examples of free mining of knowledge and metadata (Library of Congress Linked Open Data Service portal, n.d.) are The Library of Congress http://id.loc.gov/ which supports the interoperability and sharing of cultural information, The New York Metropolitan Museum (The New York Metropolitan Museum , n.d.) http://www.metmuseum.org/ which provides a multitude of artworks on data sharing platforms, etc.

Based on the above, museums, archives, and even more so libraries have adopted the necessary policies and have proceeded in using wikidata as an auxiliary service for publishing their data or even as a form of data registration and data augmentation deriving from their catalogs, bibliography related resources, curatorial work, and standardized descriptions. The idea of having augmented metadata through wiki practices and using crowdsourcing capabilities did not seem to come into the picture for formal information organizations. However, the simultaneous use of other similar institutions and their contributions was rather welcome. It seems that this has become one of the benefits of wikidata providers. True crowdsourcing from independent experts, nonformal art galleries, or local collections has not been as yet an option, whilst libraries, archives, and museums see this type of open data gathering as not trustworthy.

According to (Zhu, Xu, Deng, Heng, & Li, 2023) Wikidata has proved to offer the following benefits to libraries and cultural heritage institutions:

- Wikidata enhances the adaption of Linked Open Data.
- Wikidata provides URIs and facilitates the use of the semantic web at the level of entities.
- Wikidata items are reused, referenced, and linked to other resources.
- Authority data, deriving from institutions' authority files, can be distributed through wikidata.
- Items can be multilingual.
- Items can be continuously updated and enriched, incorporating geo data, images, and biographical data.
- Bibliographic data can be converted to RDA/RDF and BIBFRAME through wikidata and other sources.
- Wikidata can be visualized in graphs.
- Wikidata platform is open to anyone for contributions following guidelines and practices.
- Wikidata offers a form of standardized description of items and an ontology for semantic management.
- Wikidata offers structured data, making its content machine readable, securing interoperability, and serving as a repository of sources (Vrandečić, 2023).

Cultural institutions, in general, aim at providing equal access to their holdings to all members of the community; as this service is shifted from the real world to the digital, this task has become easier, more readily available, and meets many of the necessary aspects for personalized, on-demand, current information characterized by wholeness, precision, and validity. Wholeness and versatility rely on collaborations among institutions across countries, languages and types (these being libraries, archives, museums, galleries, parks, research labs, etc). These institutions have recognized the importance of Wikimedia projects (Perry, 2021) and the potential of wikidata for forming the infrastructure of information. In order to secure their presence in the digital world, they have come to the understanding that their participation in global wiki platforms is of the essence (Chemello & Leva, 2018) .In summarizing, wikidata elements do need to secure their correspondence to existing description standards, though significantly augmented in order to accommodate the data store's objectives and administration of contributor's activities and validation. They also need to secure the management of semantics and make the most of linked data for existing and upcoming projects.

Furthermore, policies are of main concern in order to secure not only the contributions but also the use and reuse of wikidata information. It became evident that museums had to adapt open data and open access policies to art works themselves and solve issues of photographing and reproductions of art works for the interconnected Wikimedia project.

5 Conclusion

It is evident that wikidata can serve in a variety of ways for managing cultural information. Wikidata can be used:

- As a common registry among cultural institutions for the description, semantic representation, and visualization of artefacts, archival material as well as textual items.
- As a basis for continuous augmentation of existing metadata by either the same or other metadata providers.
- As a metadata pool for the production of a variety of coexisting or other informational derivatives.
- As a means for encouraging global contributions independently of language, format or type of work.
- As a tool for implementing linked data.
- As a broad base of information continuously expanding and updated, it can serve a variety of educational, entertaining, and professional applications.

- As a means for gathering information independently of its origin, rights holder, country, or type of institution, thus offering a common platform for search, use, and reuse of cultural information.

The initial idea for creating a central platform serving as a data store for similar wiki projects, in reality, has created a central data store with a standardized structure that could be used not only for supplying information to other wikis but in fact, offering information for a variety of activities such as information on related and complementary objects, the basis for educational games and digital museum activities, registry control, artefact comparisons, linked data, etc. It should be mentioned that Museums should have the necessary "data literacy" skills in order to access, critically use and transform wikidata into information. Understanding the way wikidata works, the algorithms, tools, and standards they use, and the potential, as well as the extent of information they provide, is the basis for their full use. In addition, the understanding of the data hype cycle is also of the essence. Data, like all information, is a non-depletable resource and is nonetheless still there for use by others. Wikidata in the museum environment will reach a peak of curators' and users' expectations before they become part of a regular museum information tool. The credibility of wikidata is critical throughout this cycle.

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Phygital Heritage Experiences in Refugee Attica

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Abstract. The Greco-Turkish war's aftermath led to a significant refugee crisis in 1922, with over 1.5 million fleeing Asia Minor for safety in Greece. The Digistoryteller project aims to document and share narratives of these refugees' struggles to establish homes in Attica, using digital storytelling and crowdsourcing features. This project, through its database and mobile apps, allows for city exploration and contributions from experts and the public. A key focus of the project is the concept of "phygitality," which combines physical and digital experiences. Phygitality encompasses various combinations, including augmented reality, 3D printing, and holograms. In cultural heritage, phygitality offers new ways to engage with historical sites and enhance cultural experiences. Different phygital products developed within the framework of the project will be presented. In the case of Vyronas, a municipality in Attica founded as the first urban refugee settlement, the project introduces phygital objects like paper reconstructions of historical buildings. These objects, like the Old Town Hall, provide educational and touristic value by allowing users to assemble them and access augmented reality information about the building's history. Initial user testing has shown promising results, with plans to integrate these objects into educational programs and museum shops. The municipality of Vyronas intends to produce these objects for both educational and touristic purposes.

Keywords: Cultural Heritage, Phygitality, Augmented Reality

1 The Digistoryteller project

The Greco-Turkish war in Asia Minor came to an end in 1922. Following the conclusion of that conflict, a massive refugee crisis forced over 1.500.000 people to flee their homes in Asia Minor and Thrace and seek safety in Greece. A large number of these individuals settled in the prefecture of Attica. Over 100 years later, the goal of the Digistoryteller project (https://digistoryteller.eu), which is devoted to the refugee crisis, is to share narratives about the difficulties and attempts of refugees to establish homes in the Attica region. The project created a rich database and mobile apps to support city exploration with the use of digital storytelling and crowdsourcing features which allow contributions from experts and the public.

More specifically, the Digistoryteller includes a repository of information related to the arrival, settlement, and gradual integration of Asia Minor refugees in Attica. The reference period is from 1914 to 1949, with a focus on the period 1922-1928. Despite the various commemorations of the Asia Minor Catastrophe, primarily by Asia Minor organizations, the emphasis usually lies on the catastrophe itself and the development of municipalities with predominantly refugee populations, a phenomenon occurring from 1934 onwards. Research into the initial phases of these people's settlement, their continuous relocations until finding suitable living and working conditions, their entrepreneurial activities, the lack of access to basic goods, and the support networks and social organizations they created, has only recently begun. Many aspects regarding urban planning, its political ramifications, relations with the indigenous population, and the process of economic integration are illuminated through archival research and the development of new inquiries.

The guiding function is developed on two levels:

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In guided tours using documents collected, selected, and entered by the project's research team, forming a route within each municipality, supplementing historical information for each point of interest with multimedia material (photos, music, recorded testimonials, video interviews, and recipes).

In the participatory crowdsourcing system, the public (residents, inhabitants, visitors) can upload their documents and information from their family archives or even simple testimonials from grandparents, grandmothers, or parents, allowing previously unknown material to emerge.

In addition, a large part of the project focused on creating relevant phygital products which would be used to provide reconstructions of monuments and elements of cultural heritage involving users in unique ways and allowing them to explore the past. Such products included (indicatively):

a) A coloring book and an adjoint series of 6 coloring cards, based on authentic photos which were provided by the Asia Minor Society of Egaleo “Nees Kydonies” (Figure 1); the original photos are accessible through the AR application, which works both on the black-and-white and colored-in pictures.

Fig. 1. The coloring book with the painting card series and the AR application.

b) A narrative card game which comes together with an original audiobook, titled *A Day in Kastraki: Stories from the Refugee Settlement of Drapetsona, 1922-1960*. The game is based on the power of narration and storytelling, and can be played either in conjunction with the story of the audiobook or autonomously. The AR application accompanying the game activates the camera of the mobile device and scans each of the cards to provide access to a different excerpt of the audiobook each time, allowing for various playful and educational applications.

c) An activity book for use by children aged 9-14, based on the approach of “mind maps”, to help children approach aspects of Asia Minor memory and cultural heritage as shaped through the refugee experience. The organization of the content and the structure of the book invite each reader to complement it with their own multimedia material (photos, audio recordings, videos), mapping their family and local history in their own way. To facilitate the recording and organization of user-generated multimedia material, the accompanying application has been designed, which activates the recording applications of the mobile device on which the application is installed and allows for the management of files in accordance with the organization of the book's sections-collections (Figure 2).

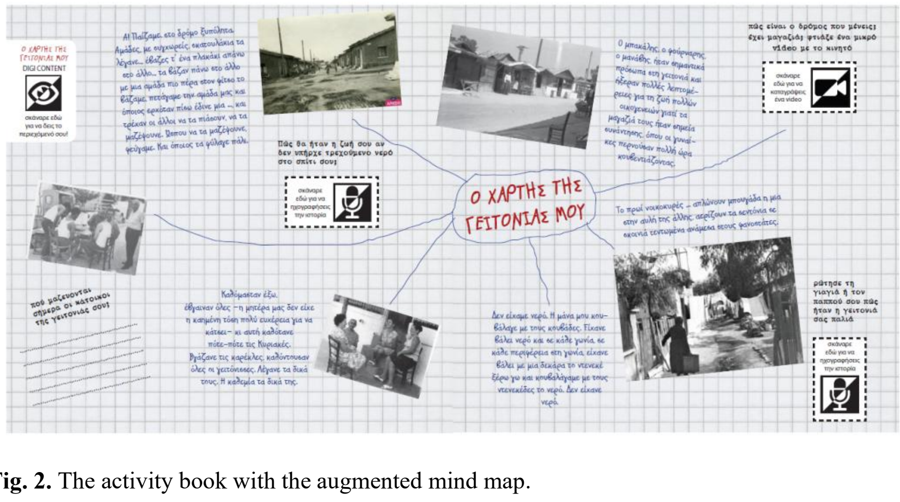

Fig. 2. The activity book with the augmented mind map.

2 Phygitality

The term phygitality was introduced to describe new forms of hybrid experiences which combine physical aspects of the experience with augmented reality, 3D printing, holograms, etc. This umbrella term generically describes any such combinations without being defined in concrete ways. Thus, phygitality refers to an ecosystem of various combinations of physical and digital experiences [1]. A recent literature review revealed four main dimensions of phygitality: phygital objects and applications, phygital spaces, phygital user journey (user decision-making is assisted through the coexistence of the physical and virtual), phygital experience (the resulting enhanced cultural experience) [2].

Literature review also identifies five main areas that phygitality emerges: 1. Marketing, 2. Education, 3. Social issues and Politics, 4. Technical issues and legal matters, and 5. Cultural Heritage, Tourism and Urban Development [3]. Regarding cultural heritage, there are already research efforts that wish to introduce phygitality in the domain of heritage and first attempts provided positive results [4]. Although many efforts focus on new forms of cultural tourism [5, 6], others focus more on the cultural experience as such [7]. For example, phygitality was considered as a new way to experience one of Portugal's most known cultural sites, Quinta da Regaleira [8]. In addition, museum visitors that received phygital experiences in the form of Mixed Reality showed higher perceptions of authenticity and reported higher quality of the cultural experience [9]. Finally, phygitality was used to promote a cultural site and enhance heritage communication [10, 11].

The current work uses phygital objects and phygital experiences to engage users in cultural experiences. As mentioned in the previous section, in the context of Digistoryteller, different phygital products were developed and tested with visitors and policy makers. In the following section, we will focus on the phygital 3D papercraft of the old Town Hall of Vyronas, which represents an effort to implement the concept of phygital and game-based storytelling experiences for a built landmark, rather than for aspects of intangible refugee heritage.

3 The case of the old Town Hall of Vyronas

3.1 Focusing on the physical aspect of "phygital"

During the last decades, there has been a notable expansion of the use of immersive digital technologies, such as Virtual and Augmented Reality, in order to make learning about cultural assets more attractive and accessible to wider audiences. The combination with game-based approaches, such as Serious Games, has proved very effective in various areas of education related to cultural heritage. However, most examples of such experimentation focus on digitized assets within a Virtual Reality environment, maintaining that in this way, the contact with the assets appears to be more direct and realistic [12].

Our approach came from a different point of departure: that playful experience of built cultural assets and landmarks can be served by focusing on the physicality of the educational object. Tangible interactions with educational games, especially with games incorporating analysis and documentation, are essential for turning cultural assets, including historical buildings, into educational resources for expanding learning skills and perspectives, with a special focus on school-age audiences [13]. In this, we have drawn from the experience from previous work of the project's partners with paper reconstructions of archaeological and architectural monuments, which have proven very popular with Museum visitors in all major archaeological Museums in Greece.

Moreover, the cross-curricular value of papercraft projects in educational contexts is significant: for one, they are a playful way of understanding how geometric shapes can be handled to form 3D structures, thus familiarizing users with basic engineering and spatial relationship understandings. At the same time, papercrafts entail building from templates, concentration and fine motor skills, which obliges users to actively engage with the papercraft subject and can thus build positive associations with it, sparking curiosity for further exploration. Digitally enhanced storytelling can therefore serve as an essential part of an extended and enriched experience with the cultural asset addressed. Based on this premise, we decided to test this approach for at least one historical building related to the refugee experience in Attica.

3.2 Focusing on the Old Town Hall of Vyronas

The choice of the specific historical building was due to a number of reasons:

a) Vyronas is one of the most known refugee neighborhoods in Attica, and its old Town Hall is an emblematic landmark related to the refugee settlement: originally it was the Red Cross Polyclinic (1924) and for many decades to follow the Town Hall of Vyronas (until 1996). It has since served as municipal cultural center for almost 20 years, and it is now going to host the newly established and soon-to-be-implemented History Museum of the Municipality of Vyronas. Additionally, the Municipality was looking for creative synergies with Digistoryteller, in order to promote its own activities promoting local history and refugee heritage among its citizens. All these factors made the old Town Hall building a suitable choice within the context of Digistoryteller.

b) Contrary to other historical buildings with similar advantages, the old Town Hall of Vyronas gave us access to its detailed architectural plans due to the recent museography and restoration blueprints for its transformation into a city museum. This part is essential for the 3D papercraft to be closer to a paper reconstruction, however simplified.

c) The plans of the Municipality to turn the building into a History Museum permitted us to conceptualize the product as part of the Municipality's awareness and expectation raising campaign. Also, we could draw from the narrative developed for the forthcoming Museum's exhibition, in order to build our content and storytelling around it. This ensured more focused testing sessions for our product with residents and Municipality employees.

3.3 The phygital products for the new History Museum

The principal product is the 3D papercraft, which consists of color printed pre-cut pieces on 3 A4 sheets, plus a color base on an extra sheet. By assembling the pieces, the user can build the paper reconstruction of the old Town Hall and soon-to-be History Museum (Figure 3). The key points of the building's history are presented on the information sheet included in the packaging. Through the AR application, the user who has assembled the model can be guided through a more detailed version of the building's history, including some accounts and anecdotes about the centrality of this landmark for the everyday life of Vyronas residents through the decades. The user also gains access to the VR video about the forthcoming Museum and its first exhibition.

Fig. 3. Paper reconstruction of the Old Town Hall of Vyronas.

The application is available for free installation on a phone or tablet from the Google Play Store. A QR code on the cover (packaging) of the paper construction leads directly to the application, for easier installation. The application activates the camera of the portable device and scans the object. Each side of the building opens different text bubbles, through which the history of the building unfolds in brief. Reading the back side of the building opens the VR video created by the Municipality of Vyronas for the planned Museum, guiding the user to see the next page of the building's history.

Together with the reconstruction of the historical buildings, Vyronas' visitors will be also able to use an 8-fold informational brochure for the Vyronas Municipality History Museum, double-sided (Figure 4). The interior includes a map of the wider area of the Museum (Old Town Hall) in Vyronas. Through the same AR application (but by choosing a different menu), additional visual and auditory content is projected onto the map, for points of interest near the Museum building - the Old Town Hall, which are related to the establishment and inauguration of the refugee settlement in 1924. By selecting a POI, the user can see a brief description, listen to a more detailed audio description, and view additional multimedia material (photos and videos) about the landmark.

Fig. 4. Augmented brochure for with map of the wider area of the Old Town Hall.

4 Perspectives and conclusions

The phygital objects of the Old Town Hall were presented to the Mayor of Vyronas, to municipal employees and locals in December 2023, and were given to them for user testing. Initial user testing revealed the educational potential of the 3D papercraft, as well as the commercial potential of both products, which have been picked up as saleables at the new Museum's shop. In fact, the Municipality already expressed its intention to proceed with the production of the item for use in the educational programs of the Museum, after the start of its operation, while it is also considering the possibility of production for use in the educational programs of its schools already before the opening of the Museum.

Specifically with regard to the 3D papercraft of the old Town Hall, it is noteworthy that it is addressed to younger audiences, who have no recollection of the Museum premises used as Town Hall. Therefore, it was considered a playful and creative means to familiarize younger audiences with the historicity of a building which they are only going to know as Museum, already remodelled inside and rebranded as a landmark. In this sense, the old Town Hall of Vyronas has provided a meaningful testbed for the use of digitally enhanced paper reconstructions as tools in a game-based approach to cultural and local heritage education, especially when it comes to raising awareness and re-inventing the relevance of historical buildings.

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Digital Epigraphy Encoding and Information Management

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Abstract. The inscribed text from the past on the stone represents an invaluable source for archaeologists and historians, who play a vital role in preserving and analyzing these inscriptions. Engraved on a durable material accompanying monuments, memorials, and statues or standing by their right, epigraphs are exposed to the same environmental and anthropogenic hazards threatening monuments. Their importance as historical and cultural objects is so well recognized that they retain a prestigious place among all ancient artifacts. They are the first to apply the latest technological breakthroughs for their documentation. This is evident from the application of the invention of photography to the modern use of artificial intelligence deep neural networks in textual restoration. Digitization of inscriptions represents the first step for their preservation, publishing, and dissemination among scholars and the public. However, the second step, their encoding, allows their computational analysis within the linked-data environment by generating machine-readable documents. Herein, we will describe the guidelines of the latest version of the Epigraphic Documents (EpiDoc) in Text Encoding Initiative (TEI) Extensible Markup Language (XML) (https://epidoc.stoa.org), a specialized edition for encoding of inscribed ancient text, which deals with the text and the historical context of the epigraph production. The Europeana network of Ancient Greek and Latin Epigraphy (EAGLE) (https://www.eagle-network.eu/), the Aphrodisias in Late Antiquity (InsAph) (https://insaph.kcl.ac.uk/ala2004/), the Atlas patrimonii Caesaris (https://patrimonium.huma-num.fr/documents/), and the Packard Humanities Institute (PHI) (https://epigraphy.packhum.org/) projects will be discussed in the context of the Greek Directorate for the Management of the National Archive of Monuments (https://www.arxaiologikoktimatologio.gov.gr/).

Keywords: Digital Humanities, Digital Epigraphy, EpiDoc, Conservation, Cultural heritage, Data management.

1 Introduction

The Mediterranean basin, the cradle of so many civilizations continuously inhabited from prehistory to modern times, is rich in ancient monuments, inscriptions, epigraphs, and texts. Assyrian tablets of the 21st to 16th century, Egyptian hieroglyphs of the 13th century, Linear B tablets of the same era, Akkadian scripts of the 5th century BC, Classical Greek epigraphs of the 4th century BC, Hellenistic scripts of the 3rd century BC, Persian, Israel, Roman epigraphs of the 2nd century BC to 2nd century AD, Byzantine and Western Christianity, as well as Islamic and Ottoman monumental scripts apart the complex and fertile cultural mosaic of this geographic region [1]. The inscribed text on the stone is invaluable for archaeologists and historians. The written text represents the predominant evidence of historical documentation and understanding of the past.

The inscriptions and epigraphs are the authenticated primary sources necessary for historical restoration, authorship attribution, chronological context determination, geographical information, social and cultural conditions examination, and topic critical analysis without biases or groundless assumptions. In historiography, no description can be entirely neutral; history is fundamentally ambivalent; and the account of events is not just about individuals but of groups [2]. Inscriptions when accompanying monuments deliver to us different narratives, occasionally overlapping but non-exclusive: entertaining, memorializing, commemorating, glorifying, celebrating, legitimizing, justifying, explaining, offering instruction, providing administrative records, warning, criticizing, or just immortalizing the past, delivering the truth about it. An example of administrative recording represents the inscription of the Propylaea stele found in 1836 during the Acropolis of Athens excavations, which delivers the accounts that refer to the Erechtheion construction at the end of the 4th century BC (see Fig. 1).

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Fig. 1. Details of the inscription from the Propylaea Stele documented the financial accounts for constructing the Erechtheion (408-407 BC, Acropolis of Athens Museum).

The importance of epigraphs as historical and cultural objects and the need for their preservation and documentation has been recognized since the beginning of modern archaeology, and the technological breakthroughs of each era have been applied to their recording. This is evident from the application of the invention of photography as early as it was discovered in the 19th century [3] to the modern use of artificial intelligence deep neural networks in textual restoration when necessary [4]. Despite their durable nature, as most epigraphic inscriptions have been lettered upon hard substances, such as stone, bronze, or ceramic, they are subjected to decay, spoilage, and attrition, with a significant risk of destruction and perdition. Epigraphs are laid to the environment and exposed to physical and anthropogenic hazards, such as season changes, fires, earthquakes, floods, wars, vandalism, or excessive tourism that threaten the monuments. An example of the importance of documentation and recording of an ancient artifact with inscriptions represents the case of the blocking outer doorway of Tutankhamun's tomb, full of stamps and ancient Egyptian official seals, which Howard Carter and Lord Carnarvon partially dismantled to access the tomb during their 1922 excavation (see Fig. 2).

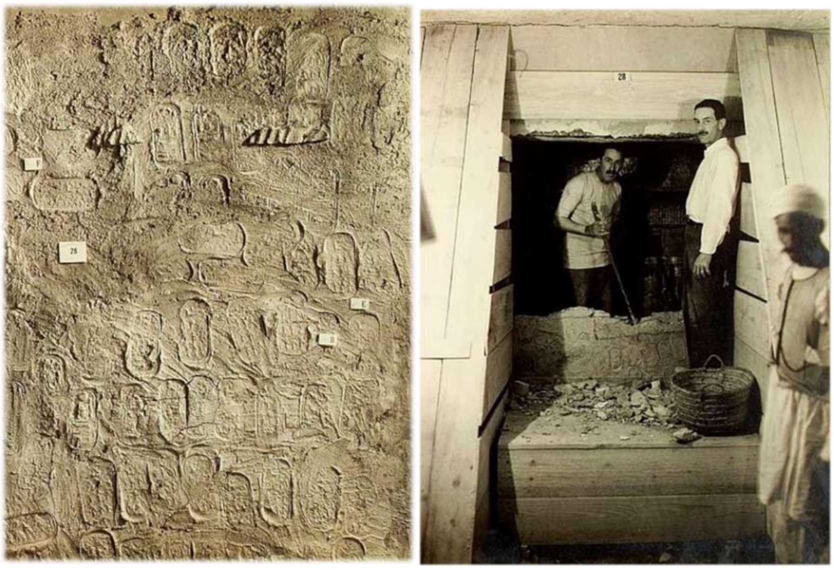

Fig. 2. On the left is a photograph of the outer doorway of Tutankhamun's tomb before any intervention, and on the right are Howard Carter and Lord Carnarvon, as they partially dismantled the doorway during the tomb's excavation in 1922.

It has been postulated that the deterioration of ancient monuments in our age has entered a crisis phase, as can be documented by the annual loss of ancient cultural heritage of such a magnitude that many of the monuments taken for granted today may not survive for the next generation [3]. Digital epigraphy offers the means to preserve this heritage, study, examine, translate, and analyze the content, and reconstruct the information from fragments or lacunae using computer technologies [4]. Photography, scanning, vector drawing, and optical character recognition (OCR) could accurately digitally represent an epigraph. At the same time, epigraphic documents (EpiDoc) in text encoding initiative (TEI) extensive markup language (XML) provides the framework for encoding epigraphic text, transcription, editorial treatment, material of the object, and attributes description [5].

2 Digital epigraphy

From the many significant transformations that epigraphy has experienced recently, incorporating digital technologies is the most disruptive and pervasive development. The digital transition of humanities calls for interdisciplinary action, developing new methodologies for artifact facsimile generation and analyzing information, storage, and management. The technological innovations concerning epigraphy are (a) the electronic textual representation and the delivery of information from analog to digital form by optical character recognition (OCR) methodologies; (b) the textual restoration, recovery of missing text, and reassembly of fragmented epigraphs; (c) the electronic delivery of context and attributes of the epigraph, including authorship, chronology, and geographic origin; (d) linguistic text parsing, part of speech tagging and segmentation; (e) philological textual criticism; and (f) translation and interpretation to facilitate modern readers demand [6].

Epigraphic inscriptions are 3D objects with text, context, and historical attributes. Deciphering epigraphic text and context through digitizing inscription facsimiles could be achieved through digital photography and electronic restoration by morphological residual modeling or through 3D scanning and contrast filtering. Vector drawing and on-site collation of the proofs, editing, and correcting would produce an accurate digital facsimile, based on algorithmic curves trace matching and not pixels, of the artifact for storage, studying, or publishing [7]. The context and attributes should accompany, as informational attachments, these electronic documents, thus providing an as complete as possible information scheme of the authorship, chronology, and geographic origin of the item [8].

An untrained linguistic analysis solution applicable to digital epigraphy could be derived from the semantic analysis of a set of terms, single words, or multi-word expressions derived from a body of texts and organized in a master index [9]. After converting multi-word expressions into single words, the index is processed dualistically as intact terms and, after their split, single words. The frequency of their appearances ranks the extracted terms or single words after duplicates are eliminated and analyzed by latent semantic analysis (LSA). The resulting index can be rebuilt after correlating external resources in the proposed paradigm to WordNet and relational analysis with the authorities and the subject headings of the Library of Congress (LCSH) and the National Library of Greece (NLG_SH). Thus, a machine-readable index is generated for further philological interpretational tasks, classified by cultural heritage criteria, searchable, and matching the original body of texts (see Fig. 3).

Digital epigraphy alleviates the pain of analyzing copious quantities of historical information from multiple resources by producing digital libraries that can be assessed online, applying social network and spatial analysis, enhancing epigraphic collaboration [6], and providing investigators with data that can be further analyzed by computational [9] or artificial intelligence technologies [10]. To these ends, text markup and encoding are of particular importance.

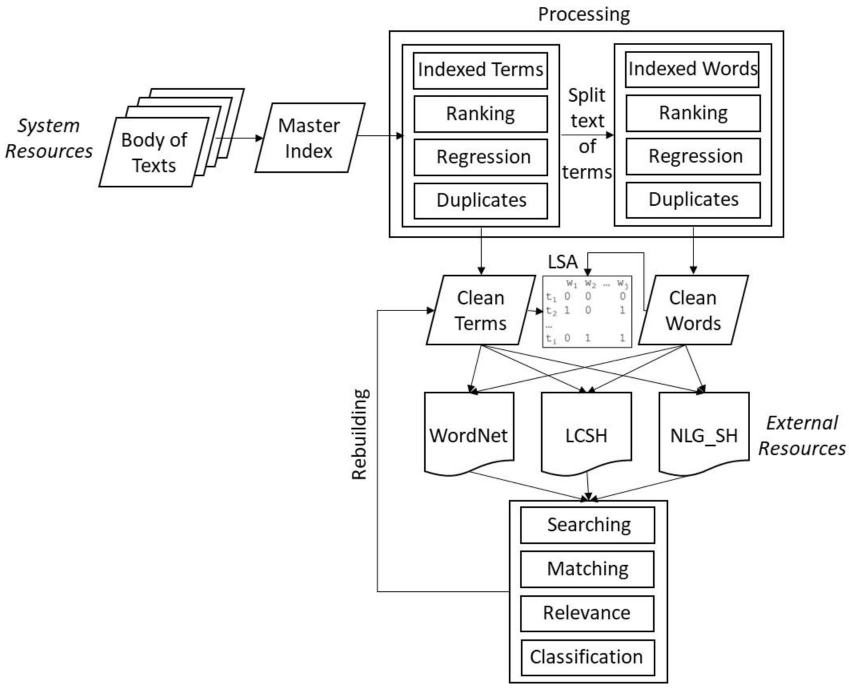

Fig. 3. Diagrammatic presentation of the building architecture of a terminology index from digital epigraphy corpora for philological interpretational tasks.

3 EpiDoc

The Epigraphic Documents (EpiDoc) standard is based upon the Text Encoding Initiative (TEI) standard, which is a form of Extensible Markup Language (XML). XML is a text markup language and a file format that, unlike HTML, has no predefined tags for encoding documents in a human- and machine-readable form, reconstructing data, storing, searching, sharing, and transmitting across different systems and platforms. This open and highly flexible, user-defined standard attracted the interest of the TEI community, which develops and maintains standards for the representation of texts in digital form. TEI issues guidelines that define the tags that contain text (opening and closing markup delimiters) as specific documentation elements, attributes, values, classes, modules, models, and datatypes [11]. In TEI syntax and XML, an element may be a child element to a parent one. TEI is an interdisciplinary standard of mostly text-based physical artifact description that serves the needs of various cultural heritage institutions (such as libraries, museums, publishers, and researchers) to represent the literature body of texts. Any sort of work or artifact can be described with TEI markup. This hierarchically structured formation significantly increases the markup language's descriptive capacity to include text, context, properties, authorship, spatial and temporal information, edition details, and copy details, including notes and attritions of the specific copy encoding. In TEI XML, tagged elements are nested, represented, and hierarchically structured. For example, for the representation of a poem in an anthology, the start and end tags are defined as an anthology; within the anthology, there is the poem, its title marked with a heading tag, and then its stanza, separately represented one by one. Within its stanza is a description of each line of the poem. The structured nested description allows the citing of specific elements encoding in the XML file. TEI guidelines detail every element, tag, class, or macro to describe any sort of work or artifact and its dimensions, notes, and attritions in the object. The development and maintenance of a highly expressive and descriptive standard format to encode text allow the delivery of different modules of hand-written or published works, such as analyses and interpretations, metadata for language corpora, print dictionaries, performance texts (drama), tables, formulae and figures, special characters and glyphs, names, dates, people and places, graphs, networks, and trees, transcribed speech (spoken), text criticism, text structure, transcriptions of primary sources, or verses, that could be applied in digital humanities.

Like the TEI community, the EpiDoc international consortium dedicates its coordinated efforts to produce guidelines for encoding in-depth epigraphic text in digital human- and machine-readable format [5]. Initially developed in 2000 for Greek and Latin epigraphy (such as Inscriptions of Aphrodisias [12] and Vindolanda Tablets [13]), EpiDoc was expanded to include the publication of papyri and manuscripts

[14] and adapted to encode other script traditions such as Egyptology, Coptic, Hindu, Maya, Mycenaean, pre-Islamic Arabian, multi-language texts, abbreviations, monograms and symbols [6]. Since CIDOC-CRM (Conceptual Reference Model), the ontology standard developed by the International Council of Museums (ICOM), is used to define the ontological layer of cultural objects, including textual entities such as epigraphs, epigraphers apply both EpiDoc and CIDOC-CRM to document epigraphs [6]. In parallel, the Europeana network of Ancient Greek and Latin Epigraphy (EAGLE) is trying to combine these two systems to deliver the text accompanied by the standardized representation of the physical aspects of an epigraph together with its context [8]. In addition, considering the broader definition of epigraphy, EpiDoc can also be used in sigillography and numismatics.

Herein, we will describe the guidelines of the latest version of the Epigraphic Documents (EpiDoc) in Text Encoding Initiative (TEI) Extensible Markup Language (XML) (https://epidoc.stoa.org), a specialized edition for encoding of inscribed ancient text, which deals with the text and the historical context of the epigraph production. EpiDoc guidelines specify a subset of the TEI standard for representing ancient epigraphic documents in digital form through XML. The annotated phenomena are linguistic (onomastic, grammatical), philological (lacunae, restorations, corrections, etc.), and descriptive of the relation between text and support (line breaks, text turning around the object) or of the internal structure of the text (genealogies, eponyms). Specialized communities of contributors focus on Greek, Latin, Egyptology, Coptic, Hindu or Mycenaean text transcriptions. EpiDoc Guidelines aim to align information according to conventions for epigraphic transcription and metadata standards. EpiDoc monumental inscription representation combines the text with the historical context of the epigraph production.

The descriptive and representation functionalities of EpiDoc are supported by sets of elements required for transcription, supporting information, and vocabulary and indexing. EpiDoc uses the same elements as TEI in most cases, but their definition is customized for EpiDoc descriptive tasks [15]. For text transcription, there are elements define (a) the structure of the text, its direction, verse lines, the manner of word divided across lines, metrical elements, and paragraphs; (b) the text per se, its clarity, cases of uninterpreted, ambiguous, damaged or erased characters, ancient corrections, illegible characters, lost characters or lines, lacuna, spaces that never contained text (vacat), changes in scribe or hand, and text not completed; (c) its form and appearance, including highlighted characters, special characters, raised or lowered, tall or small characters, reversed or inverted letters, symbols, and monograms; (d) editorial interventions, such as restored text, uncertainly text, correction, abbreviation, expansion, foreign text, and editorial note; and (e) interpretation, numeral, fraction, acrophonic and quotation marks. Another set of elements is necessary to describe images accompanying text-bearing objects following the TEI Gudelines to represent primary sources. For the vocabulary and indexing, elements such as contents, summary, keywords, and terms can be used, together with tagging of lexical words and lemmatization, personal names, prosopographical links, place names, and geographical terms mentioned in the text, titles, offices and occupations, military, religious and socio-economic terminology, events, dates, and month names. For the alignment of object, text, and context description with controlled vocabularies and authority lists outside the TEI environment, EpiDoc allows references into the element (@ref) that point to the external vocabularies. These references may point to EAGLE Type of Inscription Vocabulary [16], EAGLE Object Type Vocabulary (including monuments) [16], Getty Museum (Art & Architecture Thesaurus® Online) [17], EAGLE Engraving Technique Vocabulary [16], EAGLE Material Vocabulary [16], Salzburg Simplified Petrography [18], EAGLE Dating Criteria Vocabulary[16], date of origin PeriodO [19], EAGLE State of Preservation vocabulary [16] or EAGLE Decoration vocabulary [16]. Through these reference links, the expressiveness of EpiDoc is enhanced to describe epigraphs and monumental inscriptions in explicit detail.

4 Collections of EpiDoc Encoded Inscriptions

The pioneer EpiDoc project that greatly assisted the development of its protocols, guidelines, and tools was the *Inscriptions of Aphordisias*, an archaeologic site in Caria, southwest Turkey, with an ancient Hellenistic and Roman historical background, considerably rich in inscriptions of excellent quality [12]. Most of these inscriptions are from the late Roman period, second or the early third centuries AD. Formal inscriptions, fragmented or intact, public inscriptions, honoring rulers or benefactors, recording decrees, or dedicating buildings, as well as funerary, gameboard, place inscriptions, prayers and invocations, and verses, represent some of the different categories of text found there, located on columns, masonry blocks, panels, plaques, statue bases, most of them inscribed on marble. The inscriptions' text and context can be assessed directly from the website by number section, findspot, date, text category, or monument type, and downloaded as the inscription in EpiDoc XML format.

The *Europeana network of Ancient Greek and Latin Epigraphy* (EAGLE) is another source of EpiDoc encoded inscriptions by various contributors [16]. This website offers basic and advanced search and image search to retrieve text, images, or artifacts related to the query. Also, there are filters to select for decoration, material, object type, state of preservation, type of inscription, writing, ancient find spot, modern find spot, has image, has translation, and content provider.

Another database of EpiDoc encoded inscriptions is the PATRIMONIVM project *Atlas patrimonii Caesaris (APC)*, where a collection of nearly 5000 documents with geographic information, age, references, and details is stored [20]. The aim of the project is the research of imperial properties at the scale of the entire Roman empire. The website allows direct search and filter search by document, people, places, geographic area (map), or keywords. The geographic areas covered include Africa, Alpine provinces, Asia Minor, Balkan provinces, Britain, Crete-Cyrene, Cyprus, Egypt, Gaul and Germany, Greece, the Iberian Peninsula, Italy, Sicily, Sardinia, Corsica, and the East. The keywords of APC's thesaurus cover civic life, economy, geography, prosopography, religion, Roman administration, Roman law, and society. The references of the inscriptions of Atlas patrimonii Caesaris are stored in Zotero.

EpiDoc-encoded searchable Greek inscriptions are available from *The Packard Humanities Institute (PHI), PHI Epigraphy Project* [21]. The content can be searched directly, or the inscriptions can be browsed with the assistance of a geographic locator. The geographic locator covers Attica, Peloponnesos, Central Greece, Northern Greece, Thrace and the Lower Danube, North Shore of the Black Sea, Aegean Islands including Crete, Asia Minor, Cyprus, Greater Syria and the East, Egypt, Nubia and Cyrenaica, North Africa, Sicily, Italy, and the West, Upper Danube, and Unknown Provenances.

The Greek National Archive of Monuments recently introduced the *Arcaeholological Cadastre*, an interactive map of natural and archeological monuments, museums, and sites. The website offers navigation to these places within the limits of the Greek district [22]. Although this project is not directly associated with the EpiDoc, it facilitates the geographic location of an archaeological site of interest.

The ITHACA project is another interesting tool for restoring information on fragmented textual data [4]. ITHACA may also attribute ancient texts using deep neural networks and assist in identifying the geographical and chronological of ancient Greek inscriptions [23]. The geographical localization examines eighty-four regions of the ancient world, and the chronological attribution searched a period between 800 BC and 800 AD.

5 Discussion

Epigraphy is a discipline of research with a history exceeding one thousand years. Scholars' interest in the inscriptions of the past, historical information, and philosophical considerations delivered, hoarded in transcriptions and anthologies, have entered the 21st century into the digital era [24]. Digitization of cultural objects, documentation, recognition of information, quality enhancement, optical character recognition, bridge the physical textual sources to the electronic reconstructed facsimile. From the library and information science (LIS) perspective, the question is how to convey this raw data by encoding them in an organized, storable, searchable, retrievable, and transferable machine-readable mode to deliver them for the consumption of end users within the semantic web linked-data computational environment.

EpiDoc, a metalanguage developed by epigraphers for epigraphic, philological, and historical use, is the markup language that delivers text and context in a human- and machine-readable format. Utilizing the XML flexibility of structured and semantic markup and the TEI guidelines for defining elements and attributes to describe written or published text, EpiDoc sets a matched equivalent between Leiden codes of epigraphy and markup features for the electronic encoding to form its guidelines [24]. The attribution of authorship, spatial and chronological information, palaeographic information, and the topic of the text can also be delivered in the same file as the text. In addition, information on the investigator who first described the object, the era of discovery, and relative bibliographic citations could be included. The EpiDoc file describes the object's physical condition and possible uncertainties, lacuna, vacat, special condition of the inscribed characters and appearance, and editorial interventions, such as restored text or corrections. On top of this, EpiDoc allows references to external control vocabularies outside the TEI environment, which increases its expressiveness and descriptive capabilities of cultural fragments, items, objects, and monuments. Ultimately, the EpiDoc file delivers a complete electronic reconstruction of the described object together with background and bibliography.

EpiDoc-encoded files, despite their role in historical documentation, facilitate linguistic investigators' analysis, semantics, part-of-speech (POS) tagging, text parsing, and segmentation, as well as philological textual criticism, style, intertextual relationships, and stemmatology. Importantly, EpiDoc encoding makes possible automatic computational approaches, including artificial intelligence applications for textual restoration, as in the case of the ITHACA project [23], and fragment reassembly or automatic translation to modern-day languages, which assist comprehension and interpretation by contemporary researchers. As we proposed herein, EpiDoc files could be used for the textual organization and analysis of collections of texts, including inscriptions of geographic regions and historical eras, by performing latent semantic analysis and index rebuilding with WordNet for English-translated content and relational analysis with the authorities and the subject headings of the Library of Congress and the National Library of Greece. This approach may produce organized text corpora linked to cultural heritage information with improved search and retrieve capabilities. It should be noted that this approach may serve as a platform for cross-cultural heritage unification studies.

6 Conclusion

In conclusion, encoding of epigraphic documents and monumental inscriptions with the EpiDoc standard ensures (a) a universal standard for information delivery, (b) the preservation of ancient information, (c) the compatibility with HTML publishing, (d) the data transfer and dissemination, (e) the interoperability between different platforms, (f) the accessibility by scholars and the public, as well as (g) applying automatic computational solutions including artificial intelligence systems for organization, indexing, textual restoring and attributing parameters options.

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Beyond the Standards: Combine Different Metadata Schemas for a Versatile Museum Repository Development

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Abstract. As cultural heritage evolves in the digital age, museums face three primary objectives. Firstly, they must revise their collection management philosophy to include the new possibilities that derive from the technological progress[1]. Secondly, they must integrate data infrastructures and schemas that are user-friendly for museum staff and researchers alike [2]. Thirdly, they must start thinking of collaborative ways of managing their data, something that will add informational value to their artefacts, as well as, contribute to saving costs and time. To achieve these goals, a well-defined metadata structure for curating cultural content is essential. Implementing an ontology-based metadata policy is crucial for museums aiming to enhance digital access to their collections strategically[3]. Additionally, it's vital to test the sustainability of proposed metadata schemas in practical applications, ensuring they effectively describe artefacts or collections [4]. Subsequenlty, the need strives towards the selection of multi-functional and flexible repositories platforms providing polysemic documentation of artefacts.

In this paper, we propose and implement a holistic ontology-based metadata grid combining descriptive, reputation, conservation, and indoor navigation fields for a full documentation of artefacts and collections. One step further, the proposed metadata schema is adopted and implemented in Reasonable Graph. A platform capable of enhancing semantic intercorrelation between artefacts and collections using a diversity of thematic entities, such as geographical locations, historical periods, persons, events, and ethnographical labelling. The versatile folklore collections of Museum of Modern Greek Culture in Athens are used as testbed to assess the proposed schema and platform practicability to describe and semantically correlate the available artefacts.

To this end, the paper generally contributes to the understanding of the evolving challenges faced by museums in the digital age by proposing solutions to address these challenges and highlighting how an ontology-based schema gives a dynamic perspective on metadata management.

Keywords: Ontologies, Cultural heritage, Digital repositories, Metadata, Interoperability, Open Science

1 Introduction

Cultural heritage is a crucial field in implementing new technologies. As societies are gradually transforming their infrastructures into digital ones, cultural institutions investigate and develop their own ways to follow this trend. Especially, museums are facing the challenge of becoming more functional, more visible, more cooperative and more attractive to their visitors by incorporating digital technologies into their daily routines, not only as individual applications but also as a holistic approach to operation [5].

Considering the specific needs of managing, documenting, preserving and exhibiting objects of cultural heritage, we introduce some of the basic features of the Reasonable Graph repository platform, as a single tool for managing and presenting metadata related to cultural objects at any stage of their processing. An ontology-based approach for cultural collection management is proposed as the conceptual model of this project.

The ReasonableGraph platform has already been installed and is fully functional in many Greek institutions, which manage digital collections, however, in this context, we focus on a new innovative digital space that has been developed and prototyped for the Museum of Modern Greek Culture (MNEP) in Athens, as a case-study for the project MELTOPENLAB.

2 Research Project MeltOpenLab: case-study “Museum of Modern Greek Culture (MNEP) in Athens”

The MELTOPENLAB [6] (Museum Experience with Location Tracking Ontologies and Open Laboratories) project, addresses the aforementioned issues in a holistic manner, by developing and pilot-operating an advanced and cost-effective integrated information system for exhibition facilities, such as Museums, Multi-Cultural spaces, and Open Labs. On one hand, the project focuses on the digital documentation of exhibits/objects of modern cultural heritage and methods of their restoration/conservation and presentation. On the other hand, the project focuses on developing an advanced information system for capturing visitor movement in near real-time (in both eponymous and anonymous mode) and analyzing collected data. The system is designed in a cost-effective approach, i.e., employing technologies that are both available and energy-efficient, and is used as a platform, upon which innovative applications provide a personalized presentation and learning/entertainment experience, record and evaluate visitor interest, behavior, and satisfaction.

The Information System and Applications that have been developed and prototyped, are pilot-applied to the artefacts and exhibition collections spaces and archival material, documentation/maintenance/restoration procedures in selected exhibits (simple and complex concepts) of the Museum of Modern Greek Culture (MNEP) in Athens[7], Greece. MNEP is the only public museum dealing with the tangible and intangible modern Greek cultural heritage. For more than 100 years, it has been rescuing, studying, and highlighting everyday life and ritual symbols and objects, information on morals and customs, traditional arts, and techniques, which make up the modern Greek reality. Introducing new technologies in order to support its operation, MNEP aims to be transformed from a space of stored cultural memory and presentation, to a space of active knowledge and experience for the visitors, providing, at the same time, to the employees new tools for managing the collections.

The project currently performs Pilot Operations, validating functionalities and evaluating tools and applications for visitors and museum administrators. Preliminary results are analyzed and documented.

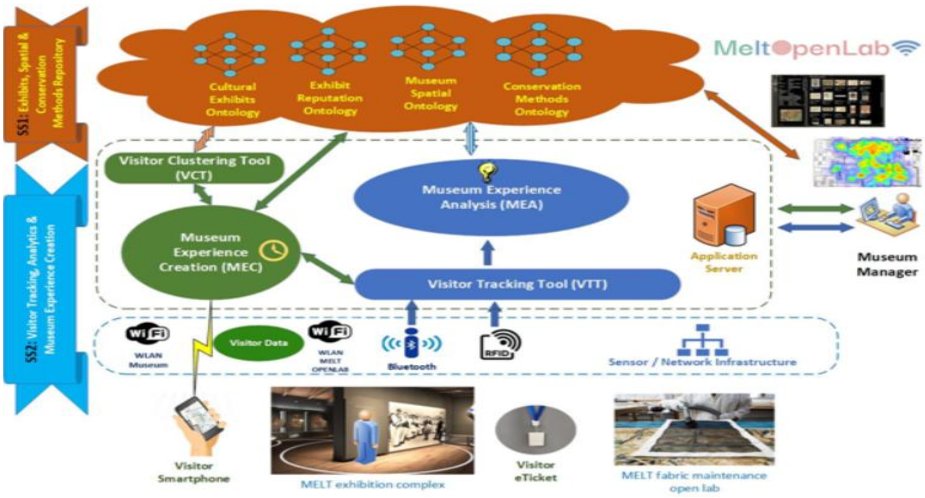

Fig. 1. Operational Architecture of High Level MeltOpenLab

3 ReasonableGraph platform

The ReasonableGraph platform (RG) is an open-source information system for managing physical and digital collections and their metadata, using ontologies and semantic schemas. RG is based on widespread open-source software technologies (Linux, PHP, PostgreSQL, Apache, Laravel, Drupal, SOLR, Nodejs). Inherently manages ontologies, specified on a scientific field or based on prototypes (e.g. FRBR-FRAD-

FRSAD/FRBR LRM, BIB-FRAME, FRBR-OO, etc), and also, offers the ability for the management of an organization collection directly as a semantic and linked open data set. In parallel, it supports cataloguing, archiving, and documenting for many different types of physical or digital items (such as books, journals, newspapers, correspondence, posters, 3D-objects, etc.) and formats (such as pdf, epub, images, wav, mp3, mp4, etc.).

The representation of the data inside the system is modeled as a graph. This graph represents a dynamic and interconnected set of data which is constantly enriched and extended while the user adds information, using the suitable data form according to the material type that he/she describes. These digital forms are either standardized or can be customized by the user to satisfy special needs. At the front edge, the external users can easily navigate or search the platform in order to explore its content.

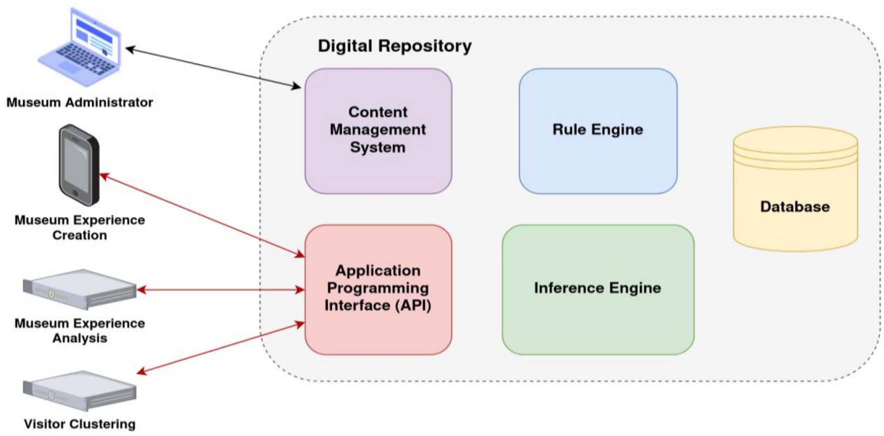

Fig. 2. RG System architecture for MNEP

4 MeltOpenLab Repository

The information system that has been developed for the Museum of Modern Greek Culture through the MeltOpenLab project, is called MeltOpenLab Repository. ReasonableGraph platform provides the digital environment for implementing the project, while it supports the creation of the proposed ontology.

Fig. 3. MeltOpenLab Repository – Main Page

4.1 Ontology of Cultural Exhibits

The operational role of the ontologies is to determine the specific conceptual context in which the museum's objects documentation is taking place [9]. Ontologies, although locally developed, should be consistent with interoperability standards in order to ensure semantic communication with other systems.

In MeltOpenLab Repository has been developed a core ontology of cultural exhibits (CEO), divided into four individual ones from different scientific fields (museology, ethnology, conservation etc):

- **Semantic Description Ontology (SDO):** hosted in the MeltOpenLab Repository in which the cultural objects of the museum are organized semantically, the SDO proposed by MELTOPENLAB combines different metadata standards for artefact documentation. It is structured on five basic elements: geographical space, historical period, historical person, historical event and ethnological determination.
- **Museum Spatial Ontology (MSO):** floor plans with exhibit allocation and coverage areas (cells) of installed sensors in the museum spaces, are integrated into the MeltOpenLab Repository overall system, providing support to both MEC (visitor experience) and MEA (visitor statistics) services. The ontology represents the building structure of the museum and the relations between its parts, starting with the separation in buildings and ending at the showcases, where the objects are located.
- **Exhibits Reputation Ontology (ERO):** hosted in the MeltOpenLab Repository in which visitors' ratings of exhibits provided during physical visits, as well as metrics/indicators evaluating their popularity based on visitor behavior, are accumulated.
- **Conservation Methods Ontology (CMO):** hosted in the MeltOpenLab Repository, complements CEO, providing documentation on methods used for conservation / preservation and restoration of artefacts. The ontology was developed in collaboration with the employees of the related department of MNEP. Part of it is physically demonstrated in the Open Lab implemented in the context of the project, in MNEP premises.

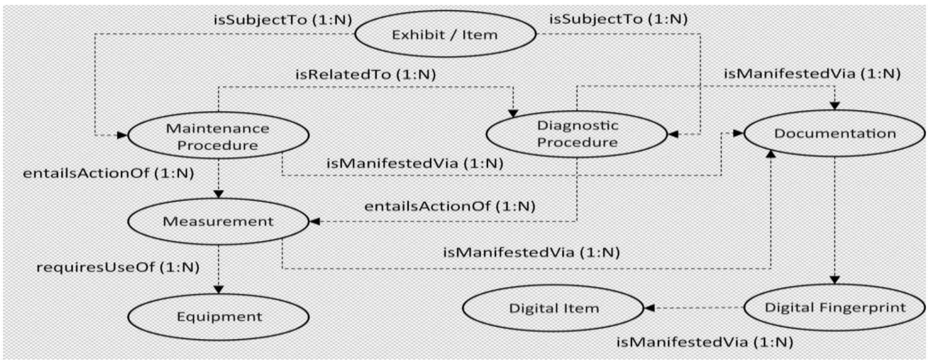

Fig. 4. Conservation Methods Ontology (CMO)

The entities of these ontologies belong to widespread international standards, such as FRBR[10], Core Categories for Visual Resources Association (VRA)[11], CIDOC-CRM[12], OntoNav and iLOC. The semantic interoperability between MeltOpenLabRepository and other systems has been ensured by following these standards.

Taking into consideration that MNEP already had an existeing repository platform (MuseumPlus), a process of data migration had to be performed. Transferring the data from the old system to the new one, the developed ontology was applied on the process. Furthermore, the system, as well as the ontology, is designed to accept data entries by humans, in an easy and friendly way, without requiring specialized experience.
The basic structure of the proposed ontology along with its sub-ontologies appears in Figure 5.

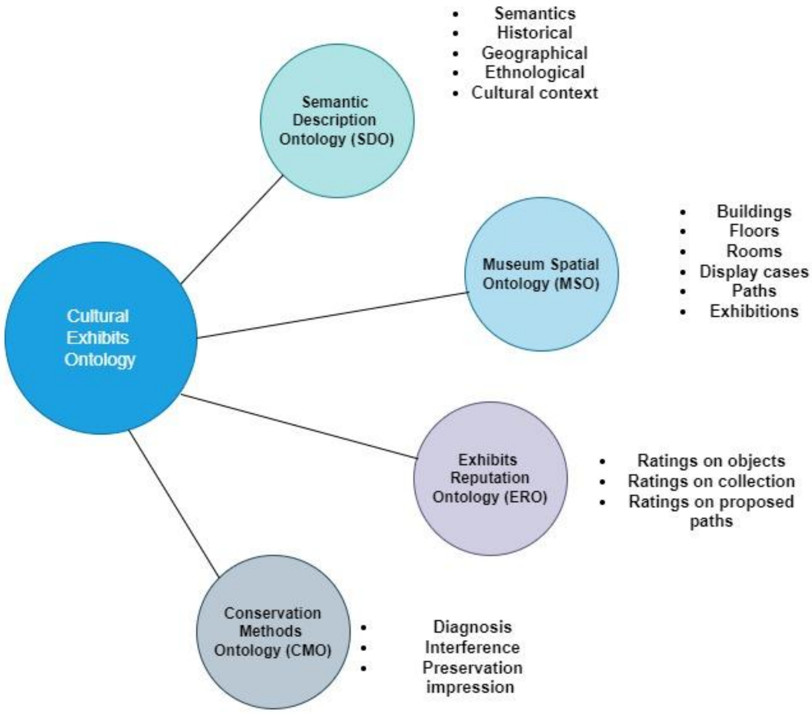

Fig. 5. Proposed Ontology for MNEP

RG platform provides the mechanism to combine all the above ontologies in order to document every cultural object in the museum's collections. Each specific ontology reflects a different view of a cultural object: its descriptive information along with its scientific data, its location, the opinion of the visitors about it and its conservation/preservation status. Scientists from different fields could use that information for their specific needs. Developing extra sub-ontologies, even more aspects of a cultural object could emerge. In that way, the whole infrastructure has, a dynamic perspective in managing cultural objects.

In addition, the graph-based structure of the system contributes to giving prominence to the relations among the information data, which results in an augmented informational value of the collections. Interconnected informational data can be realized both on an internal level of the system and on an external level. The objects of the museum communicate among themselves by having many descriptive entities in common, such as type, place of origin, showcase, or the same rating, but they also can be connected to entities, existing outside of the museum, using the technologies of linked data and opened data.

Another important feature of the ontology-based application is that it allows and also supports the collaboration of scientists who are involved in managing a cultural collection. They can all have access to the same information about objects, and document or comment on them, according to their work. For example, they would all be informed about when an object is in its showcase or has been moved for conservation reasons. Moreover, they can know who has added a specific kind of information which is ambiguous or incorrect. They can, also, combine the information to create new one, as in the case that they want to define new visitor paths in the museum.

These features resulted as an implementation of an ontology-oriented approach to cultural collection management. One step beyond, this approach could be expanded to support a network of cultural institutions, that are sharing the same technical infrastructure, ReasonableGraph platform in this case. Developing ontologies in common, cultural institutions around similar scientific areas, could work collaboratively to manage their collections and add informational value to their content.

5 Conclusion

Semantics, in the field of cultural heritage, as expressed through ontologies, have a very strong impact [13]. Cultural objects carry of huge amount of information during their long route in time and a plain descriptive recording of their characteristics does not meet the interests, not only of museum visitors, but also of the museum staff. The cultural objects should be interpreted alongside with their relation to other objects inside a semantic context that gives them the opportunity to export all their informational content. Cultural institutions should advance their management perspectives, aiming to succeed all the above by introducing new technologies that support this holistic approach of operation.

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Lorenzo Nottolini's architectural heritage in Tuscany. Digital twins and database for restoration project management.

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Abstract. The article examines methodologies for developing digital databases and digital twins as tools for the restoration and protection of architectural heritage. The focus is on the Aqueduct of Lucca, designed by Lorenzo Nottolini beginning in 1822, a complex work of significant historical and architectural value. The research combines the analysis of archival and bibliographic sources with advanced laser and photogrammetric survey techniques to create detailed three-dimensional models. The study of this case provides an opportunity to apply the described approach to a concrete example, utilizing both direct and indirect analyses. Through this inductive method, it will be possible to derive more general guidelines.

Keywords: Lorenzo Nottolini, Restoration, Digital twins.

1 Introduction

The aim of this research is to develop methodologies for the creation of digital databases and digital twins as fundamental tools for defining guidelines for restoration projects and the protection of architectural heritage [1]. This study seeks to reconstruct the work of architect Lorenzo Nottolini by comparing archival sources with the current state of his works. Despite the wealth of archival material and bibliographic production on the architect, a comprehensive and detailed analysis of his work is still lacking. This study serves as a unique case to develop methodologies for creating digital tools for the restoration and protection of historical heritage. The following article presents the first outcome of the research carried out so far.

The detailed study presented here offers the opportunity to test these methodologies on a specific case study: the Aqueduct of Lucca, designed by Nottolini beginning in 1822. Despite its aesthetic and formal simplicity, the Aqueduct is one of the most complex architectural-engineering works realized by the architect from Lucca, considering its design, historical vicissitudes, and current conservation problems. The examination of this case provides a chance to apply the described approach to a concrete example, utilizing both direct and indirect analyses. Through this inductive method, it will be possible to derive more general guidelines.

Fig. 1. Lucca, acquedotto del Nottolini, vista aerea del doppio condotto su archi, 2023.

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2 The aqueduct of Lucca, historical compendium

The work on constructing the digital database began with the collection and cataloging of archival material produced by Nottolini. Alongside the archival documentation, an examination of the existing bibliography on the subject was conducted. Through the study of the collected information, it was possible to reconstruct the history and events that characterized the construction of the aqueduct.

Until the early 19th century, Lucca's water supply for daily needs relied on town wells located in various strategic places around the town [2]. However, the water from these wells contained high concentrations of selenite, which caused liver damage, and neglect and poor maintenance often led to plagues [3]. Even today, traces of these ancient wells and their former locations can still be found in the city. One of the first attempts to bring water into the town from external springs occurred on 5 September 1732 [4], but the first significant step in realizing this ambitious project dates back to 13 May 1763, when the General Council approved a report drawn up by six citizens of Lucca, proposing to the Government of the Republic to use water from Guamo [5].

On 24 December 1763, abbot and mathematician Giovan Francesco Giusti presented a report that made the first substantial contribution to the design of the aqueduct. After inspecting the proposed springs, which were excellent both in terms of location and water quality, the abbot submitted a report with an attached project proposal to the Council. Giusti proposed an aqueduct *"like that of the Romans, followed by the Pisans and other cities, i.e., to support the conduit above the arches, as the water flows and purifies itself by depositing the impurities, and does not exert any pressure inside the conduit, thus helping to keep it in excellent condition"* [6]. On 28 August 1772, the General Council appointed Giovan Attilio Arnolfini to further the studies initiated in previous years and to advance the completion of the aqueduct [7]. The Council examined Arnolfini's project on several occasions without ever making a final decision [8].

In 1809, during the principality of Élisa Baciocchi, the construction of the aqueduct was decreed, and three projects were presented. Among these was a project submitted on 15 August 1810 by the French engineer Carlo de Sambucy, which envisaged the construction of a large cistern to purify the water from the springs and a double conduit positioned on arches with a buttress every fifteen spans. On 14 February 1812, the project was approved, and work began on connecting the first springs by fixing the line of arches. However, the building site stopped in 1813, as the engineer, considered partly responsible for the overflowing of the Serchio river, was relieved of his duties [9].

After the Congress of Vienna (1814-1815), various reigns took place in Lucca. In 1817, the Bourbon dynasty took office, and Maria Luisa of Bourbon-Spain (1782-1824) became the reigning duchess of the duchy’s capital. On 25 September 1822, Nicolao Giorgini, gonfalonier of the duchy, presented a report and a new project signed by the state engineer Giuseppe Valentini. By order of 7 October 1822, the Duchess decreed the construction, and the engineer was entrusted with the direction of the work [10].

The project drawn up by Valentini did not differ substantially from those of his predecessors, so much so that it was described by Mazzarosa as *"inferior, not only to the first project but also to that of Sambucy in terms of art and usefulness"* [11]. Even Duchess Maria Luisa was not fully convinced by the project, so Lorenzo Nottolini was commissioned to make further proposals. Thus, on 31 October 1822, Maria Luisa issued a further order that confirmed the direction of the works to the engineer Valentini but also entrusted the superintendence to the architect Nottolini [12].

In 1829, Gonfaloniere Giorgini, in a letter to his close cabinet secretary Navasquez, described the changes made to the project, pointing out not only the raising of the duct and the increase in the width of the spans but also Nottolini's decision to interrupt the duct near the walls [13].

On 13 March 1824, Charles Lodovic of Bourbon (1799-1883) succeeded his late mother, Marie Louise. On 15 April 1824, on the advice of the city's Gonfalonier and due to financial problems related to the cost of building the aqueduct, he suspended work until further notice. Despite this, work resumed in 1824 with considerable effort to complete the arches. However, at a meeting held on 24 February 1825, objections were raised to the project, particularly regarding the decision to introduce water into the city through a penstock. The Royal Architect responded to the criticism, addressing both technical concerns and emphasizing the importance of preserving the historical environment. Nottolini stated, *"the most pleasant walkway in our city after the walls is that of the Spalto that surrounds them, so it must be the main concern of those who nurture the idea of beauty to preserve it in all its parts"* [14].

Nottolini was also concerned with designing a crucial detail: the *Serra vespaiata*. Through its construction, the architect aimed to unite all the waters of the Rio San Quirico and Rio di Valle, thereby increasing the volume of water brought to Lucca. This unique structure exemplifies Nottolini's ingenuity in the realization of the aqueduct, considering every detail [15].

Towards the end of 1827, the construction of the arches above the plinth for the entire length was completed. To interrupt the monotony of a completely uniform structure and, in particular, to increase its stability, Nottolini, probably inspired by Sambucy's project, decided to build a buttress every 17 arches, resulting in a total of 26 reinforcements.

Fig. 2. Diagram of the Lucca aqueduct system.
1. The city fountains 2. The penstock 3. The terminal temple of San Concordio
4. The double conduit on arches 5. The initial temple of Guamo 6. Underground conduit
7. The system of fountains and the *serra vespaiata*

The work continued until 1832, despite numerous criticisms and bureaucratic hiccups. Although there are no documents in the archives that provide a precise date for the commissioning of the aqueduct, it can be placed in this year [16]. The first report was made by Nottolini himself on 16 September 1832, where he identified problems with the springs connected during French rule [17].

The incident clearly gave the detractors of the Royal Architect fresh impetus, placing him once again at the center of an intense and bitter controversy. On 24 January 1833, Nottolini was therefore compelled to join Carlo Lodovico in Berlin to clarify his position [18]. After carefully listening to the Royal Architect, the Duke appointed a new commission, composed of Michele Bertini and Giovanni Pacini, in a letter dated 4 March. Their task was to assess Nottolini's work and identify the cause of the cloudy waters [19].

Nottolini's management of the works received a positive evaluation from the commission, while several technical remarks were directed at the first commission [20]. The Royal Architect was thus relieved of the charges against him, and a royal decree dated 18 September 1833 reaffirmed Lorenzo Nottolini's direction of the works, also assigning him the task of drawing up the plans for the network's branches in the city. In the following years, various projects were undertaken to extend the water network by rebuilding several conduits, sewers, and fountains in the city. By 1838, the aqueduct, which Wiebeking described as one of the "most valuable monuments in Italy" [21], was completed. The Royal Architect himself was appointed to direct the maintenance of the structure, a responsibility he held until his death in 1851.

Following Nottolini's passing, the management of the aqueduct did not encounter significant difficulties. Architect Cesare Lazzarini, head of the municipal technical office, was appointed to oversee all aspects of the aqueduct. During this period, it became evident that extending buffer zones around the springs was crucial for their protection. Engineer Luigi Pasquini was therefore tasked with assessing the necessary land acquisitions and surveying the aqueduct's route from the *Serra vespaiata* to the San Colombano bastion, identifying all cadastral properties near the monument [22].

Over the years, numerous interventions were carried out, including pipeline repairs and replacements, adaptations to the distribution system, and studies and analyses on water quality, among others. As time passed and the population's needs evolved, the aqueduct gradually lost its functional importance while remaining a vital symbol for the Lucchese community. The water supply issues in Lucca and its surroundings were resolved after the First World War with the establishment of the civic aqueduct. In 1928, the decision was made to abolish the old water concessions from Guamo [23].

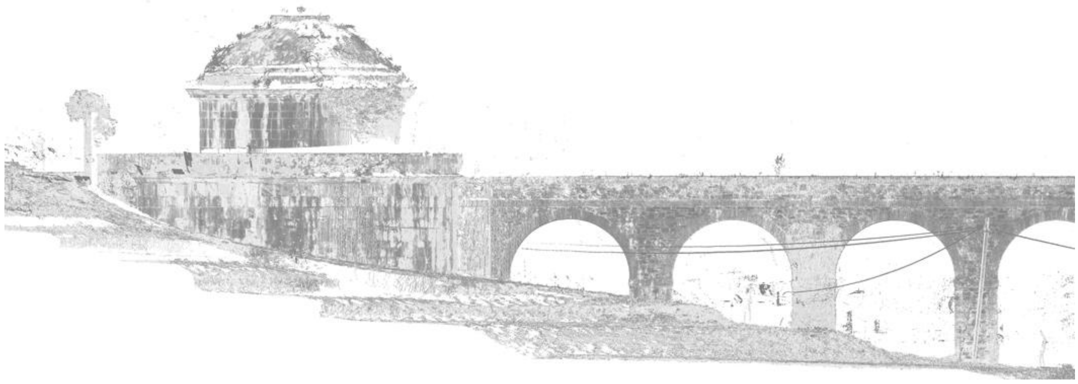

Fig. 3. Lucca, Tempietto di Guamo, orthoimage of the point cloud obtained from the laser scanner survey.

During these years, significant changes occurred to the aqueduct, particularly to the arched conduit. Between 1928 and 1932, the construction of the A11 motorway section connecting Florence to Pisa led to the demolition of a pillar and the construction of an archway that differed completely from the others, allowing passage for the new infrastructure. This same section was destroyed in 1944 by the retreating German army to impede the advancing Allied forces [24].

Later, in 1962, the motorway underwent expansion, necessitating the complete interruption of the previously modified section with the demolition of five additional pillars. This intervention caused structural issues, including noticeable horizontal cracking and longitudinal deformation [25].

Today, the aqueduct is accessible to the public via pedestrian and bicycle paths, allowing visitors to stroll along the arches and admire both the monument and the surrounding landscape. The municipality has also scheduled a series of interventions along the route to enhance accessibility [26]. Additionally, the area around the springs, known as the Golden Words, is open for visitors to explore.

3 Towards a digital twin

As evident from the preceding paragraph, the initial step in constructing a database involves systematically gathering all relevant documents related to the research topic. These may include historical documents, drawings, bibliography, published sources, photographic images, and contemporary records. This initial review of the state of the art is essential for structuring the database, understanding the types of documents to be archived, defining associated descriptive information (metadata), and estimating the volume of information to be archived to properly design the infrastructure.

The history of the Aqueduct of Lucca spans approximately three hundred years, encompassing numerous characters and events. Consequently, there exist many sources documenting the history of this artifact. The collected data has been organized into a database using FileMaker software, chosen for its flexibility in managing diverse types of data.

This approach also facilitates the future development of the final database structure in accordance with the FAIR principles for research data management. In recent years, information and documentation management has become a topic of crucial importance for the global scientific community. The FAIR principles (Findable, Accessible, Interoperable, Reusable) were developed to enhance the discovery, access, interoperability, and reuse of scientific data, thereby promoting a more efficient and transparent research ecosystem. These principles were initially published in a foundational document in 2016 and have since gained widespread adoption [27]. Managing information according to these principles not only enhances the reproducibility and transparency of research but also increases the value of the data itself, transforming it into a valuable resource for researchers and scholars. However, implementing these principles can be challenging, particularly with sources collected from public and private historical archives. These archives often have their own rules and regulations for publishing and sharing documents, which may conflict with the FAIR principles.

During the data collection phase, a direct comparison with the artifact was conducted concurrently. In the case of the Aqueduct of Lucca, the research group from the Department of Architecture at the University of Florence [28] performed various studies and analyses, including the acquisition of geometric and dimensional data. This involved conducting laser scanners and photogrammetric surveys to capture both morphological and material-colorimetric information.

From the resulting three-dimensional models, two-dimensional data were extracted and used to create thematic tables that explore the surface characteristics of the materials and their degradation. This step is crucial for developing a digital twin. The morphological-geometric information of the artifact forms an essential foundation for creating a comprehensive three-dimensional model that integrates all collected information, ranging from historical documents to detailed physical-material data and the current state of conservation of the artifact.

4 Conclusion

The methodological approach followed enabled a critical framing of the subject and identification of the distinctive characteristics necessary for creating a digital twin. Digital twins represent a powerful tool for establishing restoration guidelines and developing proactive conservation plans. However, there remain significant practical and theoretical limitations. Despite the concept being explored across various domains, a definitive and universally accepted definition of a digital twin remains elusive. Specifically within architecture and civil engineering, digital twin implementation is still in its nascent stages and primarily confined to experimental projects. Furthermore, defining a digital twin within the realm of built heritage conservation is particularly ambiguous [29]. In essence, a digital twin of an architectural artifact is a dynamic and interactive digital representation of the physical object, incorporating real-time sensor data, detailed three-dimensional models, and comprehensive structural and functional information.

The Aqueduct of Lucca serves as an exemplary case due to its formal simplicity that belies underlying complexities. As previously emphasized, this artifact, which spans a territorial-landscape scale, comprises various components differing in morphology, location, and function. Following the conducted studies and analyses, it is evident that the arched duct, undoubtedly the most monumental part of the structure, cannot be considered separately from the system of fountains with the *Serra vespaiata* designed by Nottolini, the small temples positioned at the duct's boundaries, and the network of city fountains.

Digital twins represent a significant advancement in the tools available for conservation and restoration, introducing new methodologies for managing and monitoring artefacts. However, it is essential to consistently refer to the foundational theoretical principles of restoration, various investigative methodologies, and established operational practices. This promotes a continuous dialogue between technical expertise and critical thinking.

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Part IV

Thematic Area 3 - Methodologies for Characterization and Damage Assessment

Investigation of post-restoration salt weathering at the mosaics of Dafni Monastery, Greece

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Abstract. Dafni is an 11th-century Byzantine monastery in the suburbs of Athens and a UNESCO World Heritage Site. The main church of the monastery preserves a unique complex of wall mosaics from the early Komnenian period (ca. 1100AD). The building suffered many structural problems, especially during the 1999 Athens earthquake, when the poor state of the building significantly affected the mosaics. Thus, a great restoration program was initiated. After the completion of restoration and conservation works in 2016, the mosaics presented soluble salt efflorescences and consequent disaggregation of a specific type of tesserae produced from marlstone. In order to investigate the pathology of the mosaics and study the weathering mechanisms a methodology was developed. The approach was based on non-destructive testing techniques (NDTs) combined with microclimatic monitoring and instrumental analysis. Data correlation from NDT and laboratory analyses suggests that weathering is a result of water retainment within the masonry. Depending on the microclimatic conditions, aqueous solutions evaporate through the marlstone tesserae, triggering salt weathering mechanisms.

Keywords: Dafni, mosaics, salt damage, IR thermography

1. Introduction

The Monastery of Dafni is one of the most important monuments of the Middle-Benzantine period, and it is included on the World Heritage List of UNESCO. The monastery was founded in the 6th century A.D. and its second constructional phase, dated to the end of the 11th century (around 1080), is the one preserved today. The main church is a cross-in-square octagonal-type building surmounted by a broad and high dome. The interior is decorated with superb mosaics, a unique, fine example of Middle Byzantine art. The mosaics are arranged on the dome, the cross-arms, the altar (sanctuary), and the eso-narthex of the church, while their scenes depict the life of Christ and the Virgin [1]. The building suffered much structural damage from earthquakes in 1889 and 1897, after which Italian artisans restored the mosaics and rebuilt the west side of the narthex and the dome. In 1955, a more extensive restoration

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project was undertaken by the Restorations Department of the Ministry of Culture, which continued until 1968.

Fig. 1: The mosaic of St. Averkios has been damaged on the face (left). Salt weathering occurred only on the marlstone while the surrounding tesserae has been completely unaffected (right).

After another damaging earthquake in 1999, the poor state of the building significantly affected the mosaics. The main problem was the structural damage to the building fabric that allowed moisture infiltration, triggering a series of decaying phenomena, such as cracking and detachments, reducing the preservation state of the mosaics. A great restoration program was initiated in 2000, which, apart from the structural reinforcement of the building, also aimed to protect the interior of the building from water penetration [2]. After the completion of restoration and conservation works in 2016, the mosaics presented soluble salt efflorescences and consequent disaggregation of a specific type of tesserae produced from marlstone, while neighboring tesserae and mortar joints were not affected at all. In order to investigate the pathology of the mosaics and study the weathering mechanisms, a methodology process was developed.

The present study was performed in three steps: 1) microclimatic monitoring, 2) thermographic survey, and 3) salts analysis. The approach was based on non-destructive testing techniques (NDTs) such as Infrared Thermography (IRT), Microwave Hygrometer combined with microclimatic monitoring, and instrumental techniques such as Digital Microscopy (CMOS), Scanning Electron Microscopy coupled with Energy Dispersive X-ray Spectroscopy and X-ray Diffraction.

The mosaics investigated are located at the dome, the altar (sanctuary), and the narthex of the church. The weathering phenomena were mainly observed on the mosaics at the altar and the narthex, where humidity accumulation has been identified in the past due to water penetration. It is important to mention that salt weathering was not observed before or during the interventions.

2. Non-destructive techniques survey of the mosaics

2.1 In situ passive thermography for the inspection of mosaics

Among the different non-destructive techniques, thermal imaging can accurately obtain subsurface features information without compromising the structural integrity of the inspected target. The above along with the non-contact nature of this technique have resulted to its wide use in cultural heritage conservation field [3, 4].

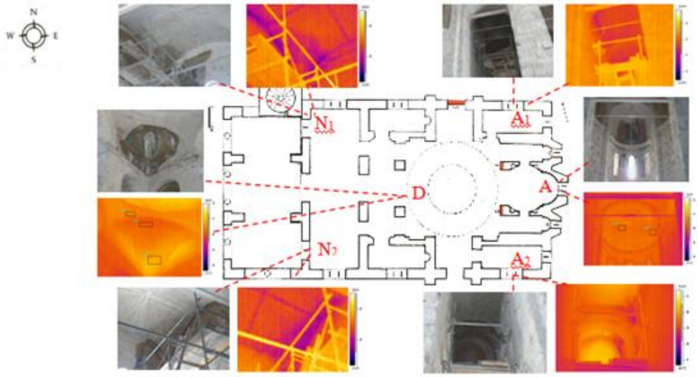

Fig. 2: Ground plan of the Monastery–Church at Dafni, illustrated by photos and thermographs.

The investigated areas of the narthex (N1, N2), the dome (D) and the altar (A, A1, A2) are highlighted with red dotted lines on the plan. Moisture was detected mainly on the stone masonry next to the mosaics of the narthex and on the northeast (A1) and southeast (A2) apses of the altar. The mosaics investigated on the angular imichonia of the dome (D) showed thermal uniformity.

In the present study, the passive infrared thermographic investigation was performed using a ThermaCAMTM SC640 long-wave thermography system (7.5 – 13 μm). The mosaics investigated are located on the angular mahonia (squinches) of the dome, on the apses of the altar (sanctuary), and on the upper walls of the narthex. The altar is situated at the east part of the church, while the narthex is located at the west end.

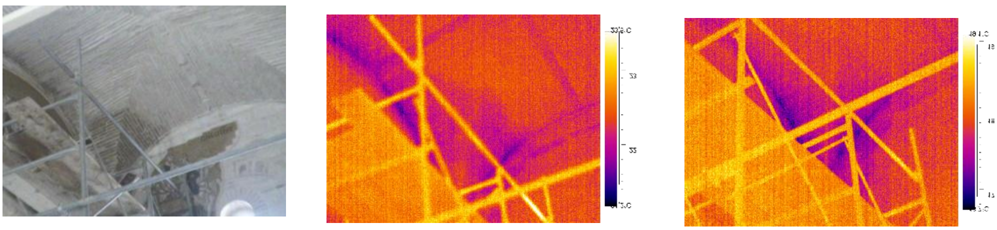

Fig. 3: View of the northwest area of the narthex, where the mosaics 'Betrayal of Judas' and 'Washbowl' are located (from left to right), visible light photo, thermal image taken in September and thermal image taken in November. The suspected wet areas are visible in these thermographs as blue, while dry areas are presented as red and yellow. The color bar shows the measured temperature range.

The wall-mosaic surfaces were scanned in segments by taking single IR images together with their visible-light photographs, as shown in Figures 3-4. The IRT tests were performed during daytime hours over repeated cycles for a six-month period (July-November 2016). The main

purpose of this survey was to monitor any spatial variations of the surface temperature distribution in order to detect moisture accumulation on the wall mosaics.
Representative thermal images and digital photos of some areas of the monastic building are illustrated together in Figure 3. Temperature variations were observed mainly on the stone masonry next to the mosaics of the narthex and on the apses of the northeast and southwest parts of the altar (sanctuary). Thermographic investigation of the mosaics on the angular imichonia (squinches) of the dome showed temperature uniformity that indicates the absence of moisture accumulation.
More specifically, the thermographic image taken on the north side of the narthex in September and November additionally showed thermal variations on the stone masonry, mainly next to the mosaic depictions of the 'Betrayal of Judas' and the 'Washbowl' (Figure 4). In Figures 4b,c, the suspected wet areas are relatively cool and clearly visible in these thermographs as blue areas, while warmer-dry areas are presented as red and yellow. Moisture was also detected on the stone arch next to the mosaic of 'Saint Avercios', which is located at the southeast part of the altar. Nevertheless, in this case, the suspected wet areas were limited (Figure 3 A2).

2.2 In situ moisture measurement of mosaics substrate

A non-invasive microwave hygrometer (Protimeter MMS) was used to measure the mosaic subsurface moisture content. The wall-mosaic surfaces were scanned by taking several spot measurements, as shown in Figure 5. The tests were performed during daytime hours over repeated cycles for a six-month period (July-November 2016). The main purpose of this survey was the monitoring of moisture levels in the wall-mosaics subsurface. The results were evaluated comparatively. Representative images and plots of moisture content data collected per test period are illustrated together in Figure 5.

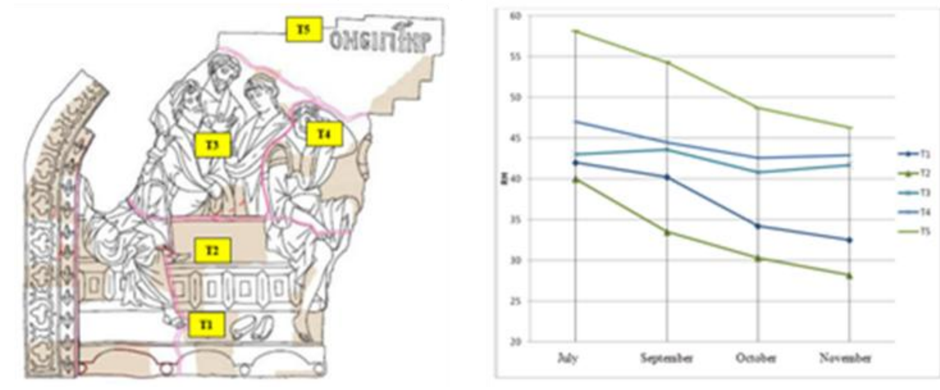

Fig. 4: Drawing of the mosaic 'Betrayal of Judas' where the areas measured are highlighted by yellow color (left) plot of RH data per test period (right).

Results obtained show that the moisture content of mosaics substrate is decreased gradually. The indoors atmospheric temperature and RH were continuously monitored for a six months period by means of data loggers. During this period there was no evidence of dew formation.

3. Salt Weathering Analysis

3.1 Microscopy and Microanalysis of salts

Microscopic in situ observations by means of digital microscopy (CMOS) revealed that the damaged tesserae partially maintain their external surface while the internal pore system has collapsed. The surrounding mortars were completely intact, and the salt efflorescence contained particles that probably derived from the disintegration of the tesserae. It was also evident that damage had already advanced to a point where consolidation would not be plausible. These preliminary fast observations dictated the sampling strategy. The samples from the damaged areas were analyzed by EDAX, while samples for crystallographic analysis were collected from surrounding efflorescence, which was clear of disintegration particles.

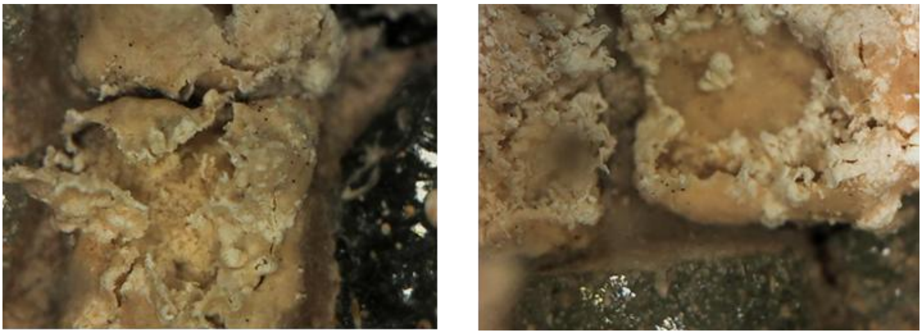

Fig. 5: Microphotographs of the marlstone tesserae show internal sand disintegration.

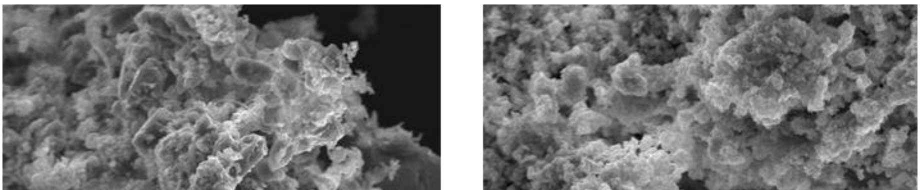

Fig. 6: SEM photographs of salt efflorescence from the damaged tesserae. The efflorescence is a mixture of tesserae disintegrated particles and sulphate salts.

Sampling took place at the maximum temperature, and thus, we presume that the majority of salt species were collected. The SEM-EDAX results from the damaged areas are consistent and reveal high concentrations of sulfur, mainly related to calcium, followed by magnesium and, in some cases, sodium. The salt crystals are amorphous and they are mixed with calcareous and quartz particles. The salt crystals were highly unstable during analysis, indicating hydrated species. The efflorescence samples from other areas contained various elements such as sodium, chlorine, and calcium. The results of the crystallographic analysis of the damaged areas identified gypsum, quartz, and calcite. XRD analysis of the marlstone tessera identified the presence of magnesite.

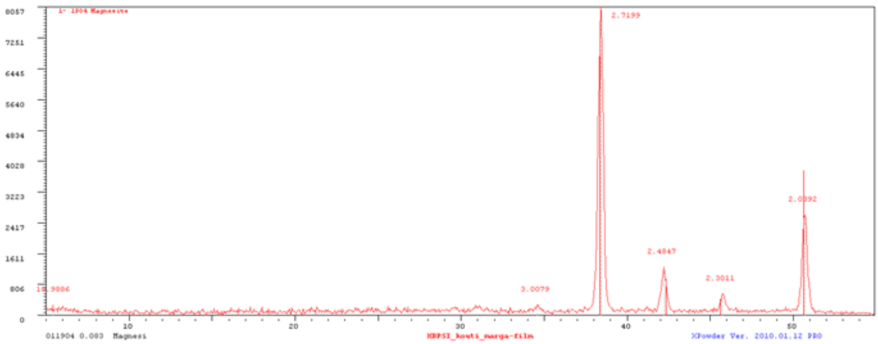

Fig. 7: XRD spectrum of undamaged marlstone identified the presence of magnesite.

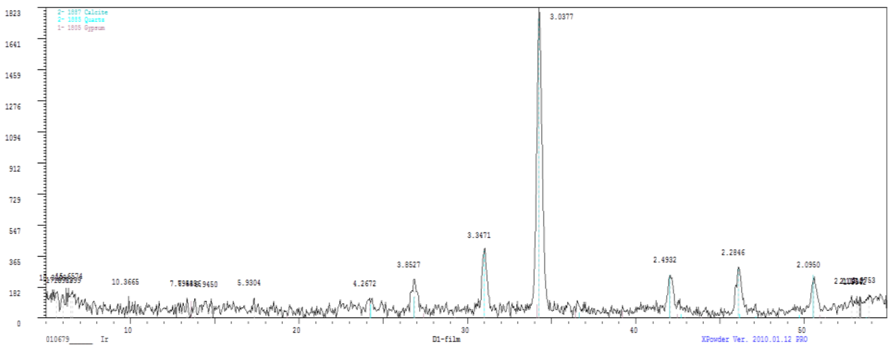

Fig. 8: XRD spectrum of efflorescence from damaged tesserae.

Discussion

Data collected from the IR- Thermography suggests the existence of areas on the interface of mosaics and wall masonry suffering from moisture accumulation. However, in order to gain the best possible understanding of the detected thermal effects and the best possible interpretation of the acquired results, a thorough knowledge of the history of the investigated structure is required. The affected mosaic areas present high moisture accumulation and have been treated in the past with cement grouts. Apparently, the climatic conditions during the restoration interventions of the monument have not been appropriately considered. Taking into account the scattered surface temperature variations of the wall masonry, we can assume the existence of water accumulation in the masonry during the restoration works. The moisture front has been directed towards the internal surfaces of the masonry, which evidently provided a more effective evaporation site.

The presence of gypsum in monuments is connected to various sources but mainly air pollution to external surfaces, pesticides, marine aerosols, and, in some cases, restoration cement [5]. In this particular case, the presence of sulfates is more likely related to previous restoration works since there is no evidence of any other active source. Sulfate contained in cement grouts can be released gradually over a period of time due to the delayed carbonation of ettringite [6]. Magnesium probably derives from the building materials while the investigated tesserae contain magnesite as well.

Although the monument is close to the sea, the presence of chlorides cannot be related to the direct deposition of marine particles due to insufficient entry points. Still, the infiltration of rain waters, which in this environment might be enriched in chlorides, could be an effective source. Contrary to sulfates, which usually crystallize first, chlorides might be transported to the surface more easily.ref The continuous presence of moisture and indoor evaporation have probably permitted the salts to transport toward the surface of the mosaics without whatsoever any evidence of damage in these areas.

The damaged areas are mainly affected by less soluble salts. Even in conditions with high moisture content of the building materials, their transport is quite restrained, and they present few crystallization and dissolution cycles. Still, gypsum presents several phase transitions to hydrated states. According to environmental data, dehydration, and rehydration cycles could take place before the occurrence of damage. Damage phenomena were evident at the surface, probably later than the initiation of internal disintegration. We can suppose that since no other efflorescence was evident in the proximity, the particular marlstone tesserae were porous enough to permit moisture penetration.

Nevertheless, salt infiltration alone does not necessarily justify the generation of damage. Porosity is the only evident variable that distinguishes marlstone from the adjusting tesserae, while the salt species and the environmental conditions are common. The pore structure of marlstone is theoretically responsible for the intensity of damage since it is composed of pores of various sizes [7], but more research is needed in order to argue soundly on the generation of damage. The conditions of damage gradually declined, and evidently, there were no other damage phenomena or salt efflorescence during the next period.

Conclusions

The investigation related very rapidly moisture content to damage phenomena, indicating the necessary actions ahead. The potential of more damage to other areas has been excluded providing time for further research. Also we avoided unnecessary and potentially harmful treatments like desalination or consolidation that are usually performed as immediate measures.

The mobilization of salts has been triggered by trapped moisture during restoration works. The moisture front has been directed to the internal surfaces even during high-temperature outdoor conditions, probably due to the external consolidation of the monument with low porosity mortars. The generation of damage that affected a specific tesserae type can be attributed to the hydration-dehydration cycles of gypsum. The role of the pore properties of the tesserae is also under investigation, although the surrounding tesserae consist of either glass or very low porosity stones.

Still, it was evident that damage was an individual incident that was receding with the evaporation of the trapped moisture and probably it would not occur periodically. Thus no

further interventions like desalination or cleaning needed to take place. The environmental conditions are still monitored and thermography investigations will take place in longer intervals for precautionary measures.
Post treatment evaluation is necessary in extended conservation works. This evaluation must depend on fast and reliable techniques in order to avoid damage phenomena. Especially in the case of salt damage which can act undetected under the surface of the monument, evaluation should take place immediately after the completion of conservation. Evaluation should definitely include fast temperature readings like digital thermography as well as selective moisture investigation since they can easily detect non-uniform areas and alterations that might be indicative of potential problems.

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Evaluation of salt weathering in stone using a new test procedure: a comparative laboratory study

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Abstract. Exposure to natural weathering and deleterious agents poses a significant risk to traditional porous building materials, like stone and mortar, with salt crystallization featuring as a prominent degradation mechanism. Despite the existence of standardized laboratory tests to assess the salt crystallization resistance of stone, the international scientific community still seeks more reliable and reproducible alternatives. In this framework, RILEM TC ASC-271 recently recommended a novel accelerated test procedure for assessing the resistance of natural stone and fired-clay brick units against salt crystallization. This study assesses RILEM's recommendation by comparing results from laboratories in Cyprus and the UK on a particular lithotype. The interlaboratory results show similar mass losses, with higher values reported with an increase in the salt concentration used. Micro-destructive cutting tests adopted to locate the salt crystallization front at the end of the procedure revealed layers of increased resistance behind the evaporation surface of the test specimens because of pore clogging. The reproducibility of the results reported and the efficiency of the micro-destructive cutting techniques employed in mapping the salt front suggest that the new test recommendation may be used effectively in the lab to predict damage due to salt crystallization in natural stone.

Keywords: Salt crystallization, Natural stone, Micro-destructive tests, RILEM.

1 Introduction

Salt crystallization is among the most damaging weathering phenomena affecting building materials [1, 2], leading to profound and often detrimental effects on the structural integrity and aesthetic value of historic monuments. Throughout history, civilizations have grappled with the challenges posed by salt-induced weathering, as evidenced by the weathered facades of ancient structures and the gradual erosion of monumental sculptures.

The sources of soluble salts are diverse and ubiquitous, ranging from natural, such as saline soils, sea spray, and airborne pollutants, to anthropogenic activities and biological agents [3, 4]. Salts infiltrate building materials during construction or are deposited in them over time, remaining dormant until the right environmental conditions (temperature and relative humidity) trigger their activation. Upon activation, soluble salts may crystallize within the porous matrix of building materials, exerting significant pressure on pore walls [5] and leading to cracking, spalling, and overall deterioration [6, 7]. This process is exacerbated by cyclic wetting and drying, as well as fluctuations in temperature and humidity. The manifestation of salt crystallization, whether as visible efflorescence on material surfaces or concealed sub-florescence within pores, presents unique challenges for conservators and heritage professionals. Efflorescence, while often regarded as visually unsightly, is generally considered less harmful compared to sub-florescence, which can lead to pore clogging and irreversible damage. Early detection of sub-florescence is crucial for implementing timely conservation interventions and mitigating the long-term effects of salt crystallization.

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Despite the existence of standardized laboratory tests for the assessment of salt crystallization resistance of natural stones, researchers worldwide are continuously seeking reliable and reproducible alternatives. In this framework, RILEM TC ASC-271 recently recommended a novel accelerated test procedure for the assessment of the resistance of natural stone and fired-clay brick units against salt crystallization [8].

In this paper, the authors follow the aforementioned salt crystallization test protocol and carry out an inter-laboratory comparison using a specific lithotype, aiming to assess the efficacy of the recommended test procedure. Additionally, this study delves into innovative methodologies of micro-destructive testing to spatially map the progression of salt crystallization, thereby facilitating a more comprehensive examination of salt distribution within stone substrates. Through the advancement of knowledge regarding the dynamics of salt crystallization, the authors aim to contribute to the development of effective strategies for safeguarding heritage materials for future generations.

2 Materials and Methods

2.1 Materials and Sample Preparation

Lympia stone, extracted from the broader Lympia village region within the district of Larnaca in south-eastern Cyprus, was used in this study. XRD analysis confirms that the composition of this stone is almost exclusively calcitic, with minor traces of quartz. The stone exhibits a notable open porosity > 40%, a unimodal size distribution and a capillary absorption coefficient ca. 140.5 $g/m^2s^{1/2}$ [9].

The RILEM TC 271-ASC protocol adopted for sodium sulfate (Na_2SO_4) salt crystallization testing involved six core specimens (50±0.5 mm diameter and 50±0.5 mm height) for each laboratory; these were meticulously prepared in Cyprus with precision drilling techniques to minimize substrate damage. After drying and sealing to maintain their moisture content, the specimens in each lab underwent an accumulation phase, during which they absorbed Na_2SO_4 solution at different concentrations through capillary action, as shown in Table 1. This was followed by a propagation phase consisting of four cycles, each lasting three weeks. During each cycle, the specimens were subjected to specific environmental conditions, including temperature and humidity control. Damage assessment after each cycle involved detailed photographic documentation and categorization based on established atlases. Total material loss was quantified post-test, providing valuable insights into the impact of salt crystallization cycles.

Table 1. Summary of the specimens tested and the concentration of solution used.

Sample ID	Salt concentration solution	Laboratory setting
L1CY	5% Na_2SO_4	University of Cyprus, Cyprus
L2CY		
L3CY		
L4CY	10% Na_2SO_4	
L5CY		
L6CY		
L1UK	5% Na_2SO_4	Newcastle University, United Kingdom
L2UK		
L3UK		
L4UK	10% Na_2SO_4	
L5UK		
L6UK		

2.2 Micro-destructive assessment techniques

The scratch tool and the Drilling Resistance Measurement System (DRMS) were used to locate the salt crystallization front at the end of the test. The two aforementioned micro-destructive techniques follow the same principle of operation, determining the resistance of a material to either scratching or drilling;

the result in both cases is directly related to the mechanical properties of the test specimen. Both techniques had previously been used for the evaluation of a range of stone properties [10], and to provide key information on the assessment of stones in situ [11]. They have also been utilized for the evaluation of the mechanical properties of mortars [12, 13, 14], whilst they further seem to offer new paths for understanding salt distribution patterns and assessing the extent of salt-induced damage within porous materials [15, 16, 17].

The scratch tool operates by creating shallow grooves with incremental depth (d = 0.01-2 mm) on a specimen's surface, using a 10 mm wide polycrystalline diamond compact (PDC) cutter. During the test, both the normal (F_n) and tangential (F_t) components of the force acting on the cutter are recorded (see Equations (1) and (2)); ε signifies the intrinsic specific energy, and ζ denotes the ratio of vertical to horizontal force on the cutting face [18].

$$F_t = \varepsilon w d \quad (1)$$

$$F_n = \zeta \varepsilon w d \quad (2)$$

In this study, all specimens underwent an initial rectification through successive shallow grooves made by the machine's PDC cutter to level their surfaces. Subsequently, five consecutive scratches of constant depth (d = 0.05 mm) were made on each specimen (Fig. 1a). The forces (F_n and F_t) recorded during these scratches were utilized to estimate the average total cutting force (F), which was then plotted against the PDC cutter's position.

The Drilling Resistance Measurement System (DRMS) comprises a drilling machine and a computer for synchronous processing, visualization, and data storage. The system is equipped with a diamond drill bit and measures the drill position, the penetration force, and the rotational and penetration speeds.

In this study, measurements were conducted using a 5 mm diameter twist diamond drill bit with a rotational speed of 600 rpm, a penetration rate of 10 mm min^{-1}, and a depth of 10 mm. Three holes were drilled on each sample (Fig. 1b) to determine the average drilling resistance, reflecting the force reacting to the drill bit's weight or thrust.

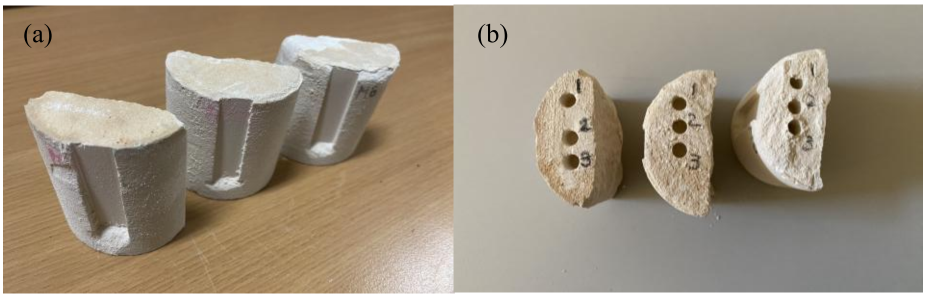

Fig. 1. Samples subjected to micro-destructive tests: (a) scratching groove; (b) drilling holes.

3 Results and Discussion

A summary of the macroscopic (visual) observations made during the test is provided in Table 2. Table 3 lists the damage type, severity and mass losses reported during this interlaboratory study.

The results indicate significant similarities in terms of visual inspection, damage type, severity, and mass losses. Moderate damage was reported for all specimens contaminated with the 5% salt solution; this was mainly evidenced through a powdery surface due to efflorescence. In contrast, severe damage occurred in the specimens contaminated with 10% Na_2SO_4; this appeared as loss of surface cohesion and bursting due to sub-florescence.

The comparable average mass losses reported in the two laboratories for samples treated with either 5% or 10% Na_2SO_4 salt solutions underscore the consistency and reliability of the experimental procedure adopted. The lab in Cyprus obtained an average mass loss of 0.72 g for samples treated with 5% w/w Na_2SO_4 salt, while the one in the UK obtained an average mass loss of 0.65 g for the same samples. Higher mass losses were reported for the samples treated with 10% w/w Na_2SO_4 salt, as expected: 3.70 g in the laboratory in Cyprus, compared to 3.81 g in the laboratory in the UK.

Table 2. Macroscopic (visual) observations on specimens contaminated with Na_2SO_4.

Sample ID	Reference	Accumulation	Propagation				End of test
			Phase 1	Phase 2	Phase 3	Phase 4	
L1CY							
L1UK							
L2CY							
L2UK							
L3CY							
L3UK							
L4CY							
L4UK							
L5CY							
L5UK							
L6CY							
L6UK							

Table 3. Damage type, severity of damage and material loss.

Sample ID	Damage type	Severity	Material loss (g)
L1CY	Efflorescence, Crust, Powdery	Medium	0.90
L1UK	Efflorescence, Crust, Powdery	Medium	0.69
L2CY	Efflorescence, Crust, Powdery	Medium	0.66
L2UK	Efflorescence, Crust, Powdery	Medium	0.65
L3CY	Efflorescence, Crust, Powdery	Medium	0.60
L3UK	Efflorescence, Crust, Powdery	Medium	0.62
L4CY	Bursting with sub-florescence	High	3.43
L4UK	Loss of surface cohesion with sub-florescence	High	4.01
L5CY	Bursting with sub-florescence	High	4.22
L5UK	Loss of surface cohesion with sub-florescence	High	3.68
L6CY	Bursting with sub-florescence	High	3.45
L6UK	Loss of surface cohesion with sub-florescence	High	3.73

The cutting resistance patterns depicted in Fig. 2 and Fig. 3, arising from the scratch tool and the DRMS, were utilized to identify alterations, such as pore clogging, in the microstructure of the salt-contaminated samples compared to the reference ones. Following salt contamination, a prominent peak was observed with the scratch tool ca. 0-2 mm behind the evaporation surface of the specimen contaminated with 10% salt solution. Albeit such a peak was not evident in the case of the sample contaminated with the 5% salt solution, the intensity of the overall scratching resistance was increased in both groups of contaminated samples (compared to the reference).

The cutting resistance peaks observed in the DRMS tests demonstrated peaks ca. 0-1 mm behind the evaporation surface of both groups of salt-contaminated samples, irrespective of the salt solution concentration used. These were more pronounced in the samples contaminated with the 10% salt solution. Since such peaks were absent in the reference samples, one may safely assume that they are attributed to pore clogging caused by the accumulation of salt crystals behind the evaporation surface of the salt-contaminated samples.

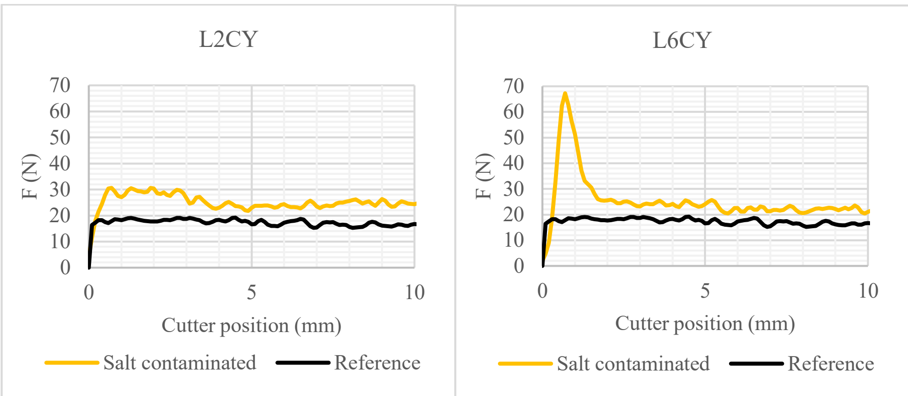

Fig. 2. Average scratch tool patterns for indicative salt-contaminated and reference samples (refer to Table 1 for sample code and description).

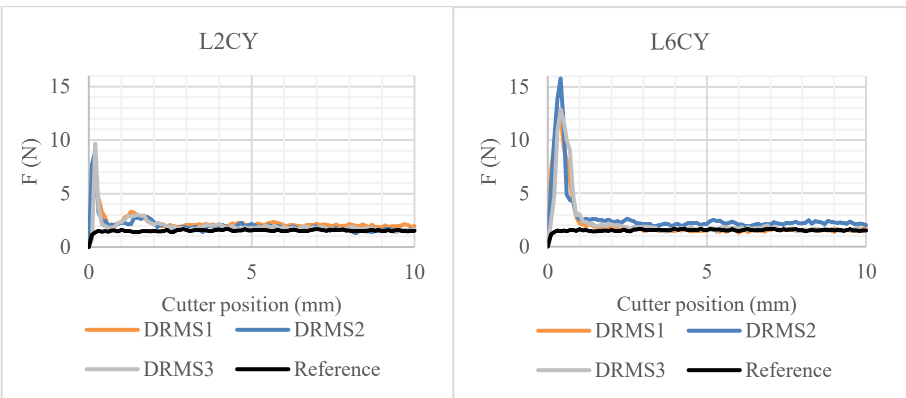

Fig. 3. DRMS patterns for indicative salt-contaminated and reference samples (refer to Table 1 for sample code and description).

4 Conclusions

This research focused on evaluating the salt crystallization test protocol recommended by RILEM TC-ASC-271, through interlaboratory comparison of results on a specific lithotype. The findings suggest notable similarities in the visual inspection and the mass losses reported by both laboratories after the test, thus confirming the reliability and reproducibility of the new test method.

Furthermore, this research concentrated on the use of two micro-destructive cutting techniques for the analysis of salt distribution in stone. These revealed the presence of significant peaks in cutting resistance ca. 0–2 mm behind the evaporation surface of the salt-contaminated specimens. Such peaks were absent in the reference samples and may thus be attributed to the tendency of Na_2SO_4 to crystallize near the evaporation surface of limestones, essentially leading to pore clogging. The versatility and efficacy of both micro-destructive techniques hereby used in assessing salt distribution in limestones render them valuable tools for preventive conservation. Especially, the DRMS could be employed on-site in monuments and historic structures to identify pore clogging before it escalates, thus serving as an early warning system for conservators to implement remedial actions and prevent damage from sub-florescence in masonry materials.

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Non-invasive pigment identification of post-Byzantine wall paintings from 11th century Monastery of Daphne in Athens (Greece)

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Abstract. This work is the first systematic research study to acquire information on the pigments and the painting technique and assess the conservation status of the post-Byzantine wall paintings in the Byzantine Monastery of Daphne (Attica, Greece). A combined non-invasive methodology including Portable X-Ray fluorescence (XRF), portable Fourier Transform Infrared Spectroscopy (FT-IR), multi-spectral imaging (MI) and digital microscopy (DM) was employed *in situ*. The identification of pigments hematite, goethite, green earths, carbon black, calcite, massicot and the creation of the wall paintings by different artists in different time periods were confirmed. MI and DM images gave useful insight into the conservation status of the wall paintings, revealing surface ware with microcracking, loss of color and original material as well as parts of the underdrawing of the painting.

Keywords: Non-invasive techniques, XRF, FT-IR, Multispectral imaging, Digital microscopy, post-Byzantine wall paintings, pigments, painting technique.

1 Introduction

Historical paintings are regarded as a main part of human culture and one of the oldest forms of artistic expression. The characterization of pigments, binders and materials employed is essential for the understanding of historical value paintings and provides information on the painting techniques, the supply and production of pigments from raw materials as well as community connections. In recent years, the accurate determination of the artwork state and indication of previous undocumented restoration or conservation works contribute to the planning of future conservation procedures [1-4].

Non-invasive techniques are a group of powerful tools with a minimal impact on the artwork, to obtain a large amount of data for the characterization of materials as well as for the diagnosis of damage and the assessment of maintenance interventions. X-ray fluorescence (XRF) and Fourier-transform infrared spectroscopy (FT-IR) are non-invasive, well-established and rapid techniques, allowing analytical information without causing damage to the artwork. XRF provides an immediate determination of the elemental composition of materials as it performs surface and in-depth analysis. The portable FT-IR version is a useful diagnostic tool for organic and inorganic compounds, including binders, pigments and the painting technique. In addition, digital technologies are effective and suitable to produce satisfactory results in representation and visualization [4-10].

The present research work aims at the identification of pigments on post-Byzantine wall painting which are dated back to the 11th Century and originate from the Byzantine monuments of Monastery of Daphne, located in Athens, Greece. The Monastery of Daphne is one of the most important Byzantine monuments of Greece, inscribed in UNESCOs' World Heritage List. Their great archaeological and artistic value did not allow any sampling, settling the need for a strictly non-invasive investigation. Therefore, a combined non-invasive analytical methodology was employed involving portable XRF, FT-IR, MI, and DM to acquire information on the pigments, the painting technique before the restoration of the paintings and assess their conservation status.

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1.1 Description of the wall paintings-historical data

The Daphne Monastery is located on the axis of the ancient road that led from Athens to Elefsina, in the area where the traveler Pausanias in the 2nd AD century mentions that there was a building enclosure and within it a temple dedicated to the god Apollo, as well as a stoa or similar building with columns [10, 11]. The main church of the monastery is called "Katholikon" and belongs to the octagonal type. It was built on an original early Christian church dating back to the 6th century AD. The position of the temple was strategically importantas the pagan mystics of the Eleusinian Mysteries passed through this point since ancient times [12].

The wall paintings are related to events in the life of Christ and the Virgin, as well as individual figures of archangels, prophets, saints, martyrs and bishops. The scenes and individual figures are characterized by grace and fluidity of movements, restrained and contemplative expressions on the faces of the saints and love for the natural environment, symmetry and harmony. The lower section of the walls was covered with beautiful marble slabs, which were replaced by wall paintings of mediocre quality in around 1650 [10,13].

2 Materials and Methods

2.1 *In situ* measurements of wall paintings

In this study, four wall paintings were examined from the Katholikon Church (see Fig.1). The measurement spots were selected with the criterion of the greatest coverage of the color palette and accessibility restrictions imposed by the location of each wall paintings. Color measurements were divided in white, yellow, red, green, blue, orange, brown, pink and black impressions [10].

2.2 Portable Digital Microscope (DM)

A Dino-Lite Edge Digital Micro-scope AM7915MZT-EDGE was used for the microscopic observation of the wall paintings. This is 10 cm long and is equipped with an automatic magnification ranging between 10 and 220×, a 5-megapixel resolution sensor, a light polarizer, 8 switchable LEDs, an extended depth of field and an extended dynamic range system. All the images were acquired by DinoCapture 2.0 software.

2.3 X-Ray Fluorescence (XRF)

In situ measurements were initially performed at multiple spots of all painted areas by a Bruker-AXS Tracer III-V portable XRF spectrometer. The instrument is equipped with a rhodium tube from which X-rays are emitted and a Peltier-cooled, silicon PIN diode detector, operating at 40 kV and 15 μA from an external power source for 200 live seconds using a filter composed of 1 mil titanium (Ti), and 12 mil aluminum (Al). The setting for the X ray tube eliminates the Rh L to assure that the trace elements could be detected in the raw spectrum. Elemental and quantitative analysis were performed using the S1XRF and ARTAX spectra software developed from Bruker-AXS.

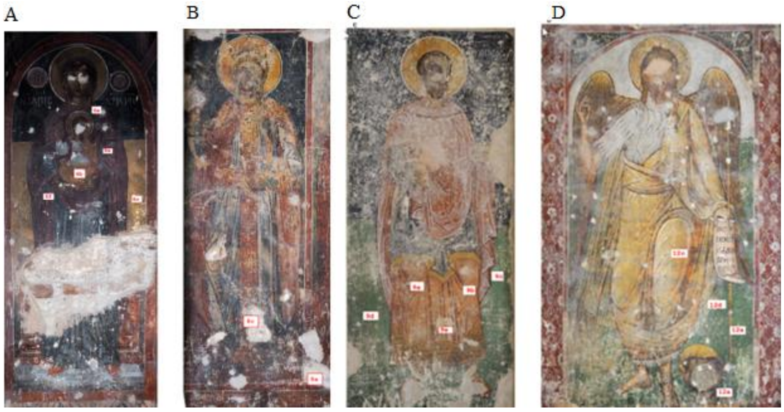

Fig. 1. Wall paintings originating from the Katholikon representing A) Virgin (No.6), B) Figures of Holy women (No.8) C) Agios Kosmas (No.9) D) Agios Ioannis Prodromos (No.12) and the relative measurement spots (Photos from the research team record).

2.4 Portable Fourier Transform Infrared Spectroscopy (FT-IR)

The Agilent 4300 Handheld FTIR spectrometer was applied for *in situ* measurements of wall paintings. This analytical method provides information on the chemical composition and molecular structure of materials. In paintings, highly informative analytical responses are frequently obtained through FTIR spectroscopy both for organic and inorganic compounds, such as binders, varnishes, and pigments.

2.5 Multispectral imaging (MI)

The wall paintings were analyzed by MUSES9-MS spectral camera, that addresses information in a wide spectral range from UV (370 nm) to IR (1000 nm). The camera integrates a spectral band tuning mechanism for selecting or for fully automatic scanning of up to 12 spectral bands. Innovative image filtering allows for the real-time display and side-by-side review of several megapixel-size spectral images. The camera was placed at a height of approximately 1.5 m from each wall painting. Vis and IR images obtained were processed with Adobe Photoshop CC program to correct contrast, tone and other parameters. Due to the lighting conditions in the interior of the monument, as well as accessibility restrictions, it was not possible to take images in the UV spectrum [10].

3 Results and Discussion

There are various rapidly developing non-invasive techniques for the analysis and evaluation of artworks. The methodology developed in this work included the following techniques [1,4, 6,10]:

Step 1 - Visual inspection. It was applied with the naked eye, providing information about the final stages of deterioration, such as cracks, discolorations.

Step 2 – In-situ application of DM. The obtained images provided a high level of detail, acquiring information for the nature and morphology of the varnish and color layers.

Step 3 – In-situ application of XRF. The elemental composition allowed the identification of the pigments in the surface layers and the underlying preparation layers (substrate).

Step 4 – In-situ application of FT-IR. The analysis offered valuable information on pigment and binding media as well as the painting technique.

Step 5-In-situ MI. The images provided information on the conservation state of the wall paintings, including surface damages such as microcracks, loss of color impressions, color fading, detachments, flaking, and losses of original material.

3.1 Macroscopic investigation and DM

The examined wall paintings showed considerable damage, which has probably been caused by blows with sharp objects and led to a loss of paint and substrate material. The damage in the region of eyes and face and graffiti with names and words was observed in most wall paintings. The handheld DM was used to capture images with a high level of detail to obtain information regarding the nature and morphology of the varnish and color coatings [10,14]. The application of the color in layers to achieve a lighter tone is evident (see Fig.2). The loss of the painted surface and substrate was observed in all wall paintings. Microcracks in the orange and black colors were also indicated. In several cases, black grains were observed in the paint layer, which were related to carbon dust used to modify the shade.

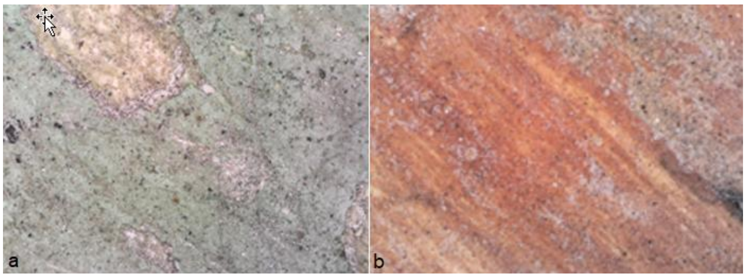

Fig 2. Digital image of green color impression of wall painting No. 9 (left) and orange color impression of wall painting No. 8 (right).

3.2 XRF analysis

XRF spectroscopy was employed in the characterization of the pigments present in the four wall paintings. The presence of calcium was indicated in white color impressions. The use of lithopone and lead white were excluded due to the absence of zinc, barium and lead [4,8,10].

The black pigments of carbon (such as bone black, carbon dust, etc.) can be indirectly identified due to the absence of other elements. Moreover, the use of black carbon pigments, separately or in mixture, was a common practice in post-Byzantine painting. The use manganese dioxide (MnO_2) for black hues was not indicated, as manganese was not detected.

XRF analysis of the yellow color impressions revealed significant concentrations of Fe that indicate the presence of hydrated iron oxide as a primary component of the pigment (yellow ochre) in the form of goethite [$FeO(OH)$] or limonite [$FeO(OH)\cdot H_2O$]. In wall painting No. 9, the same pigment in a mixture with red ochre was apparently applied to achieve darker orange hues. The results of brown colors showed the detection of high concentration of iron and lead (see Fig.3A). Manganese was not present, indicating the pigment is a mixture of yellow ochre with yellow lead oxide (PbO) and carbon [10, 14].

The red impressions of the wall paintings were investigated. In most cases, the high concentrations of Fe detected indicated the use of hematite (Fe_2O_3) as the pigment for rendering the red color impression. In the wall paintings No. 8 and 12, the presence of lead leads that the mixture of red ochre with red lead pigment such as minium or white lead carbonate was employed. The dispersion of red pigments on a white substrate (such as calcium hydroxide) conducts to pink shades (see Fig.3B).

XRF analysis of the green color impressions showed high concentrations of iron, while copper was barely detectable. Thus, it appears that copper pigments were not used for the green impressions but probably green earth pigments such as celadonite or glauconite.

The most common blue pigments were azurite, ultramarine and cobalt blue. Sodium was not detected by XRF, thus the use of ultramarine cannot be confirmed. Additionally, its high cost does not align with the specific wall paintings. The absence of copper also rules out the use of azurite. Therefore, the combined use of carbon black, oxides, and calcium carbonate to achieve blue color impressions has been reported extensively [9,10,14].

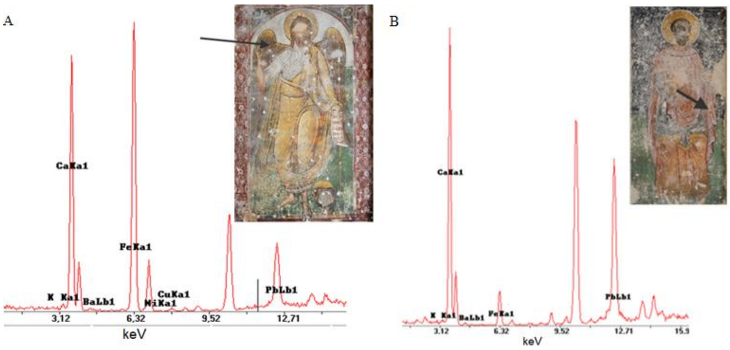

Fig. 3. XRF spectra A) Brown color impression of the wall painting No. 12. B) Pink color impression of the wall painting No. 9. The arrows show the points of measurement.

3.3 FT-IR spectroscopy

FT-IR spectroscopy is a successful and established technique for characterizing organic materials in historical wall paintings. A representative FTIR spectrum obtained at the point of the red color impression of wall painting No. 6 is shown in Fig. 4. The presence of calcite and clay pyrite compounds was observed, while organic materials were also detected. Thus, in the spectral region of 700 – 1490 cm^{-1}, the absorption bands are attributed to the stretching and bending vibrations of carbonate ions CO_3^{2-}. These data are also confirmed by XRF analysis, indicating that the *fresco* technique was applied in the construction of the examined wall paintings and calcite was used for white color impressions. The intense absorption bands at 1029 cm^{-1} are attributed to the in-plane stretching vibrations of the equatorial Si-O bonds of kaolinite [9]. The weak bands (2960 -2850 cm^{-1}) are attributed to the asymmetric and symmetric stretches for methylene (CH_2) and methyl (CH_3) groups related to the organic matter. The bands at 892 and 1466 cm^{-1} are attributed to the asymmetric out-of-plane bending and stretching vibrations of $v_2CO_3^{2-}$. The band near 1790 cm^{-1} is attributed to the v_1+v_4 combination mode of calcite. The band near 1652 cm^{-1} is attributed to the vC=O carbonyl stretching vibrations of the main and secondary amide groups as well as to the in-plane δC-N bending. It is the most characteristic absorption band of proteins in FTIR spectra and is strong evidence for the use of an organic binder (e.g. egg) for the preparation of paints. This is also confirmed in the FT-IR spectra of red, green and blue color impressions in the examined wall paintings. The presence of the bands corresponding to amides II and amides III absorptions (1211 and 1571 cm^{-1} respectively) combined with the peak of the absorption band assigned to vC= O vibrations (1692 cm^{-1}) in lipid molecules showed the employment of a mixed wall painting technique involving both *fresco* and *secco* [1,4,8,10].

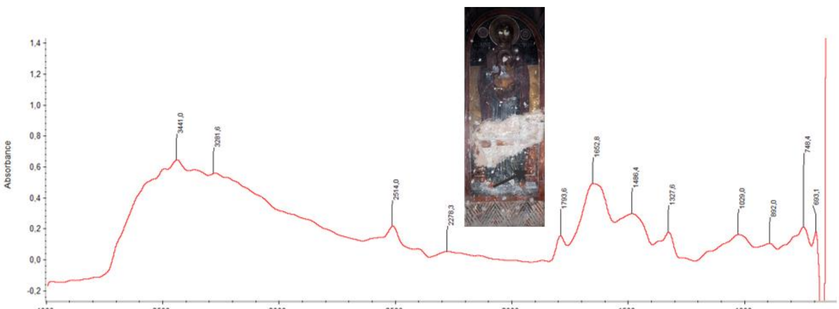

Fig. 4. FT-IR spectrum of red pigment in the wall painting No.6.

3.4 Multispectral imaging

The obtained Vis and IR images were processed with Adobe Photoshop CC to improve color tone and contrast. The combinations of shots with different filters were also made to highlight features that are not clearly visible in the visible spectrum. In wall painting No. 8, the state of conservation is poor with color surface losses, abrasions and fillings. Combining the Vis image with the IR (with increased contrast) using Photoshop's “Luminosity” mode gave Fig.5b, the scribbles, particularly in the folds of the clothes, are highlighted. From the false-color IR image (Fig. 5.c), the pigments for the yellow color impression on the vestments and halo of the left Saint have potentially similar composition as well as in the red color hues [1, 8-10].

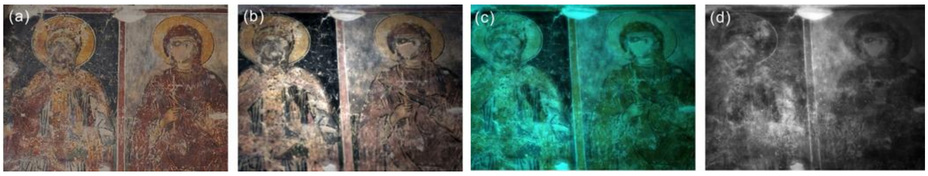

Fig. 5. Multispectral images of the wall painting No. 8: (a) Visible (Vis) image, (b) Mixed Vis and IR images (luminosity), (c) false-colour IR image, (d) UV images.

4 Conclusions

A non-invasive methodology with portable instrumentation such as XRF, FT-IR, DM and MI was employed for the characterization of post-Byzantine wall paintings (12th Century) of the Monastery of Daphne, Athens. The color palette of the post-Byzantine artists was found to comprise typical *fresco* pigments such as calcite, red and yellow ochre (hematite, goethite). For brown impressions, a mixture of umbra, yellow ochre and massicot was employed. Celadonite or glaucophane was used for green color hues while carbon black, iron oxides and calcite were applied for blue color impressions. The employment of a mixed wall painting technique involving both *fresco* and *secco* was indicated. The wall paintings were created in different time periods by different artists due to the use of various pigments for the same color impression combined with different stylistic characteristics. MI combined with DM and direct visual observation revealed surface damage such as microcrack grids, loss of color impressions, color fading, peeling, flaking, and loss of original material. Finally, the combined non–invasive methodology could be regarded as a valuable tool for the identification of the pigments, the painting technique and the existing state of conservation of the wall paintings.

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The application of non-destructive imaging techniques for the study and revelation of sketches under the whitewash layers of the interior walls of the House-Museum of Giannoulis Halepas, in Tinos Island, Greece

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Abstract. Giannoulis Halepas (1851-1938) is considered one of the most famous yet tragic sculptors in Greece. During his tumultuous life, he produced several masterpieces that are currently exhibited in galleries, museums, and public places in Greece. After his death, his house on Tinos Island was declared a historical monument and turned into a museum. The walls of his house, layer by layer, cavity by cavity, bear traces of his unending inspiration, as he used to sketch on them. The current paper presents the systematic investigation and research of the interior walls of the upper floor of the House-Museum of Giannoulis Halepas in Pyrgos, Tinos Island, in order to locate, digitally reveal and highlight sketches the artist made on the walls, as well as investigate the possibility of mechanically revealing them, by exploiting both non-destructive imaging techniques, such as infrared reflectography and USB microscopy, and micro-destructive ones, such as sections.

Keywords: House-Museum Giannoulis Halepas, Imaging techniques, Wall paintings, Graffiti, Sketches, Infrared reflectography, InGaAs camera, Sections, USB microscope.

1 Introduction

Giannoulis Halepas or Chalepas (1851-1938) is considered one of the most famous yet tragic sculptors in Greece. Following his father's steps, he joined him in his marble sculpture business in Pyrgos, Tinos Island. His talent was so evident that in 1873, after finishing the School of Arts, the Panhellenic Foundation of Evangelistria Tinos gave him a scholarship for postgraduate studies at the Academy of Arts in Munich. There, he excelled and was awarded several times in exhibitions. When he returned to Greece, he received commissions, the most famous of which being the sculpture of the deceased Sofia Afentaki, also known as Sleeping Female Figure, situated at the 1st cemetery of Athens. From 1877 onwards, Halepas experienced multiple nervous breakdowns during which he destroyed most of his works. This disease and his consequent behavior finally led to his institutionalization in 1891 by his own parents. Following his father's death in 1901, he was allowed to return to Tinos Island and live with his mother. After his mother died in 1916, Halepas slowly started to do sculptures again, but the years of inaction, in combination with his heavy mental state, were evident in the variety of sculptures he produced. Whereas in his early life and career, his work was characterized by academic qualities, his later years' creations bear the stigma of the heavy burdens he experienced.

Halepas was well known for the numerous sketches he produced as a result of his endless inspiration [1]. He would sketch on any surface he could find, such as loose paper, books, bills, wood, and even on the interior walls of the house he lived in [2,3]. However, the walls were whitewashed over and over again. Elderly people in Pyrgos, still remember having seen the sketches of Giannoulis Halepas in his

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house. As the years passed, Halepas relocated to Athens, where he spent his final years at the house of one of his nieces. After his death, his house in Tinos was bought by the Panormos Municipality in 1950, was declared a historic monument [4] in 1968, and in 1977, it was turned into a museum dedicated to Halepas. The house is a well-built, two-story building with a kitchen and utility room downstairs and the main spaces upstairs. It constitutes an almost typical example of a Tinian house. Upstairs is the hall, which is the everyday room for the family, and two smaller chambers are used as bedrooms.

By most scholars, the artist's work is divided into three periods, defined by critical turning points in his life: (a) the youth period, from 1870 to the onset of his illness in 1878, which follows the patterns of his academic apprenticeship, (b) the period from 1918, when he started working again after his mother's death, until 1930, when he lived and worked in Tinos and (c) the last years of his life, from 1930 until his death in 1938, which he lived and created in Athens. There are no known sketches of the artist's first period. From the second and third periods, apart from the sculptures, a large number of sketches have been preserved.

Sketches known to belong to the second period were made mainly in nine account books of his father's marble sculpting business. As they are sketches made exclusively for himself, they are often overlapping, restless, and fragmentary (Fig.4 right). It is not easy to distinguish stylistically the sketches of the second and third periods, although the ones from the third period are more specific, the line is more stable, the composition is clearer, and the themes are more understandable [5].

Halepas' sketches help approach problems associated with his sculptures. By sketching his subject from many angles, one can see his preparation of a project, its completion, and even solutions that he rejected. We learn about works that are not saved or about works that he ultimately did not realize in three dimensions. His sketches present his preferences or reveal his amazing visual memory.

As historic graffiti are the object of research for a long time [6], the purpose of the present study was the systematic investigation and research of the interior walls of the upper floor of the House-Museum of Giannoulis Halepas, in Pyrgos, Tinos Island, in order to locate, digitally reveal and highlight sketches the artist made on the walls, as well as investigate the possibility of mechanically revealing them. This paper includes the preliminary results of this effort.

2 Methods and Instrumentation

Non-destructive imaging techniques, optical microscopy, and physicochemical methods were applied on the interior wall surfaces according to existing protocols [7] and using instrumentation from ARTICON Lab (Advanced Research Technologies for Investigation and Conservation), the Wall painting conservation Lab and the Stone Conservation Lab from the Department for Conservation of Antiquities and Works of Art, University of West Attica (UNIWA). The non-destructive techniques that were applied were visible photography (VIS), thermal imaging (TI), and SWIR thermography/infrared reflectography (IRRef). Macroscopic and microscopic observation was also carried out, and in areas where the plaster facilitated the procedure, incisions were made so that outer layers would be removed to enable the possible detection of sketches on inner layers.

Visible Photography. Apart from reference photos, the surfaces were also captured with raking light to highlight the relief, the texture, the multiple color coatings, the cracks, and the detachments of the mortar. In cases of special interest, details were photographed with a macro lens. A Nikon D800 FX-format camera with a 36.3 megapixel CMOS sensor (59.4 x 84.1 cm/ at 200 dpi) was used, in combination with lenses micro NIKKOR 60 mm f/2.8D and NIKON AF-S NIKKOR NANO CRYSTAL ED 24-70mm.

SWIR Thermography/ IR Reflectography (SWIR/IRRef). These methods in the region of 900-1700nm were applied to exploit the penetrating ability of infrared radiation, and to study the existence of sketches at the greatest possible depth. InGaAs AVT Goldeye P-008 SWIR Cool thermographic camera with Peltier cooling system was used in combination with KOWA 16mm/f1.4 and 50mm/f1.4 CCTV lenses as well as NIKON micro NIKKOR 60mm f/2.8D. Consecutive images of an approximately 20x20 cm^2 area were acquired from the floor up to a height of two meters on all the walls of the hall. In room 1 and room 2, the images corresponded to a 40x40 cm^2 area. This led to the acquisition of more than 1500 exploitable images that covered more than 36 m^2 of wall surface.

Examination with a visible microscope USB Dino-lite. In situ microscopic examination using a digital polarizing measuring microscope (USB Dino-lite AM7013 MZT with a resolution of 2592x1944 was used for the study and documentation of the micromorphology of the surface of the walls, their stratigraphy, and the understanding of their pathology.

The images obtained were organized by wall and by method and were processed with image processing software PS Adobe Creative Cloud, Photoshop CC, 2015.0.0 Release, Version for Macintosh for the best extraction of the information.

Macroscopic examination was carried out in order to determine the areas where there were indications of the existence of sketches and to obtain information about the construction technology and the state of preservation of the walls and plasters. The figure presents the floor plan of the upper floor of the House – museum "Giannoulis Halepas," bearing all the walls that were examined with the aforementioned techniques (pink).

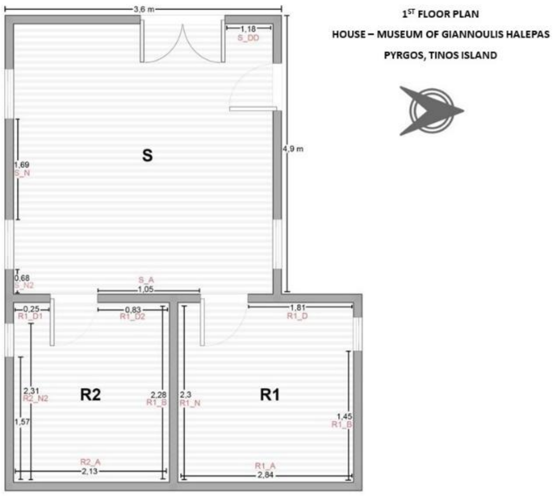

Fig. 1. The plan of the upper floor of the House – museum "Giannoulis Halepas".

3 Results and Discussion

3.1 Hall (S)

The microscopic examination established the presence of at least 11 layers of coatings (fig.2 left), from the first one, a rough, solid white layer and then a succession of light green and white layers of small thickness and finally two yellowish layers, of newer synthetic constitution. The thickness of the coatings varies even in different areas of the same layer. Characteristic traces of a paint roll can be seen in the two uppermost layers, and lime aggregates in several of the older white layers. Sketches are scattered in layers 2,3,4,6,7, and 9, without excluding their presence in other layers as well.

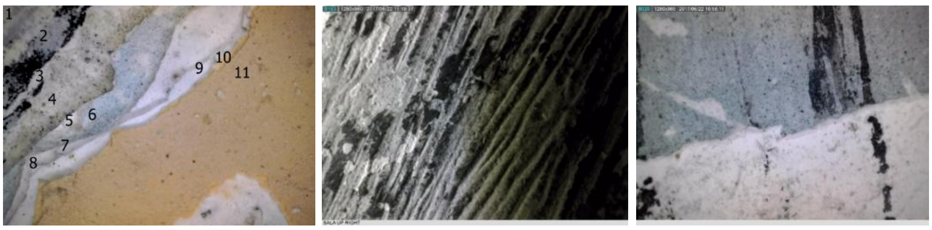

Fig.2. Left: Succession of layers on the west wall. Middle: Discontinuities due to the existence of different sketches on different layers. Right: Discontinuities due to the rough morphology of the surface.

The consistency of the layers varies by strata and area, such as in areas affected by humidity, where also disintegration and poor cohesion appear. There is also limited cracking of the upper coating layer in areas of loss, possibly due to the effect of moisture or another external factor, such as solvent from cleaning material. The sketch lines generally have a writing width of 2-4 mm and appear to have been made of a soft black material (probably pencil or hard charcoal) [5]. Their imprint shows characteristic discontinuities in the deposition of material due, on the one hand, to the morphology of the substrate and, on the other, to the nature of the material (fig.2 middle and right). This fact makes them particularly vulnerable to mechanical damage.

Examination of the walls by SWIR/IRRef showed that the west wall, to the left of the main entrance when entering the building, bears the largest and most complete sketch, which depicts the face of a figure (fig.3). The revealed sketch bears the characteristics of Halepas' sketches, with discontinuous lines that form the eyes, the nose and possibly the outline of the face, while around it there are irregular lines that may be parts of another composition of the artist, similar to his usual way of sketching [1,5,8]. Sketches visible to the naked eye are shown in intense black, while the ones revealed under the whitewash are recorded in a grayer tone, which is found to be a continuation of the visible ones, forming a face and possibly pleats of a cloth.

Fig. 3. Left: Visible image of part of the west wall. Middle: Infrared reflectogram of the same part, which reveals the sketch of a figure's head. Right: One of Halepas' sketches, which belongs to the National Gallery-Museum of Alexandros Soutsos and shows the similarities in the artist's style [5].

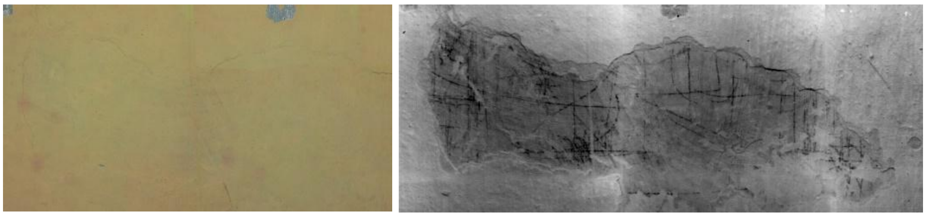

Fig.4. Left: Visible image of part of the east wall. Right: Infrared Reflectogram of the same part of the east wall, which reveals several geometric designs.

The other walls display both individual small sketches and larger ones. Although the sketches are fragmentary, as on the rest of the walls of the hall, it is nevertheless possible to distinguish a rich writing, as if they were parts of a larger composition. On the east wall (fig.4), several geometric designs were revealed, which depict a circle divided vertically, horizontally, and diagonally with a note on the side that rests on the plane line.

3.2 Room 1 (R1)

Room 1 presents visible sketches limited in areas where test sections were made and in areas of damage where observation and examination was made macroscopically and with the help of a digital microscope as well as with the help of raking light. Six (6) test sections were studied, but only one showed the presence of sketches. The east wall bears extensive repairs, leading to the hypothesis that if there were sketches on this wall, they would be of a limited extent.

Microscopic examination showed the presence of 6-14 layers of whitewash. The loss at the bottom of the south wall makes its deep stratigraphy visible. Thus, the wooden partition, layer of clay mortar, white plaster, and stratigraphy of plaster can be distinguished from the first rough, solid white layer and then white layers of thin lime. In the same area, filling with newer mortar was also observed.

Fragmentary lines were observed on the south and east walls, limited and in poor condition, due to the detachment of the lime coatings that act as a substrate and eventually cover them. Typical examples of sketches developed on two different whitewash layers were also observed, which proves the presence of losses in the past as well. Traces of black color of limited extent were observed on the east and north walls, which are,, however, also distinguishable with the naked eye. These lines are covered by a thin layer of plaster of such a small thickness that it allows transparency and, by extension, the reading of the lines.

3.3 Room 2 (R2)

Room R2 is next to room R1, where ten (10) test sections were studied, five of which established the presence of sketches between layers (fig.5). All surfaces are plastered with the same good quality mortar about 3-4 mm thick that was found in the other two rooms (Hall and room R1). No sketches were found in this layer.

Up to 10 plaster layers were observed in room 2: white lime plasters, a bluish one, and finally, the newer yellow plaster that presently covers the walls of the Hall and room 2. The thickness of the coatings varies even in adjacent areas of the same layer. Sketches were observed on the south, east, and north walls, some of which extended over more than one layer, which proves that when they were created, the wall was already damaged and was not a single-layer substrate.

Fig.5. Presence of sketches found during the test sections.

Adhesion between layers of coatings varies depending on the area and materials and is judged from good to weak in areas with humidity problems. The more recent yellow layer is in a good state of preservation.

SWIR/IRRef was unable to reveal underlying sketches on the wall surfaces, except for a few traces on the south wall, although there was evidence of their presence from the exploratory sections (see above). This fact is due, on the one hand, to the great depth of the layers and, on the other hand, to the fact that, as can be seen from the exploratory sections, the possible sketches are found in inner layers.

4 Conclusion

On the walls of Halepas' house, superimposed layers of whitewash and, in some cases, with the addition of pigments, have been found, and the maximum number of counted layers was 14. The thickness of the whitewash layers varies even in different areas of the same layer. There are discontinuities and differences in the texture of the coatings, which document their – in many cases – fragility and poor cohesion. This fact makes them particularly vulnerable to mechanical damage and stress.

Sketches were revealed, which are found to span in more than two layers. As a result, layers of whitewash covering a sketch are difficult to remove. Therefore, it is not possible to define one layer against another, but the whole of the walls seems to constitute a kind of palimpsest, which could only theoretically be partially revealed, since mechanical cleaning is not recommended due to all the aforementioned characteristics of the plasters. In a total of twenty-two test sections, traces of sketches were found in seven of them (a percentage of 31.8% on the number of sections and not on the unit area). The largest number of sketches was revealed in the Hall. In these cases, the sketches were the richest in lines and design details so that they could be further digitally editable and exploitable. In the remaining areas of the walls, although several sketches were found, they were fragmentary, incomplete, and limited in extent in relation to the entire surface of each wall. Sketches are seen as single or superimposed lines, sometimes interrupted due to loss of overlays, sometimes the same sketch spans more than one layer, sometimes the sketch is composed of individual design lines coming from different layers so that they do not show logical continuity resulting in limiting the possibilities of revealing a composition as a whole. It is further pointed out that the non-detection of sketches with the followed methodology does not imply the non-existence of sketches, as is typically demonstrated in Room 2, where despite the indications of the exploratory sections for the existence of sketches in several underlying layers, it was not possible to locate them with infrared radiation, mainly due to increased thickness of coatings.

In conclusion, the research to identify and reveal possible sketches in underlying plastering of the interior walls in the Giannoulis Halepas House-Museum highlighted a complex and multiparametric issue with important aspects that need special attention due to the historical and possible artistic value of the sketches and the importance of the building. The axes of further approach to this issue can be (briefly):

– dealing with humidity problems, monitoring the condition of masonry and plastering, and investigating how to deal with detachments so that there are no material losses.

– taking protective measures to preserve and monitor the state of preservation of the sketches. Actions in these two directions are considered primary.

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Non-invasive pigments identification in Macedonian Tomb of Hellenistic period

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Abstract. The aim of the present research work is the characterization of pigments using non-invasive spectroscopic techniques. Ten samples found at excavations in a funerary monument located in East Macedonia and dated in the Hellenistic Period were investigated. Five powder samples were collected from the painted surface of the caisson ceiling of the tomb and five parts belonged to the painted surface of the detached entablature of the tomb. Due to the high historical value of the samples and their small quantity (granules), they were investigated using X-Ray Fluorescence (XRF) and VIS-Near IR Fiber Optics Diffuse Reflectance Spectroscopy (FORS). The measurements were conducted in every color impression (white, red, yellow, blue, black) of the samples in order to determine the elemental chemical composition and analysis of the spectral reflectance of their pigments. Additionally, the Fourier Transform Infrared Spectroscopy (FTIR) technique was performed to characterize the organic binders and painting technique used. Scanning Electron Microscopy with Energy-Dispersive X-Ray Analysis (SEM-EDX) was also applied to show the architecture, identify image particles and determine elemental analysis. Calcite, cinnabar, red ochre, yellow ochre, Egyptian blue and amorphous carbon were identified. Furthermore, marble was the major component of the architectural surfaces of the tomb. Regarding the painting technique, the detection of a high concentration of calcium and the presence of a protein-binding medium in all samples likely suggests the employment of a mixed wall painting technique involving both *fresco* and *secco*.

Keywords: non-invasive techniques, X-Ray Fluorescence, VIS-Near IR Fiber Optics Diffuse Reflectance Spectroscopy, Fourier Transform Infrared Spectroscopy, Scanning Electron Microscopy with Energy Dispersive X-Ray Analysis, pigments.

1 Introduction

Color is not only an aesthetic element but also an important characteristic that helps us interpret and understand works of art. Pigments represent a component of high artistic, technical or historical significance in artworks. The chemical and mineralogical characteristics of pigments can provide information on technological knowledge, the painting techniques, the capabilities in the supply and production of pigments from raw materials and ancient community connections, material degradation. Therefore, pigments are indicators of human thinking and technical choices. [1-4].

The application of analytical techniques for the complete characterization of materials and the information gathered from historical and archaeological studies in artworks are crucial in order to apply the proper methods of restoration–conservation. The use of traditional analytical methods to investigate archaeological works is not feasible due to the strict regulations for the protection and preservation of cultural heritage. The uniqueness and value of archaeological artifacts necessitate the application of non-destructive or micro-destructive techniques. Recent technological developments have led to the employment of non-invasive methods for *in situ* elemental analysis, preserving the object or sample untouched and in place during measurements. Among the predominant and well-established methods employed for this purpose are XRF, SEM-EDX, XRD, FORS, FT-IR, and Raman spectroscopy. These techniques provide a wide range of information, including elemental composition, microstructural analysis, and characterization of molecular structures [1, 5-8].

The aim of the present research work is the characterization of pigments using non-invasive spectroscopic techniques. Ten samples found at excavations in a funerary monument located in East Macedonia

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and dated in the Hellenistic Period were investigated. Due to the high historical value of the samples and their small quantity (granules), they were investigated using XRF and FORS. The measurements were conducted in every color impression (white, red, yellow, blue, black) of the samples in order to determine the elemental chemical composition and analysis of the spectral reflectance of their pigments. Additionally, the FT-IR technique was performed to characterize the painting materials (pigments and organic binders) and technique used. SEM-EDX was also applied in one sample in order to show the architecture, verify any possible significant morphological and chemical inhomogeneities among different points, and determine elemental analysis.

2 Materials and Methods

2.1 Samples

Ten samples found at excavations in a funerary monument located in East Macedonia and dated in the Hellenistic Period were investigated (Table 1). Five powder samples were collected from the painted surface of the caisson ceiling of the tomb and five parts belonged to the painted surface of the detached entablature of the tomb of headings. Additionally, the reflectance spectra of pigments in pure powder (supplied by KREMER) were recorded in order to provide a knowledge base on the pigments' spectral features and identify the pigments of the samples.

2.2 X-Ray Fluorescence

A portable XRF Tracer III-V (Bruker-AXS) was used for the non-destructive analysis of samples. It was equipped with a rhodium tube from which X-rays are emitted and a peltier-cooled, silicon PIN diode detector, operating at 40 kV and 15μA from an external power source for 200 live seconds using a filter composed of 1 mil titanium (Ti), and 12 mil aluminum (Al). The setting for the X- ray tube eliminates the Rh L to ensure that the trace elements can be detected in the raw spectrum. Elemental and quantitative analysis of the XRF spectra were performed using the S1XRF and ARTAX spectra software developed from Bruker-AXS [1,2,9,10].

Table 1. Description of samples collected from the painted surface of the tomb

Sample	Origin	Color impression
df1	Caisson ceiling	Deep red
df2	Caisson ceiling	Deep dark blue
df3	Caisson ceiling	Yellow
df4	Caisson ceiling	Deep blue black
df5	Caisson ceiling	Deep dark blue
D1	Detached entablature	Red
D2	Detached entablature	Blue
D3	Detached entablature	Light Yellow
D4	Detached entablature	Dark brown
D5	Detached entablature	White

2.3 VIS-Near IR Fiber Optics Diffuse Reflectance Spectroscopy

Measurements were also performed on all samples using a portable Ocean Optics, USB4000-VIS-NIR Fiber Optic Reflectance Spectrometer. The instrument features a high-performance 3648-element linear CCD-array detector, installed with a multi-band pass order-sorting filter to cover the 350-1000 nm wavelength range, and a 25 μm entrance slit for optical resolution to 1.5 nm. The instrument is equipped with a QR400-7-VIS/NIR reflection bifurcated probe providing illumination and detection of diffused light from the same direction, an HL-2000 tungsten- halogen light source and a probe holder positioning the QR400-7 at 45^{o} for diffuse reflection in order not to include specular reflectance. The use of this device also allows one to guarantee a correct contact with the surface to be analyzed, to keep constant the sample-to-probe distance (about 4 mm), and at the same time avoiding external light contributions. Diffuse reflectance spectra were referenced against WS-1 Diffuse Reflectance Standard, provided by Ocean Optics, and guaranteed reflective at 98% or more in the spectral range investigated. Diffuse reflectance spectra were recorded in the range of 350-1000 nm. Spectral data treatment was performed with the SpectraSuite software (Ocean Optics) add-on for Origin [1,2,9,10].

2.4 Fourier Transform Infrared Spectroscopy

A ThermoScientific Nicolet 6700 Fourier Transform Infrared Spectrometer (FTIR), equipped with an Attenuated Total Reflectance (ATR) accessory, for the characterization of the pigment's molecular structure. Transmission IR spectra were recorded in the mid-IR spectral region 4000-400 cm^{-1}, at a resolution of 4 cm^{-1} and by collecting 120 co-added scans for each spectrum. The great advantage of the ATR technique utilized is that no sampling preparation is involved, enabling the obtaining the IR spectra of the samples in their native state without any KBr pelletization. Further data processing was carried out using the OMNIC 7.1 Software (Thermo Nicolet) [1, 2, 9, 10].

2.5 Scanning Electron Microscopy with Energy Dispersive X-Ray Analysis (SEM-EDX)

A FEI Quanta 200 Environmental Scanning Electron Microscope (ESEM), coupled with an Energy Dispersive X-Ray Detector (EDX) was used. During the microstructure analysis, three types of images were shown by the respective detectors: a) the secondary electron (SE) by the Everhart – Thomley detector (ETD), depicting morphology, b) the backscattered electron (BSE) by the Solid State Electron Detector (SSD), showing phase distributions and c) a mixed picture (mix) which was a digital combination of the former images. SEM imaging parameters, selected based on the overall quality of the image, were as follows: 30 kV accelerating voltage, magnifications up to x12000, and detector dead time of 5μs for each single image. The surface elemental composition and the assessment of the bulk elemental composition (derived from measurements on a fresh-cut surface of the fragment) were determined by the EDX detector using spot analysis locally at different selected spots of special interest and surface analysis (mapping) on the whole image. High-resolution images were obtained without gold or carbon coating, thereby enabling imaging of the sample close to its original state without requiring any pretreatment [1,2,9, 10].

3 Results and Discussion

The results obtained from XRF, FORS, ESEM-EDX and ATR-FTIR analysis of the collected microsamples led to the following observations and results regarding the identification of pigments, organic binding media and the technique applied for the construction from the painted surface of the caisson ceiling and the detached entablature of the tomb [11].

3.1 XRF analysis

The first step of the combined methodological approach was the elemental chemical compositions of the entire sample set from the painted surface of the caisson ceiling (df1-5) and the headings of the tomb (D1-5) by portable XRF. Strong peaks of K_{α} and K_{β} calcium (Ca) were revealed, indicating the presence of calcite ($CaCO_3$) and the application of *fresco* or *secco* painting technique for the creation of the wall paintings of the caisson ceiling of the tomb. The peaks of lead (Pb) and zinc (Zn) were attributed to impurities in the minerals of the pigments. The detection of K, S, P, Sr and Si were related to the soil [1,9,11].

In Fig 1a, the XRF spectra of the red color impression (df1) showed the presence of a high concentration of Hg, indicating the use of cinnabar (HgS). On the contrary, the red color (D1) from the tomb 's headings showed an intense peak of Fe, leading to the use of red ochre.

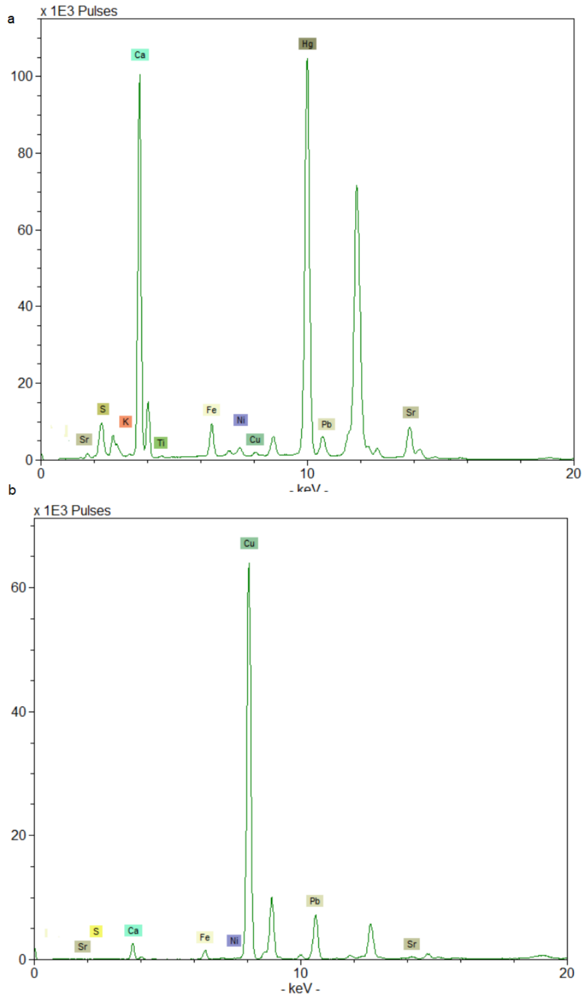

Fig. 1. XRF spectra of a) red color (df1), b) deep blue color (df2) samples.

The elemental analysis of blue color samples (df2, df4, and D2) identified high Cu content as the dominant element with a minor amount of Fe, leading to the use of a Cu-based pigment, such as azurite ($Cu_3(OH)_2(CO_3)_2$) or Egyptian blue ($CaCuSi_4O_{10}$, cuprorivaite). Additionally, the sample df5 with a deeper blue from the other two blue samples showed the presence of Cu and Hg (see Fid 1b).

The XRF results of the yellow color impression (df3) identified high Fe content, suggesting the presence of hydrated iron oxide, possibly in the form of goethite [FeO(OH)] or limonite [$FeO(OH)\cdot H_2O$] as the major component. The XRF chemical analysis results of the light yellow and white samples (D2 and D5) revealed the presence of high Ca content, suggesting the presence of calcium compounds. Moreover, in the dark brown color impression (D4), the high Fe content indicated the presence of yellow ochre [1,9,11-13].

3.2 FORS analysis

In the second step of the methodology, Vis-Near IR FORS was employed in all samples with the aim of non-destructive identification and characterization of their pigments. The study was based on the comparative analysis of the diffuse reflectance spectra obtained from the FORS measurements of the colored samples, with appropriate spectral reference databases of pigments developed in the laboratory, as well as reference spectra from the literature [1,9,11-13]. The white impressions were not analyzed as they exhibit a high maximum reflectance. The accurate identification of a pure pigment is based on the spectral characteristics. In ancient Greece, two materials were used for the red color impressions, cinnabar and red ochre. From the comparative spectral analysis of the red color sample (df1), it was observed that the curve presented a sharp positive slope near 600 nm, which is characteristic of cinnabar (Fig. 2a). Regarding the red color sample from tomb headings (D1), hematite was identified due to the sharp positive slope between 525 and 600 nm, a maximum near 760 nm and two absorption bands, a strong one at 485 nm and a weaker in the near-infrared (between 850 and 870 nm).

The diffuse reflectance spectra obtained from the yellow color impressions of the sample (df3) are presented in Fig. 2b. From the comparative spectral analysis, it was observed that the curves presented a typical S-shape, characterized by a positive slope between 500-580 nm and a broad absorption band (minimum) near 660 nm, coinciding with the reference yellow ochre spectral features. In addition, all spectra presented a weak shoulder between 450-480 nm and a broad absorption band near 930 nm which could be attributed to goethite [1-4]. For the light yellow impressions (D3), the reflectance spectra demonstrated a different shape from those analyzed above, implicating a mixture of yellow ochre and calcite. The aforementioned findings are in good agreement with the high Fe concentrations detected by XRF results and confirm the utilization of yellow ochre in the form of goethite for the production of the yellow color impressions [1, 9, 11-15].

The diffuse reflectance spectra obtained from the blue color impression (df2, D2) presented similar spectral features, especially at higher wavelengths, with the reference Egyptian blue curve. The spectra showed an S-shaped curve with two strong absorption bands of about 925 and 730 nm. Moreover, the sample blue color (df5) revealed the use of a mixture of cinnabar and Egyptian blue. The spectral characteristics of sample df4 and D4 didn't show any similarities compared to the reference pigments spectra.

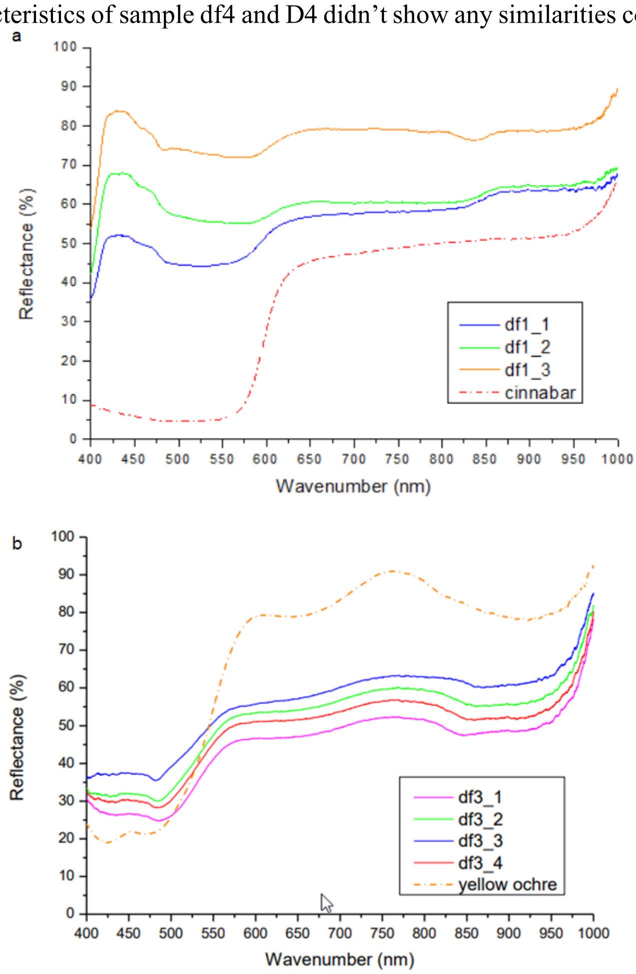

Fig. 2. FORS spectra of a) red color (df1), b) yellow color (df3) samples.

3.3 FT-IR spectroscopy

The third step of methodology employed FT-IR spectroscopy for the characterization of the pigments molecular structure, substrate and environment of all micro-samples. Due to the small amount of some samples, the corresponding FT-IR spectra were not conclusive.

The obtained spectra of the cinnabar sample (df1) presented the peaks at 3621 and 3401 cm^{-1} attributable to hydroxyl groups (Fig. 3). The peaks at 2977, 2921, and 2869 cm^{-1} correspond to the symmetric and asymmetric stretching vibrations of methyl and methylene groups νCH_3 and νCH_2, indicating the presence of proteins. The band appearing near 1867 cm^{-1} corresponds to the carbonyl stretching vibrations νC=O. Absorption bands of amides coupled to C=O are at about 1625 cm^{-1} (amide I), indicative of proteins.

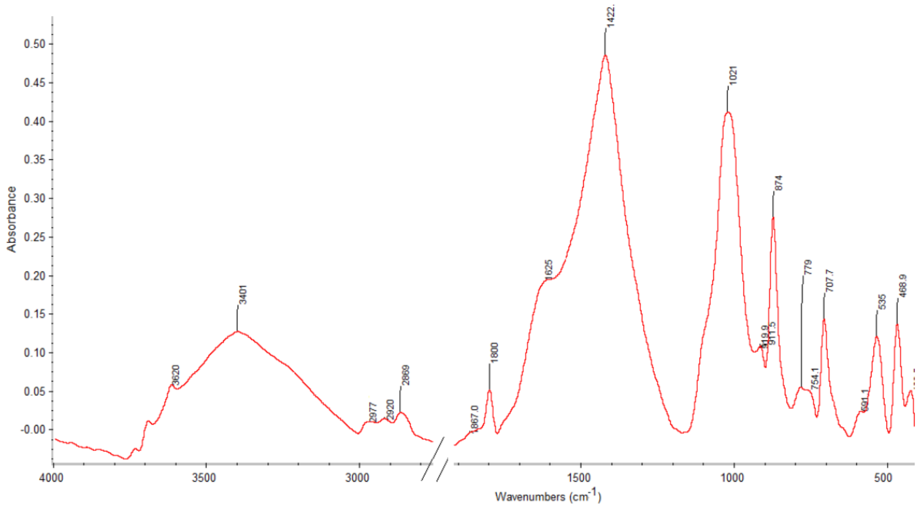

Fig.3. FT-IR spectra of red pigment cinnabar (df1).

The band appearing near 1867 cm^{-1} corresponds to the carbonyl stretching vibrations νC=O. The peaks at 1800, 1422, 874, and 708 cm^{-1} are attributed to calcite. The shoulder at 1100 and the peaks at 1021, 779, 754, 536, 469, and 434 cm^{-1} are attributed to the presence of kaolinite. The peak at 912 cm^{-1} corresponds to the bending vibrations of hydroxyl groups δOH or the bending vibrations δAl-OH of kaolinite. The peak at 591 cm^{-1} is due to the bending vibrations δSi-O, suggesting to the presence of quartz. It is well known that the red pigment cinnabar does not absorb infrared radiation in the range of 4000–400 cm^{-1}.

The FT-IR spectra of the blue pigment (df2) were almost identical to the red pigment, as calcite was the main component of these samples. Absorption bands at 1167, 1052 and 1000 cm^{-1} as well as the peaks at 756, 665, 588, 524, 479 and 420 cm^{-1} are related to Egyptian blue. From the similar FT-IR spectra of deep blue color (df4), it was determined that calcite was present in a higher proportion relative to Egyptian blue (Fig. 4). This indicates that a smaller amount of Egyptian blue was used and an additional pigment was added. Based on the dark color, amorphous carbon is a potential pigment.

In the analysis of yellow ochre (df3), the spectra showed similar characteristics to the other pigments. A distinct peak at 459 cm^{-1} is attributed to hematite or limonite or to the Fe-O bond vibrations of goethite. Additionally, these bands correspond to the bending vibrations of Si-O-Si bonds or the stretching vibrations of Al-O bonds in kaolinite [1,9, 11].

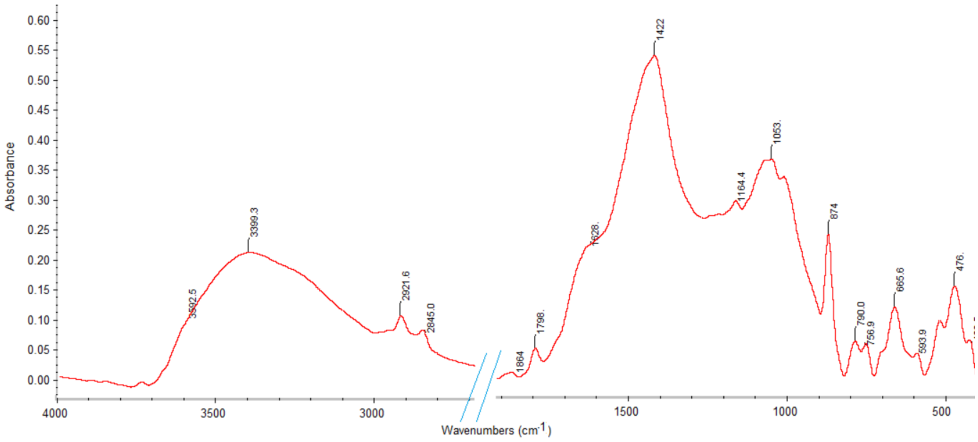

Fig.4. FT-IR spectra of deep blue color pigment (df4).

Based on FT-IR analysis, a combination of *fresco* and *secco* techniques may have been applied in the wall paintings due to the presence of calcite and the proteinaceous material. However, due to the degradation of the original compounds, a limited number of samples, or small sampling areas, complementary methods such as gas chromatography-mass spectrometry (GC–MS) or liquid chromatography-mass spectrometry (LC-MS) are required to determine the type of protein employed [1,9,11-16].

3.4 SEM-EDX

SEM-EDX is generally a useful tool for obtaining an overview of the morphological and elemental characteristics of the sample. The fragment D5 from the tomb headings was analyzed. Three types of images were obtained from the corresponding detectors: the LFD for secondary electrons, the SSD for backscattered electrons, and the mixed image. The chemical elemental composition was determined by the EDX detector using spot analysis at selected points and area analysis over the entire image. The surface layer was quite homogenous among different points.

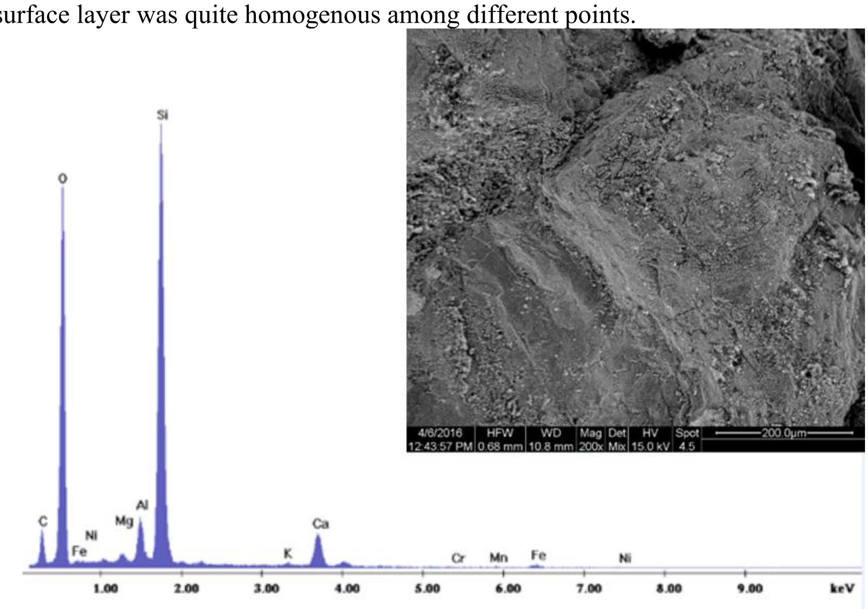

Fig. 5. SEM-EDX analysis on fragment, the EDX spectrum obtained from the area corresponding to Mix image.

The EDX chemical elemental analysis results revealed the presence of high Si content as major component of the sample (Fig.5). The strong intensity of the silicon, oxygen, aluminum, calcium, and carbon peaks in the EDX spectrum, along with the high weight percentages of these elements, lead to the conclusion that the fragment contains aluminosilicate compounds, primarily kaolinite due to the clay and calcite due to the marble [1,9,11].

4 Conclusions

The combination of the chemical elemental analysis results with the molecular information provided by XRF and VIS-NIR FORS, respectively, confirmed that the two spectroscopic methods were complementary, providing accurate identification of the pigments. Calcite, cinnabar, red ochre, yellow ochre, Egyptian blue and amorphous carbon were the applied pigments for the performance of white, red, yellow, blue and black color impressions. Regarding the painting technique, a combination of *fresco* and *secco* techniques was probably employed. Marble was the major component of the architectural surfaces of the tomb.

Finally, the obtained results confirm the combination of non-invasive techniques XRF, FORS, FTIR and SEM-EDX as a valuable, efficient and reliable tool for the investigation of cultural objects regarding the characterization/evaluation of materials, the decay patterns detection and assessment, where sampling is not allowed.

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Creating a dataset of digital images of Byzantine frescoes for analysis and classification using machine learning techniques

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Abstract. The methodology for creating a database of fresco images, mainly of the Macedonian School (13th-14th century), is presented here. This base will be used later for digital image processing for classification using machine learning. For this purpose, modern digital data analysis tools in Python were used. The collection of appropriate material, the digitization of images, the input of information and the categories examined are presented in detail, along with the tools used. One of the main problems of the research was that there were no open digital libraries to cover with images of the specific period examined, so the material gathered comes from corporate sources such as books, studies and collectors. After analyzing the art historical information from Byzantine frescoes not only for their measurability and reliability, but also for availability, a python application that manages the data as an object-oriented relational graph is created. This is a first approach to such material that combines easy-to-use tools with historical knowledge and provides a ready-to-use and development base.

Keywords: Byzantine art, Fresco, Macedonian School, Python, Dataset, Digital image processing

1. Introduction

In recent decades, there has been a leap forward in machine learning techniques in many fields such as medicine, science and art. The development and simplification of systems that manage data, graphics cards and ever-growing computer vision have contributed significantly to this. This study presents in detail the creation of a database consisting of color images of frescoes, mainly from the late Byzantine period, historical observations entered as categorical data and the organization of disparate material structured so as to be useful for further analysis. For this purpose, a system was created with open-source tools in Python that manages the data.

All stages are developed from finding the appropriate material, gathering information, and creating systems that manage files, up to and including the completion of the database that has the possibility of enrichment and development. This database will later be used by us for machine learning for classification. The purpose of this research is to make an approach to the classification of Byzantine wall paintings which we do not know for sure as to which artist created them. It essentially combines art history with computer vision and can be used as an additional tool for scholars.

Firstly, the research began with art historians collecting as much detailed information as possible about Byzantine art and more specifically about the last period of Byzantine fresco painting.

The data we collected is focused on:

- Consistency in the availability of historical data
- Ease of finding information
- Reliability/Objectivity of historical observations
- Possibility of using them as categorical data

Byzantine art from its beginnings (4th century) is a purely religious art, which introduced symbolism and spirituality into its subject matter. Thus, within the bosom of the church, art developed, evolved, matured and reached its peak in the last centuries of the empire (13th to 14th centuries) presenting works of exceptional dynamics and aesthetics. It is no coincidence that the specific period was called the "Palaeologan Renaissance" [1], as not only intellectual people gathered in the two great urban centers of the empire, Constantinople and Thessaloniki, and made them nuclei of philosophical and theological thought, but also, art flourished with now famous artists [2].

There were two main Schools that dominated at that time, the School of Constantinople as the capital of the empire, and the Macedonian School based in Thessaloniki which flourished artistically after the

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first fall of Constantinople (1204) by the Crusaders [3]. The general characteristics of art during the late Byzantine period can be summarized as follows [4]:

- Mainly mural art as the empire was in decline murals were more economical to make than mosaics made of precious and semi-precious stones
- Multiple compositions: the compositions are enriched with forms that frame the main characters of the works and tell a story
- Figures are not static but possess movement which is distinguished in the grace with which the clothes are drawn or in the limbs of the saints
- The background plays an important role in the performance, in contrast to previous centuries when the saints stood in front of a monochromatic, mostly blue or gold background. Architectural elements are presented which suggest a place, a place, interior or exterior. Central perspective, which was never a requirement of Byzantine artists, is inverted and architecture or objects are presented from multiple viewing angles
- Enrichment of the pictorial program with new themes such as the miracles of Christ, the lives of the saints and the life of the Virgin Mary
- Distortion of forms: lengthening of the faces and limbs -disproportion of the body which conflicts with their striving for standards from antiquity
- Expressiveness in expression in terms of facial expressions, limb movement and body posture
- The known, so far, names of the painters who worked at that time are Michael Astrapas and Eutychios [5], of George Kalliergis [6], of Manuel Panselinos [7], and of Michael Proelefsis, as either signatures and monographs have been found on monuments or historical references and notes in monastery diaries.

But there are a lot of works that we don't know who made them because there is no strong evidence. First, art historians through macroscopic observations have recorded and analyzed the technique, style and painterliness in rendering the works of the above artists and have speculated about the creators of the unsigned.

Then, after a thorough study of Byzantine art as a whole, the selection of the most important monuments of the Paleologan era was made based on the frescoes they contain. Thus, we ended up studying mural ensembles from Thessaloniki, Serbia, Mount Athos and Macedonia.

Analysis methods that take advantage of machine learning algorithms work best with large datasets. So, the goal at this stage is to collect as many photos of the frescoes as possible. Ideally, a digital archive of these works would meet the following criteria:

- there should be no distortion of the murals due to the shooting angle. This could be achieved by orthophotography or photogrammetry techniques [8]
- color fidelity to the original works through
- to be able to calculate the scale of the projects

Here comes the first and very important problem we had to face and that is that there is no open library with photos of Byzantine frescoes as there are correspondingly other periods of art from international organizations, museums, etc.. The private image collectors and research theses studied [9] met some of the basic criteria as they provided some information on image capture, equipment used, lighting, etc., but were incomplete in terms of specific criteria. The Byzantine art books, although rich in images, did not meet the specifications to be used as an exclusive document of the work they depict, as they did not provide scale information or the ability to correct the image's color. The material from the internet was photos from sites mostly of Byzantine churches and religious and historical content, which met specific requirements as they were intended for information. Such material was also not ideal because any attempt, either to control the shooting angle or to correct the color for uniformity

within the data set, could not be carried out. Additionally, scale is completely ignored as the images are presented in various sizes. For this research, material from the internet, private scholars of Byzantine art, research and studies that have been carried out in institutions such as the NTUA and Byzantine art books were used. As none of the sources could provide digitization to use as the primary source for a work, a system that can hold more than one representation of a work came up without considering anyone as the definitive source of truth for the work. With this focus on the quantity of samples per project and modern data augmentation techniques, the present material's deficiency in quality could be compensated for.

1.1 Implementation

In the present study, the following procedure was followed for the pre-processing stage of the data:

- Any processing done has been done exclusively with the derivatives of the original images, which are generated dynamically and not preserved with the original material.

- To achieve maximum flexibility in the selection of tools at each stage of pre-preparation, the application supports pre-preparation chains and temporary storage of the calculations made.

- The 'View' class creates a set of _Photos_ with a chain of edits,
- e.g. 'fp-patch_512'. Hyphens separate routines and underscore parameters. Each process corresponds to a class defined in 'process.py'.
- All intermediate steps are kept in '/derivatives' after their initial creation and are not recalculated unless deleted by the user. After it is created, the 'View' class maintains an 'items' parameter, a dictionary '{row_id: [image list]}', with derivatives for whatever photos we have supplied it for further processing. The class maintains its own Loader and access the data

From the Python libraries where used:
- NumPy manipulation of data in the form of arrays [10]
- Pandas, which allow importing data from various file formats and images are translated into large data tables [11]
- Matplotlib, which allows visual access to massive amounts of data [12]

After gathering 123 color images from Byzantine frescoes, in order to compile and utilize the information material that had been gathered, the entities are organized in a chart as follows:
- Picture: (Photograph), of a project. Where image data and Exif metadata are included, Project reference, ownership and usage rights
- Work: This includes the name, location and possibly an author reference
- Artist: (Creator), where the artist's name (if know) and historical information about his life, are included

In Fig.1. [13] shows an example of entering information divided into categories. This approach was applied to each of the images studied. We examined which fields had values that could be used without processing, such as the title of the Project, the monument it belongs to, the date of its implementation, and the name of the Creator. Some of the fields needed more development, such as the life dates of the painters, which are not known, as there are no records to indicate such facts. For this reason, the specific dates were indicated with the indication "xx" in the last two elements as we knew the century of their activity from the date of creation of their works. In addition, Unknown Artist is the largest number of works we study. So, the specific field was left blank, indicating the lack of information.

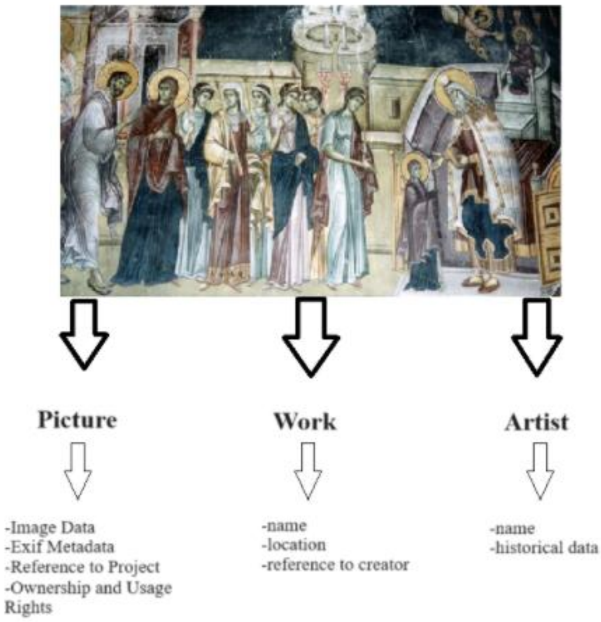

Fig. 1. *: Presentation of Virgin Mary from Zitcha monastery*

Files are stored in a horizontal structure with names derived from the sha256 hexdigest and their format, as detected by Pillow [14]. This process acts as (cryptographically secure) identification and avoids the problem of double importing files. The application manages entities in an object-oriented manner, allowing each metadata entity to be changed and stored independently. The application for data entry was done from a console, where the system asked recursively per image. For each photo, all possible fields are automatically recalled, and all previous values of the relevant field are presented as options.

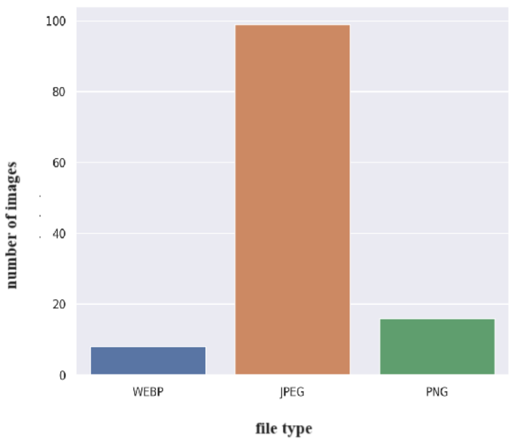

Fig. 2.: *Types of files*

The collected files are shown in detail in the diagrams (Figure 2 and Figure 3) where the unevenness of the information can be seen. The diagram [Figure 2] shows the type of files that were initially collected from the available sources in JPEG, PNG and WEBP formats and, in the diagram in Figure 3 the number of pixels per image used were recorded.

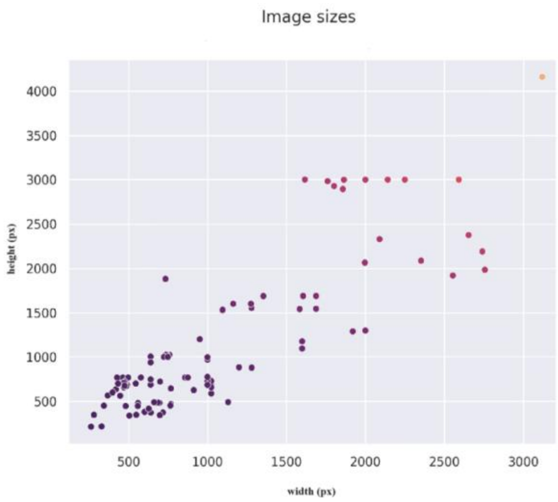

Fig. 3.*: pixels per image*

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1.2. Development prospects

This base is the first approach with images that are not in open libraries and their quality varies. So the challenge also lies in whether this kind of material is usable for further analysis. The presented database will be used for machine learning in order to make an approach to image classification and artist recognition. In addition, the dataset can be constantly enriched with new data and developed. As many images as possible can be entered in this way that we presented in the database, the more reliable results we will get. Also, more categories of data such as the geographic location of the project with GIS or CIELab color analysis methods [15], can be useful in extracting results.

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Simulation-aided infrared thermography with a new efficient channel attention mechanism aided Faster R-CNN model and decomposition-based noise reduction for detecting defects in ancient polyptychs

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Abstract. In this study, we investigate how to automatically and efficiently detect defects in ancient polyptychs by infrared thermography (IRT), combined with numerical simulation, deep learning networks and machine learning algorithms. Through an innovative improved Faster-RCNN model and LRTDTV denoising method, the recognition of surface and internal defects of ancient artworks is effectively improved. This improved Faster-RCNN model introduces an effective channel attention (ECA) mechanism in the feature extraction stage, which significantly improves the performance of the model in recognizing small defects, and a comparison with the original Faster-RCNN model reveals that the average detection accuracy_50 (AP_50) of the improved model is significantly improved to 86.9%. The average precision_small (AP_s) especially improved to 59.1% when detecting small-size defects. The experimental results verify the practicality and efficiency of the method in cultural heritage protection, which helps to maximize the protection and transmission of cultural heritage. In addition, the method in this study can achieve fast and accurate detection of defects in any type of cultural heritage object while avoiding secondary damage to the samples, providing effective technical support for cultural heritage protection.

Keywords: Numerical simulation, Machine learning algorithms, Faster R-CNN network, Attention mechanism, Defect detection, Deep learning.

1 Introduction

Cultural heritage, critical for civilization's progress, includes polyptychs, valued for their historical and artistic significance. These artworks often depict important cultural narratives but are prone to damage like cracks or splits over time. Timely and accurate detection of these defects is essential to preserve their integrity and continue their cultural transmission.

Non-destructive testing (NDT) [1] is essential in various industries for ensuring material safety and integrity without damage. NDT's especially crucial in cultural heritage to protect irreplaceable artifacts during restoration. Currently, the main NDT methods include infrared (IR) photography, ultraviolet imaging, X-ray photography, acoustic emission, and terahertz.

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Infrared thermography (IRT) has become a key tool in the NDT of materials due to its non-invasive, immediate and superior imaging. Particularly for artwork detection [2], IRT is popular for assessing artefact defects due to its ability to scan large areas quickly, with high resolution and without contact. IRT operates in two phases: the first phase involves recording temperature changes on the surface, and the second phase identifies defects by differential analysis of thermophysical properties, resulting in a clear infrared contrast. However, if the heat source is not calibrated in the first stage, there is a risk that the IRT of the artwork may fade. Furthermore, the second stage detects the artwork by analyzing the reflected near-infrared and short-wave IR spectra, but this method is difficult to deal with deep internal defects and requires a visual inspection, leading to possible errors in defect assessment.

To prevent thermal discoloration in IRT used on cultural heritage, two strategies are effective: reducing input energy and employing numerical modelling to optimize and standardize testing procedures. This study focuses on numerical simulation, which enhances IRT system design by predicting outcomes and understanding heat mechanisms in complex materials. In order to avoid possible errors in the second-stage defect assessment, this study constructs an automatic defect detection system based on numerical simulation using deep learning networks and machine learning algorithms to reduce possible errors in actual defect detection and optimize the defect detection process.

This study focuses on a reproduction of a 1320 polyptych by Pietro Lorenzetti, preserved in Arezzo, Italy, as shown in Fig. 1 [3].

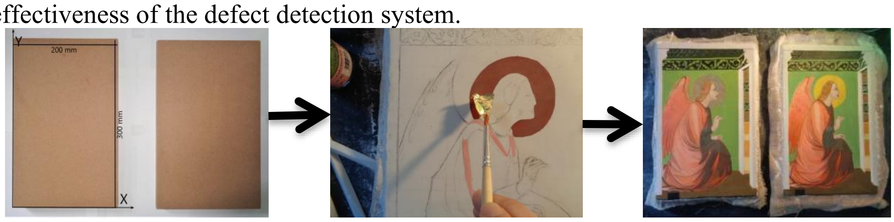
(a) (b)

Fig. 1. (a) A photograph of the polyptych, (b) a zoomed view on the reproduced part.

2 Description of the samples under test and numerical simulation setup

2.1 Description of the tested sample

In order to validate a numerical simulation-assisted approach to detecting defects in polyptychs via IRT, two simulated polyptychs were created on wood panels using a 14th-century pen-and-pencil technique. These boards were simulated with rabbit skin glue and Teflon inserts to simulate defects, then coated with multiple layers of *gesso di Bologna* and rabbit skin glue, and finally layered with tempera paint to complete the final artwork, as shown in Fig. 2. For more details on the production of the replica, see the author's article [3]. This setup was intended to approximate the replication of historical, artistic methods to test the effectiveness of the defect detection system.



(a) (b) (c)

Fig.2. Brief description of painting samples: (a) the boards are used as support, (b) using a damp cotton ball to adhere the gold leaf, and (c) the fabrication of the samples is completed.

2.2 Geometric modeling instructions

This section describes the process of constructing a geometric model of the sample under test in order to numerically simulate the temperature distribution on the sample surface. In this study, the surface of the geometric model was constructed by first drawing the surface contours (X and Y axes) through *CAD* software and then stretching the depth of the work plane where the contours were completed (along the Z axis). However, the remaining layers of the model were constructed using the linear tetrahedral units of the *COMSOL Multiphysics* software. Finally, IRT experiments were simulated using the Solid Heat Transfer module of *Multiphysics 6.0.* For more details on the modelling, see the authors' paper [3].

3 Methodology

The aim of this research is to enable faster and more accurate automatic defect detection in IRT using numerical simulation, deep learning networks and machine learning algorithms. This section introduces the content of the method to achieve faster and more accurate automatic defect detection.

3.1 The total-variation regularized low-rank tensor decomposition denoising method (LRTDTV)

Here, the thermographic image restoration method uses LRTDTV model to reduce noise. The approach leverages Tucker decomposition and total variation regularization, focusing on the spatial and spectral smoothness. Given the non-convex nature of the problem, the augmented Lagrange multiplier (ALM) method is used for optimization.

Define a third-order tensor $y := \{Y^1, Y^2, Y^3, \dots, Y^B\}$, where $Y^i \in R^{H \times W}$ $(i = 1,2,3, \dots, B)$ represents the i^{th} frame of a thermographic sequence, with B being the number of frames, and H and W being the height and width of the image, respectively. Our data can be considered a mixture of a noiseless image and two types of noise, represented as:

$$y = X + N + S \tag{1}$$

where X is the noiseless image of our data, N is Gaussian noise, and S is sparse noise. For more details, check out the authors' article [3].

To eliminate noise in thermographic images, LRTDTV model is used; the visualization of the decomposition can be found in Fig. 3. The objective function is:

$$\begin{gathered}\min_{X,N,S} \tau \|X\|_{\text{SSTV}} + \lambda \|S\|_1 + \beta \|N\|_F^2 \\ \text{s.t.} \quad y = X + N + S \\ X = C \times_1 U_1 \times_2 U_2 \times_3 U_3 \\ U_i^T U_i = I \quad (i = 1,2,3)\end{gathered} \tag{2}$$

where $\tau,\ \lambda$and β are regularization parameters. The $C \times_1 U_1 \times_2 U_2 \times_3 U_3$ represents Tucker decomposition, and $\|X\|_{\text{SSTV}}$ is the anisotropic Frobenius norm, exploiting the spatial-spectral continuity of thermographic images:

$$\|X\|_{\text{SSTV}} = \sum_{i,j,k} \omega_1 |x_{i,j,k} - x_{i,j,k-1}| + \omega_2 |x_{i,j,k}| + -x_{i,j-1,k} \omega_3 |x_{i,j,k} - x_{i-1,j,k}| \tag{3}$$

where $x_{i,j,k}$ is the $(i,j,k)^{\text{th}}$ entry of X, ω_j $(j = 1,2,3)$ are the weights controlling regularization strength, and k represents the dimension of the thermographic data.

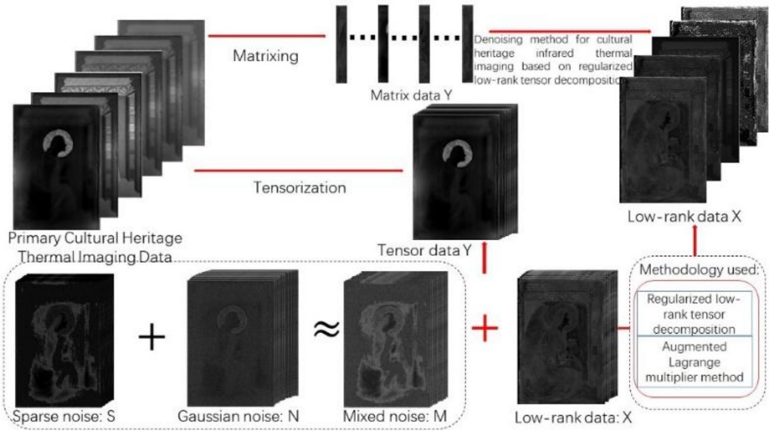


Fig. 3. Schematic diagram of the LRTDTV denoising method.

To solve Problem (2), one can introduce auxiliary variables to reformulate it into a simpler minimization problem:

$$\begin{gathered} \min_{C,U_i,X,\mathcal{F},S,N} \tau\|\mathcal{F}\|_1 + \lambda\|S\|_1 + \beta\|N\|_F^2 \\ s.t.\ y = X + S + N, X = Z, D_\omega(Z) = \mathcal{F}, \\ X = C \times_1 U_1 \times_2 U_2 \times_3 U_3, U_i^T U_i = I \end{gathered} \tag{4}$$

where $D_\omega(\cdot) = [\omega_1 \times D_h(\cdot)\,; \omega_2\times D_v(\cdot)\,; \omega_3\times D_t(\cdot)]$ is the so-called weighted three-dimensional difference operator, and D_h, D_v, D_t are the first-order difference operators respect to three different directions. Since this is a non-convex optimization problem, the ALM method is used for optimization. Based on the ALM method, the problem can be transformed into minimizing the following augmented Lagrangian function:

$$\begin{gathered} \mathrm{L}(X,S,N,Z,\mathcal{F},\Gamma_1,\Gamma_2,\Gamma_3) = \tau\|\mathcal{F}\|_1 + \lambda\|S\|_1 + \beta\|N\|_F^2 \\ \langle \Gamma_1, y - X - S - N\rangle + \langle \Gamma_2, X - Z\rangle + \langle \Gamma_3, D_\omega(Z) - \mathcal{F}\rangle + \frac{\mu}{2}(\|y - X - N\|_F^2 \\ + \|X - Z\|_F^2 + \|D_\omega(Z) - \mathcal{F}\|_F^2) \end{gathered} \tag{5}$$

where μ is the penalty parameter, and Γ_i $(i = 1,2,3)$ are the Lagrange multipliers. Enhancing the Lagrangian function requires optimization iterations, which requires iterative updating of each variable. For a detailed iterative procedure for the parameters U_i, X, Z, $\mathcal{F}$, S, N, and Γ_i, see the authors' separate manuscript [3].

These steps are repeated iteratively until convergence, using an adaptive approach for the penalty parameter μ. After completing this process, the noise-free image can be effectively separated from the noise components.

3.2 Improved Faster R-CNN internet

Ross B. Girshick introduced the Faster R-CNN in 2016 [4]. The model starts with normalizing data to handle various inputs and uses networks like VGG and ResNet for feature extraction. It features a region proposal network (RPN) that identifies potential defects, which are refined through non-maximum suppression (NMS) to highlight crucial areas. The selected regions undergo Region of Interest Pooling (RoI Pooling) and are processed by a fully connected layer for accurate defect classification and localization. The Faster R-CNN includes three main components: feature extraction, region proposal, and detection networks.

This study enhances the Faster R-CNN by incorporating the efficient channel attention (ECA) mechanism, which focuses on local interactions within each channel using a one-dimensional convolutional (C1D) layer instead of a fully connected one. This modification not only reduces the model's parameters but also boosts its accuracy and efficiency in localizing defects in complex thermal images.

ECA Mechanism Steps:

1. Adaptive Kernel Size Selection:

The kernel size K is dynamically determined based on the number of channels C:

$$C = \phi(K) = \gamma * K - b \tag{6}$$

Typically, channels C are powers of 2, so the kernel size K is set as:

$$K = \varphi(C) = \left|\frac{\log_2 C}{\gamma} + b\right|_{odd} \tag{7}$$

Here, $|\cdot|_{odd}$ rounds to the nearest odd number.

2. Generating Channel Attention Weights:

Apply Global Average Pooling (GAP) to input feature maps to get a $1 \times 1 \times C$ vector. Use a C1D on this vector to compute α_i:

$$\alpha_i = \sigma\big(C1D_k(y)\big) \tag{8}$$

The equation can be expressed as:

$$\alpha_i = \sigma\big(\textstyle\sum_{j=1}^{k} \omega_i^j\, y_i^j\big),\ y_i^j \epsilon \Omega_i^k \tag{9}$$

Here, ω_i^j are learning parameters and $\sigma(\cdot)$ is the sigmoid activation function.

3. Applying Channel Attention Weights:

The weights α_i are applied to the input feature map X:

$$X' = X \otimes \alpha_i \tag{10}$$

X' is the resulting feature map, and $\otimes$ denotes channel-wise multiplication.

This approach efficiently recalibrates features for improved defect detection. For an improved computational visualization of ECA for the Faster-RCNN model see Fig. 4.

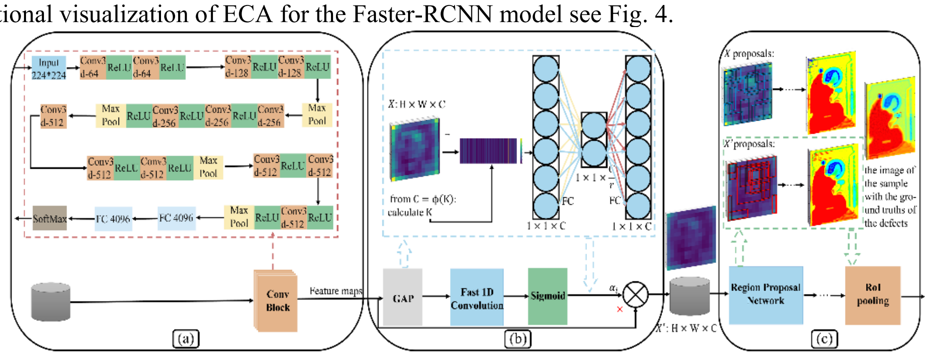


Fig. 4. (a) Original image input forward VGG16 network structure, (b) ECA module structure diagram, visualizing input feature map X and re-weighted output feature map X', (c) comparing the visualizations of X and X'proposals.

4 Experimental results and analysis

The aim of this study is to improve the speed and accuracy of automated defect detection in IRT experiments through numerical simulation, deep learning and machine learning methods. The study includes the production of IRT experimental datasets and numerical simulation datasets, performing model training and analyzing the results. First, we collected 28 thermal images of polyptychs using a 640x512 pixel IR camera. To increase the limited number of images, we extended the dataset to 812 images by numerical simulation, including 28 camera-collected images and 784 COMSOL-simulated images. 90% of the images were used for training and 10% for testing. Training was performed using a Faster-RCNN network, optimized by stochastic gradient descent (SGD) and VGG backbone.

After the completion of the network training experiment, this study also conducted the original Faster R-CNN network training experiment and simultaneously made a clear comparison between the original Faster R-CNN model and the improved Faster R-CNN model. In order to visually evaluate the advantages and disadvantages of these two models, the evaluation results of the two models are detailed in Table 1.

Table 1. Comparison of model testing performance metrics

model	AP_{50} *[%]*	AP_{75} *[%]*	AP_S *[%]*	AP_L *[%]*	AR_1 *[%]*	AR_{10} *[%]*	AR_{100} *[%]*	Detection time *[s]*
Faster R-CNN	**83.5**	**71.3**	**51.3**	**67.3**	**50.1**	**56.1**	**56.1**	**0.23**
Improved model	**86.9**	**74.1**	**59.1**	**69.3**	**57.8**	**62.4**	**62.4**	**0.22**

In order to have a more intuitive feeling of the enhancement of machine learning algorithms and deep learning networks for the detection of defects in infrared thermal imaging, we show four types of experimental results of infrared thermal imaging (see Fig. 5): the images in each row are, in order, the infrared thermal image of experimental sample A, the infrared thermal image of sample A after LRTDTV de-noise and Fourier transform, the infrared thermal image of experimental sample B, and the infrared thermal image of sample B after LRTDTV de-noise and Fourier transform.

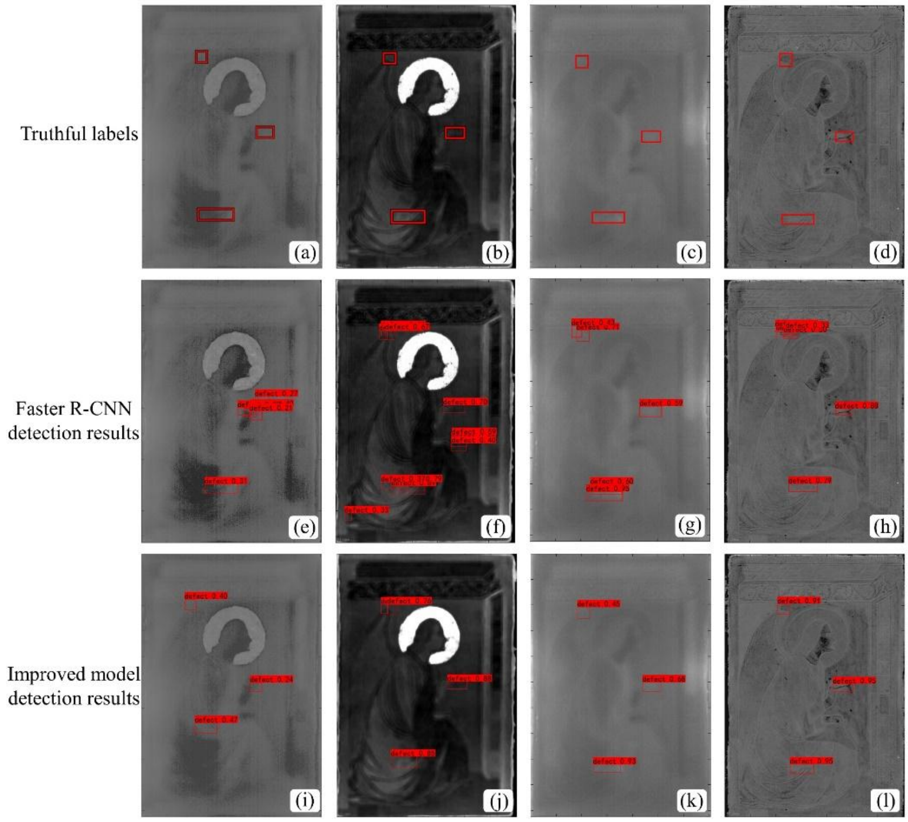


Fig. 5. IRT experimental results with real labels: (a) the raw sample A, (b) the sample A after LRTDTV de-noise and Fourier transform, (c) the raw sample B (d) the sample B after LRTDTV de-noise and Fourier transform. The defect detection results of IRT: (e) the raw sample A after applying the Faster R-CNN model, (f) the sample A after applying LRTDTV de-noise, Fourier transform, and the Faster R-CNN model, (g) the raw sample B after applying the Faster R-CNN model, (h) the sample B after applying LRTDTV de-noise, Fourier transform, and the Faster R-CNN model, (i) the raw sample A after applying the Improved Faster R-CNN model, (j) the raw sample A after applying LRTDTV de-noise, Fourier transform, and the improved Faster R-CNN model, (k) the raw sample B after applying the improved Faster R-CNN model and (l) the sample B after applying LRTDTV de-noise, Fourier transform, and the improved Faster R-CNN model.

By observing the results of this experiment, we can find the following: comparing Fig. 5(b), Fig. 5(f) and Fig. 5(j), it can be seen that the automatic defect detection network based on the improved Faster R-CNN can better detect the tiny defects that are difficult to be detected by human eyes. Comparing Fig. 5(c), Fig. 5(g), and Fig. 5(k) with Fig. 5(d), Fig. 5(h), and Fig. 5(l), it is shown that the LRTDTV de-noising method can effectively remove the noise interference in infrared thermal imaging.

5 Conclusions

In this study, IRT was used to perform non-invasive inspection of the ancient polyptychs and care was taken to avoid secondary damage. To protect the ancient polyptychs from secondary damage, we use numerical simulations to match the experimental surface temperatures and an LRTDTV decomposition model to efficiently remove Gaussian noise from the thermal images, thus facilitating the detection of defects in the samples by IRT. In addition, an improved Faster-RCNN model is proposed, which utilizes VGG16 for feature extraction and incorporates an ECA mechanism in the feature pyramid network (FPN), which greatly improves the defect detection capability of ancient artworks. After comparative experiments, the results of the study proved the efficiency and practicality of the model, which can provide strong technical support for cultural heritage protection. It greatly improves the accuracy and rapidity of IRT for cultural heritage protection and defect detection.

Acknowledgements

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The database of notarial bindings- a tool for the study of historical binding structures and their condition

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Abstract. A PhD research project has recently been undertaken to study notarial bindings kept in Greek archives and libraries, aiming to classify the different types of binding structures, record their present condition, and give explanations of deterioration mechanisms and styling influences. In the ongoing research, a survey form for the documentation of the bindings is used to collect data concerning manuscript identification, codicological elements, the text block, the inks used for writing and indexing, the technique of the binding, and the particular binding features. A section of the survey form is dedicated to the detailed description of the present condition of the bindings, including a general condition assessment of the volume based on a four-grade system. Each survey form is accompanied by a detailed photographic documentation report.
This paper discusses the database specially designed to accommodate the information gathered from the systematic recording of the notarial bindings features. The tables of the database are related to the sections of the survey form. Checklists of predefined values are used for more efficient processing of the data collected both in the sections of the survey form and the database tables. The processing of the gradually compiled data is expected to: a. give statistic elements useful for the classification of the different structures found in the category of notarial bindings, b. reveal similarities of construction that show possible influences from local artisans or from larger centers of production, and c. provide an overall view of the condition of the bindings.

Keywords: database, notarial bindings, survey.

1 Introduction

Among the different binding structures used for archive purposes, notarial ledgers were used to keep records (deeds, contracts, etc.) and usually have simple yet stable binding structures. These bindings present structural characteristics of great significance for both the historical point of view and the

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preservation of the codices. The materials and techniques used for their construction are also of historical and technological importance for the study of earlier methods of production and constitute evidence of archival practices of a certain era. The bibliography on archival binding structures is remarkably limited [1, 2, 3], excluding the detailed publications of Janos Szirmai [4] and Nicholas Pickwoad [5].

A PhD research project is recently undertaken to study notarial bindings kept in Greek archives and libraries, aiming to classify the different types of binding structures, record their present condition and give explanations of deterioration mechanisms and styling influences.

Currently, numerous bindings of this type are preserved in the collections of the General State Archives of Greece (GSA), in Athens and regional archives (Fig.1). The GSA is a public service belonging to the Ministry of Education and consists of the Central Service based in Athens, seven Directorates, 64 Regional Services, and seven Provincial Archives scattered across the mainland and the islands of Greece [6].

Fig. 1. Some types of notarial bindings (GSA-Central Services, Athens and GSA-Kythera).

2 The survey process

A field survey was scheduled to study the notarial bindings found in the repositories of the Central Services of the GSA, where representative archive material from various areas of Greece is kept as well as in the regional archives across the country. The bibliographical research in the catalogs of the archival material [7,8,9,10] revealed that several notarial ledgers, covering the period between the end of the sixteenth century and the nineteenth century, are preserved in the central services, and most of them in the Ionian Islands (Kythera, Kefalonia, Corfu, Lefkada, etc.). In these islands, some of the oldest notarial registers in Greece are possessed, starting from 1472 (Corfu Archive) and extending to 1900 (Kefalonia Archive). Record keeping presents a continuous chronological sequence in this area of Greece. In these regions, once under Venetian rule, well-organized archives were kept, including the notarial archives, where wills and codicils, marriage and sale contracts, verdicts, and compromises were preserved. It is estimated that more than 2000 notarial ledgers are located in the repositories of the GSA. However, most of the bindings have suffered serious damage. There are plenty of volumes preserved as loose folios or gatherings. Only those bearing their original bindings are selected to be included in the survey process.

This paper discusses the database specially designed to accommodate the information gathered from the systematic recording of the features of the notarial bindings. For the purposes of the documentation of the bindings, a specially designed survey form is used to collect data grouped in the following five sections:

Section 1. **Manuscript Identification** (catalog number, place, name of notary, dates of writing, labels of indexing),

Section 2. **Codicological Elements** (dimensions of the volume and the text block, total number of leaves and pages, number and composition of the gatherings, pagination),

Section 3. (Fig. 3) **Binding Technique** (limp, semi-limp, full binding, half, or quarter) and the particular binding features, such as the materials and cover decoration, the attachment system of the cover to the textblock, the sewing structure (i.e. number and materials of supports, colour, and quality of sewing thread, spine lining and shape, method, and materials of tacketing, endbands, ties). The method used for the sewing of the gatherings (all-along or two-on) is noted in the remarks field, along with a drawing describing the distances between the sewing stations.

Section 4. **Textblock** (with information on the features of the paper support, such as thickness, colour, texture, and watermarks), quality of paper, number, and format of endleaves, as well as the inks used for writing and indexing (e.g. colour, texture, etc.),

Section 5. (Fig.4) the detailed description of the present **Condition** of the book block and the binding structures (text block, cover, sewing, cover attachment, endbands, spine linings, and shape, ties or clasps, and leaves). A general assessment of the condition of the volume is given based on a four-grade system (sound, moderate 1, moderate 2, poor).

Each survey form is accompanied by a **photographic documentation report** including photographs and/or drawings of the features of the binding.

It should be noted that, in the survey form, **check lists** of predefined values are used for the more efficient processing of the data collected.

3 The database

The information gathered from the systematic recording of the notarial bindings from the survey is gradually compiled in a database specifically designed for the project’s needs in Microsoft Access. Microsoft Access has been selected since it is an RDBMS (Related Database Management System) widely used and equipped with a lot of management tools [11, 12]. It is also characterized by interoperability and compatibility with other open-source DBMS systems such as MySQL Server [13]. Relational systems are the most appropriate for implementing information environments rich in relations, as in the system presented in this article.

Each section of the survey form corresponds to a table of the database. The relations between the tables of the database are shown in the following diagram (Fig.2)

The first table of the database contains data relevant to the manuscript identification and in particular, the catalogue number, the title and place of production, the name of the notary, the description of the notarial ledger in the published catalogue, the dates of writing (the beginning and the end of the text are recorded separately), the century of production, the place of writing and the language of the text. Finally, the date of the survey, along with labeling and indexing details, are described.

In the second table of the database, the codicological elements of each volume are recorded. The fields describing the height, width, and thickness of the volume and the dimensions of the text block individually, the number of leaves, the number of gatherings, and the number of bifolios per gathering, but also the style of numbering (with ink or pencil, per page or per leaf/sheet) and the existence of indexing gatherings are included in this table of the database.

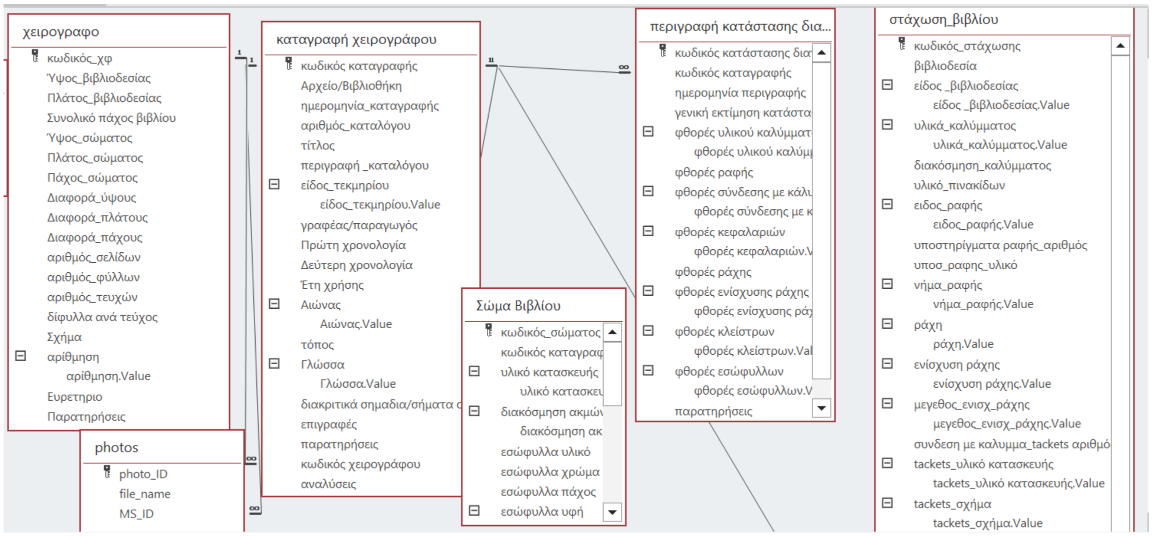

Fig. 2. The relational diagram of the database.

The binding characteristics table (Fig. 3) contains fields of predefined values of binding techniques (limp, semi-limp, full, half, or quarter binding, with or without boards, etc.) and foredge flaps (rectangular, trigonal, or trapezoid). Several alternatives may be selected for the materials used for the covering (leather, parchment, paper, decorative paper, or a combination of them), the decoration of the cover (gold or blind tooling or marbling), the materials used for the boards (wood, board, paper, not existing, other), the sewing supports structure (i.e. number and materials of supports, single, double, split, raised), the sewing method (i.e. all along or two-on sewing, packed etc.), the colour and the quality of the sewing thread. The existence of any spine lining (with materials and shape options) is also recorded, along with the attachment system of the cover (tacketing) to the book block specifying the method, the materials, and the shape (round or rectangular) of the tacketed blocks. Finally, this table contains data relevant to the use of ties (with options number and materials) and endbands, with details about the core materials (cord, leather, or other) and the threads used for their construction.

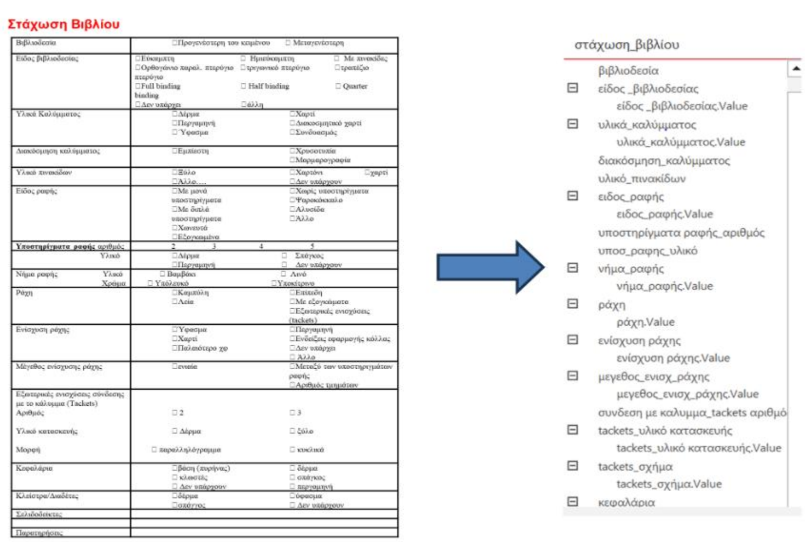

Fig. 3. The binding characteristics section of the survey form and the table of the DB where the binding is recorded.

It should be noted that during the data entry, values can be selected from predefined lists to record the number of sewing stations (possible values 2, 3, 4 or 5), the type of sewing supports (a. single, b. double supports, c. without support or d. other), the materials used for the supports (a. leather, b. parchment, c. cord, d. combination of two materials or e. do not exist). The sewing thread is described by visual observation as linen or cotton, and its colour as off-white or natural. For the shape of the spine of the bookblock, the options are: a. flat, b. rounded, c. with raised bands, d. without raised bands, e., with tacketed blocks. The number of the ties is selected between 1,2,3, or 4, and the materials used for their construction can be specified as: a. leather, b. cord, c. fabric or d. other. Finally, for the endbands, the possible options for the core are a. leather, b. parchment, c. cord, or d. do not exist, and for the woven or knitted part, the alternatives are: a. threads or b. fabric.

Any observations about the method used for the sewing of the gatherings (all-along or two-on) are recorded in the remarks field. The text block description table includes information relevant to the paper support of the gatherings (such as its thickness, colour, texture, and watermarks), the number and format of endleaves, and the inks used for writing and indexing (e.g., color, texture, etc.). Predefined values are given in the field of the paper (laid or wove, rough or even texture, off-white or natural or other colour), the endleaves (laid or wove, off-white or natural or other colour, rough or even texture) and the inks (iron-gall or carbon black or brown colour).

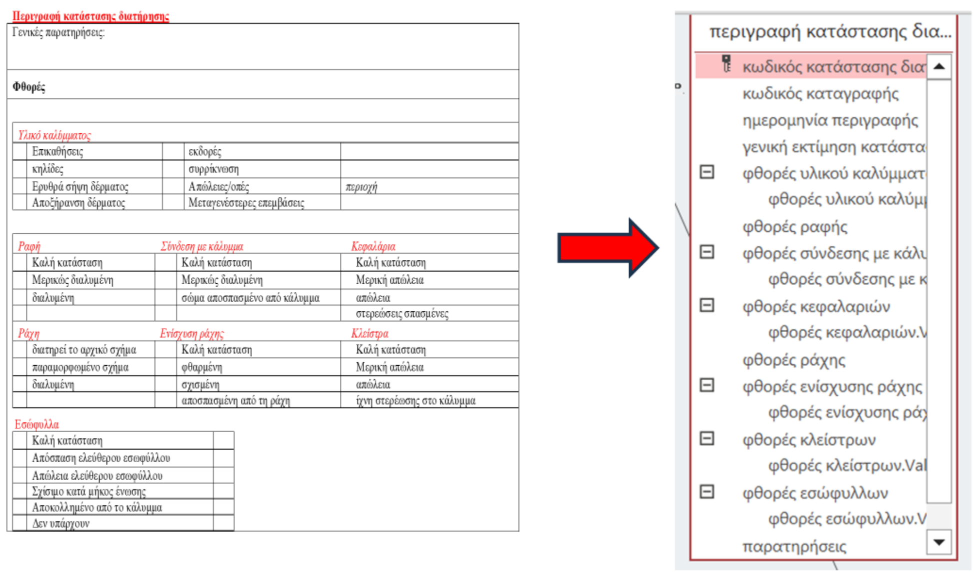

Fig. 4. The binding condition section of the survey form and the table of the DB where the condition of the notarial binding is recorded.

The condition of the binding is recorded in the last table of the database (Fig. 4), where a general assessment of the condition of the volume is given based on a four-grade system (a. sound, b. moderate1, c. moderate2, d. poor). The present **condition** of the covering material is recorded by checklists of the most common damages, such as a. surface dirt, b. scratches, c. red rot, d. shrinkage, e., blemishes, f. later repairs. For the sewing, the options are a. in good condition, b. broken, or c. partly broken, and for the cover attachment: a. in good condition, b. partly broken, or c. the cover is detached from the textblock. The endbands condition can be recorded as a. in good condition, b. partly missing, c. missing, or d. tie-downs broken. The condition of the spine shape may be in a. good condition, b. deformed or c. broken and the linings a. in good condition, b. worn, c. torn, or d. detached from the spine of the bookblock. The ties may be in a. good condition, b. partly missing, c. missing, or d. only their anchorage may be preserved. The endleaves condition options are a. in good condition, b. missing fly-leaf, c. detached fly-leaf, d. torn along the fold, e. detached from the cover, f. not existing. The term good is used when the element is not in sound condition but slightly damaged.

The digital photographs folder depicting the features of each notarial binding are kept in a separate table.

The data collected from each survey form are entered into the database either as a record (row) in the particular fields(columns) of the tables or by completing a separate form for each surveyed item (Fig. 5).

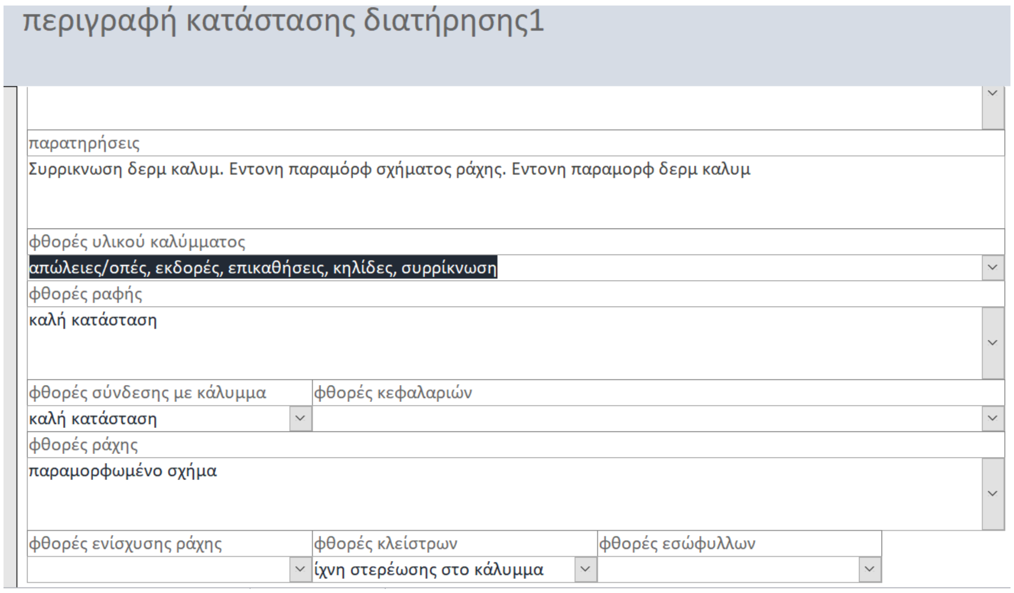

Fig. 5. The binding condition form of the database.

4 First results of the data processing

275 notarial bindings belonging to the archives of Kythera, Kefalonia, Corfu and Athens, have been recorded, dating between 1586-1841. From the ledgers surveyed, 46 notarial bindings are found in Kethyra

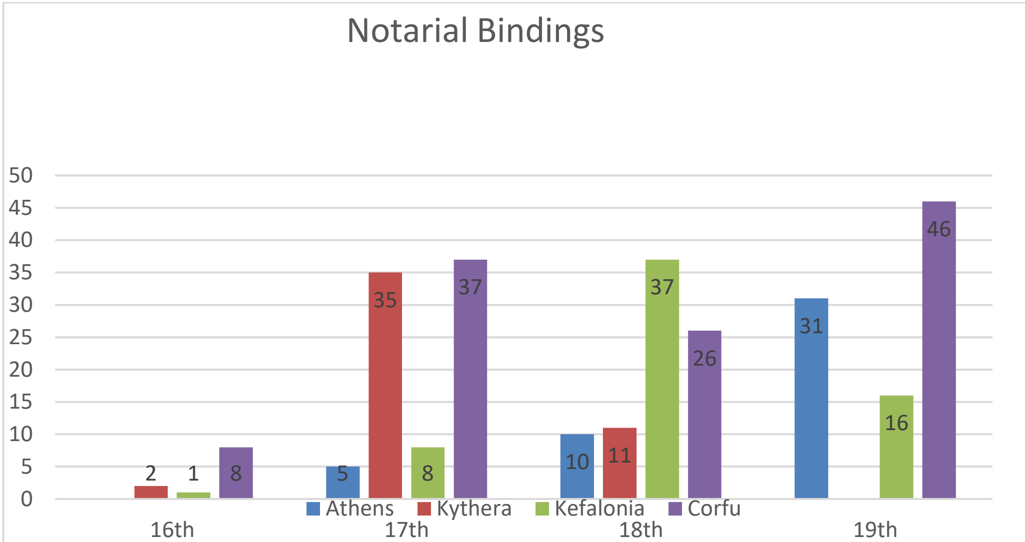

Fig.6. Chronological distribution of the surveyed bindings.

So far, 62 in Kefalonia, 120 in Corfu while 47 ledgers are recorded in the Central service of the GSA. The chronological distribution of the surveyed bindings is shown in Fig.6. The items surveyed in Athens were produced in both the islands of the Aegean and the Ionian Sea such as Paros, Naxos, Mykonos, Syros, Skiathos, Scopelos, Andros, Aegina, Chios, Kefalonia.

Different types of binding structures are recorded with full leather or parchment covers, limp vellum bindings with leather or paper tacketed blocks in their spines, half or quarter bindings with leather spine and paste or marbled papers covering their pasteboards. In some cases, simple bindings with covers made of a thick pasteboard as a wrapper were used to protect the gatherings consisting of the bifolios of the documents.

The database enables the grouping the different types of bindings. For example, a database query about the parchment covered bindings gives answers about the distribution of surveyed volumes per century found in the GSA in Athens, Kythera and Kefalonia (Fig.7.).

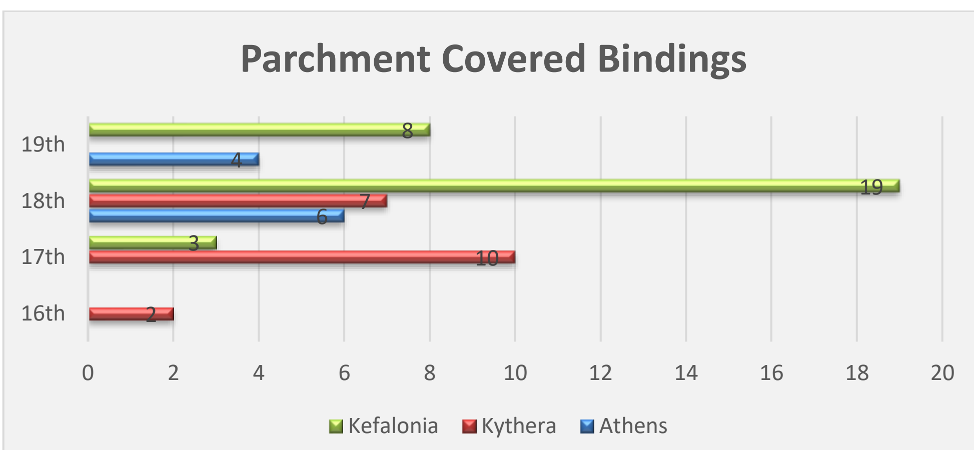

Fig.7. Chronological distribution of parchment-covered bindings surveyed (GSA Athens, Kythera, Kefalonia).

In another query about the decoration of the parchment-covered bindings surveyed in the GSA of Kefalonia, in a total of 30 volumes, 11 are undecorated, 18 are blind tooled and only one had gold tooled decoration (Fig. 8.). It is the case of a 19th century binding with a gold tooled title "Cash book" on a leather

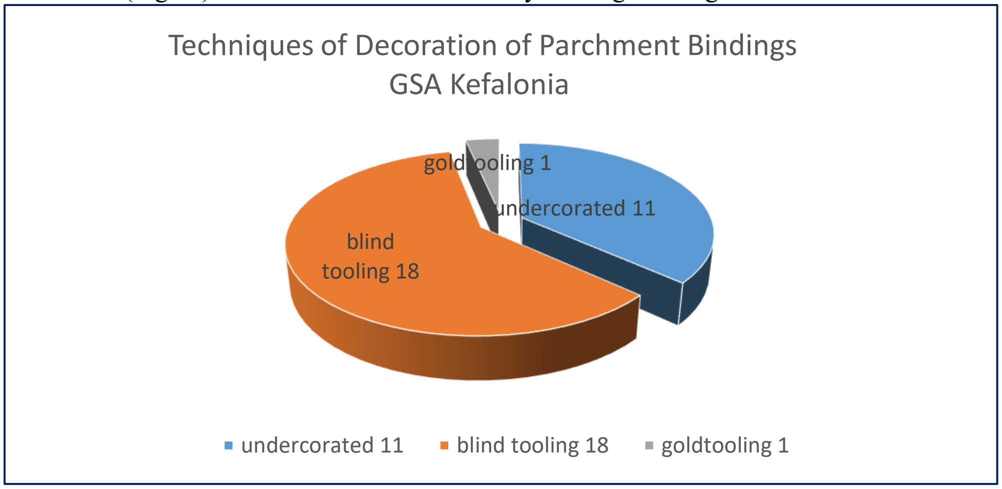

Fig.8. Techniques of decoration of the parchment bindings surveyed in the GSA of Kefalonia.

label attached to the spine of the parchment cover. It was used as a notarial ledger by the notary Valsamakis Nikolis in Livatho, Kefalonia, between 1825 and 1826, although it was primarily intended for financial record-keeping use.

It is observed that many of the notarial ledgers have covers with a foredge flap extension, usually rectangular in shape. Cases of trigonal or trapezoid foredge flaps are occasionally recorded. The database query about the distribution of the bindings having foredge flaps extending from their cover resulted in the findings presented in Fig. 9.

The foredge flap is a feature of leather bindings, but it was also preserved to protect the significant contents of the text block in later parchment cover bindings. The parchment cover is usually wrapped around a primary paper cover made of a single thin piece of board. In the surveyed sample, the paper covers with foredge flap extensions may have served as a primary binding, which never had the opportunity to be covered with parchment.

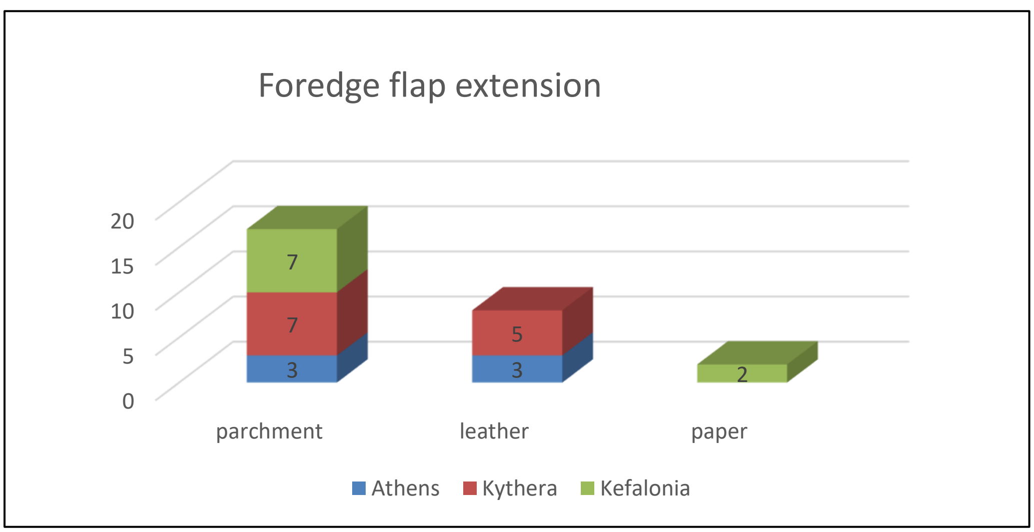

Fig. 9. Distribution of the leather, parchment or paper bindings with a foredge flap extension (GSA Athens, Kythera, Kefalonia)

Similar queries are expected to give statistical results, valuable for the classification of the different binding structures, reveal similarities of construction and provide an overall view of the condition of the bindings.

5 Future research and perspectives

The application of examination and analytical methods (optical microscopy, scanning electron microscopy combined with energy dispersive X-ray microanalysis, FTIR, colorimetry, fiber analysis, spot tests etc.) of samples taken from certain parts of the bindings (leather, parchment, paper, thread, adhesives etc.) are expected to contribute to the identification of the materials used for the structure of the recorded notarial ledgers. This will contribute to a better understanding of the manufacture and production of the bookbinding materials, such as the animal origin and tannage of leather, the processing of parchment, the origin, manufacture, and colouring materials for threads (cotton, linen, hemp fibers) and fabrics used for sewing and ties, the identification of binding mediums used for the adhesives.

This project is expected to shed more light on key questions about Greek notarial bindings. The study of the notarial practices of the era may clarify whether notarial ledgers were imported from abroad or were produced locally, where the notaries acted. It is still under investigation whether there were binding facilities in the places where the notarial ledgers were used or if there was ledger production in the Greek region by local binders. Answers will be given after historical research (i.e. catalogues of professionals and professions of the era, lists of imported products etc.) in combination with the evaluation of the codicological elements collected.

A comparison of the surveyed notarial bindings with other European samples from Venice (or other Italian cities) is regarded as necessary to reveal if they were bound in larger centers of production and traded among other stationery bindings to the places they were recorded.

On the other hand, the condition survey may serve as a useful tool for future conservation priorities, according to the levels of vulnerability of the volumes. The bindings requiring conservation treatments should be handled with respect to their historical typology and particular features, in order to preserve the intriguing information for future researchers in the history of bookbinding.

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Numerical evaluation of thermal load applied by magnetic induction and solar loading aimed at experimental analyses using thermographic techniques

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Abstract. The study describes a first approach of integration among infrared thermography inspections under solar loading conditions, and a heating provided by magnetic induction in view of a future induction thermography test. An ancient bronze helmet, part of a statue located in L'Aquila (Italy) and inaugurated on *October 14th, 1928*, is the sample under test *(SUT)* herein. The corrosion process over time (17 years: 2007 – 2024) is evaluated via numerical and experimental techniques. It requires the presence of a temperature gradient priming the heat transfer mechanism through the *SUT*. Experimental configurations of infrared thermography (*IRT*) allowed the detection of defects like *e.g.* cracks and pitting. For this reason, the study was integrated with a preliminary magnetic induction test, *i.e.* a numerical model, in view of a future *in situ* thermographic test. To determine the appropriate distance and working time of the induction heater, a modelling was carried out in *COMSOL Multiphysics*®. The ancient bronze helmet was acquired by a non-contact instrument produced by *CREAFORM model Go! SCAN 3D*®. The mesh was exported in *COMSOL Multiphysics*® for further conditioning and processing. In particular, the authors used the *magnetic field coupling with a heat transfer* package to obtain a reasonable thermal distribution on the modeled artefact. Concerning the thermographic analyses, a *FLIR S65 HS* and a *FLIR T1020* thermal camera were used in the *2007* and *2024* inspections, respectively. A preliminary post-processing of the latest thermographic data is performed herein.

Keywords: Solar loading, Infrared thermography, Numerical modelling with *magnetic field coupling with heat transfer*, Laser scanner geometric reconstruction, Bronze.

1 Introduction

The evolution of climatic phenomena over the centuries due to the natural course of events and environmental changes has led to significant corrosion problems in bronze artifacts. This involves the variation of both the chemical composition and the aesthetic appearance. The surface of bronze and copper monuments is increasingly exposed to products of crystalline corrosion, *e.g.* copper oxide (cuprite) and basic copper sulphates. In urban areas, there is an increase in the formation of copper sulphates, which leads to byproducts. The discoloration/degradation of metal surfaces is caused by acid deposition, which usually results in extensive pitting that first affects the surface layer and then penetrates deeply, resulting in profound and irreversible alterations. In this regard, the passive thermography approach integrated with numerical modelling turns out to be an excellent solution allowing the analysis of the corrosion effect [1], [2] by studying the thermal contrast generated between defective and sound areas [3-7]. An inductive

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heater was numerically modelled in our work; thereafter, the main technical parameters were inversely retrieved to obtain on the SUT the same thermal contrast initially generated by the solar loading.

2 Methodology

In 2007, an ancient bronze helmet shown in Fig. 1 was thermographically inspected using a *FLIR S65 HS* thermal camera [5]; the thermal field allowed the evaluation of the corrosion level thanks to an *ad hoc MATLAB®* script [6]. Thermographic measurements were repeated in 2024 using a new thermal camera. Fig. 1 summarizes the logical process followed in this work.

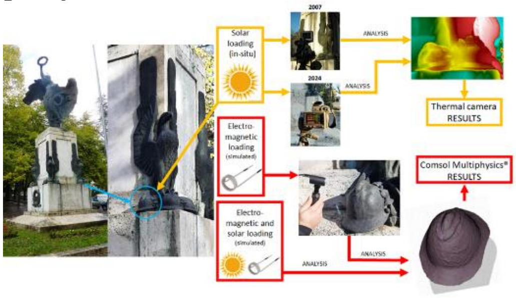

Fig. 1. Key steps followed during the numerical-experimental evaluation performed on the ancient bronze helmet.

To analyze the same helmet through numerical simulations, its geometry was recorded via *CREAFORM model Go! SCAN 3D®*. The geometry shows a rather regular pattern. However, for 3D laser scanners, the dark-green color is probably the most difficult to acquire. Usually, circular "spot" stickers are applied to the objects to form an ordered sequence of fiducials on the geometry that helps the software during the triangulation and reconstruction phases of the surface. Since the artefact is an ancient object, it hasn't been possible to apply this procedure. Furthermore, since the surface is particularly pitted – *i.e.*, a typical effect of surface corrosion -, the recording phase was further complicated; even denser point clouds were needed to guarantee detailed acquisitions in the order of a *tenth* of a *mm*. However, an initial correction of the individual point clouds was carried out. The main steps, explained in the following, are summarized in Fig. 2. The *RevoScan5®* computer program was used in our case (Fig. 2a).

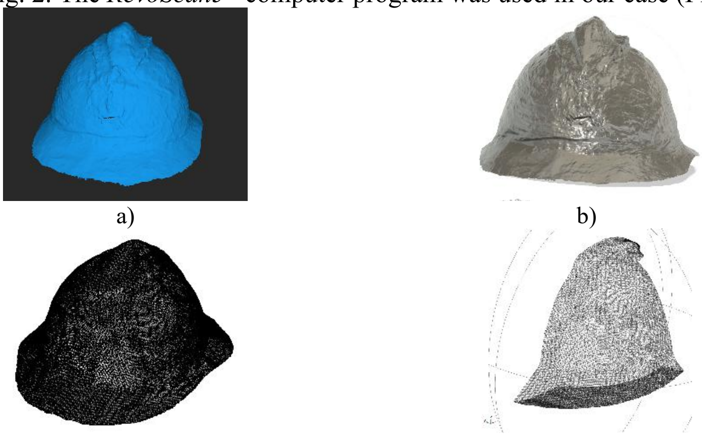

Fig. 2. Reconstruction of the geometry until the mesh; a) point cloud obtained by *RevoScan5®*; b) solid geometry via *Autodesk® Fusion® 360*; c) complete mesh obtained in *COMSOL Multiphysics®*; d) mesh analyzed in *COMSOL Multiphysics®*.

The file includes *1725426* vertices and *3442241* polygons. Given the considerable size and computational cost, it was necessary to process the point cloud using *Autodesk® PowerShape®* software; the holes were filled, and the tangent polygonal elements were regularized. The point cloud, being a surface without thickness, requires further processing to make it a solid. The reconstruction, shown in Fig. 2b, was carried out with *Autodesk® Fusion® 360.* A final solid useful for the numerical modelling in *COMSOL Multiphysics®* was finally obtained. Readers should note that the model in Fig. 2c is filled with material. However, the helmet has a non-constant thickness; it was emptied using another mesh. The reason for this step is the stability of the *.IGES* format compared to *.stl* format. Given the high computational cost of this model - *i.e.*, *4139342* nodal elements - it needs a motherboard with a *RAM* greater than *128 GB* [8]. For this reason, it was necessary to carry out a volumetric/nodal reduction of the model by exploiting the real location of the helmet that has the rear part attached to the base of the statue, while the right and left sides are approximately a plane of symmetry. A model reduction was operated (Fig. 2d), obtaining *220932* volume elements, *76686* surface elements, *73526* sides with *450595* external degrees of freedom, and *566702* internal degrees of freedom. This geometry was processed with a *12th Gen Intel(R) Core (TM) i9-12900H 2.50 GHz, RAM 32,0 GB, 14 Cores*.

3 Experimental results

As previously mentioned, the same helmet was inspected again in 2024 into the long-wave infrared spectrum (LWIR); the thermal field was initially acquired, and subsequently the corrosion areas detected using *MATLAB®*. Numerical modelling was built for thermal contrast purposes. Tab. 1 summarizes the main thermophysical parameters used in our numerical model.

Table 1. Bronze: main thermophysical parameters.

C_p Specific heat at constant pressure *[kJ/kgK]*	**0.4** [9]
ρ Density *[kg/m³]*	**8.8·10³** [9]
k Thermal conductivity *[W/mK]*	**50** [10]
ε Emissivity	**0.55** [5]

The heat transfer mechanism was based on the following governing equations set:

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p \boldsymbol{u} \cdot \nabla T + \nabla \cdot \boldsymbol{q} = Q + Q_p + Q_{vd} \tag{1}$$

$$\boldsymbol{q} = -k\nabla T \tag{2}$$

$$J = \varepsilon e_b(T) FEP_i(T) + \rho_d G \tag{3}$$

$$e_b(T) = n^2 \sigma T^4 \tag{4}$$

where ρ is density *[kg/m³]*, C_p specific heat at constant pressure *[J/kgK]*, $\boldsymbol{u}$ velocity vector air flux *[m/s]*, T temperature *[K]*, t is time *[s]*, $\boldsymbol{q}$ thermal flux vector evaluated by Fourier law for heat transfer via conduction, Q source/sink of heat *[W/m³]*, Q_{vd} viscous heat dissipation sink *[W/m³]*, Q_p point heat source *[W/m³]*, k thermal conductivity for complete materials *[W/mK]*, J total incoming radiative flux, FEP_i view factor linked to the relative sun-SUT position (it also includes the fractional emissive power of the blackbody), ε emissivity *[%]*, $e_b(T)$ power radiated across all wavelengths depending on the 4th power of temperature. The latter varies instantly and is responsible for the increase or decrease in irradiance (G) *[W/m²]* throughout the day; σ represents the Stefan-Boltzmann constant. The numerical model works with the real irradiance. The environmental parameters inherent to the closer weather station to the SUT were provided by CETEMPS (L'Aquila, Italy) and shown in Tab.2.

Table 2. Main environmental parameters recorded by a weather station.

Time	Air temperature *[K]*	Solar irradiance *[W/m²]*	Wind speed *[m/s]*	RH *[%]*
7:00 AM	**271.22**	**173.8**	**0.56**	**81.8**
8:00 AM	**275.68**	**355.87**	**0.22**	**68.87**
9:00 AM	**278.98**	**474.6**	**0.15**	**57.16**

Concerning the model of the solar loading, the orientation of the mesh towards the relative *x,y,z* axes (related to the absolute reference axes of the geographical orientation) was fundamental. The geographic coordinates provided to the model were: *42.345151, 13.397797*. In this case, the authors used the natural convection and RH values reported in Tab. 2. The *GMRES* solver coupled with the *MULTIGRID* function was implemented and applied to the data. A frame rate of five minutes during two hours of inspection (from 7:00 AM) was selected. As shown in the modelling inherent to the different time intervals (Fig. 3a), the bronze material, as a whole, has a good thermal contrast. The helmet, that is at thermal equilibrium with the ambient temperature (Tab. 1) before dawn, is fully affected by a low solar load, operating a heat flux reaching the maximum depth; it is particularly noticeable starting from 90th minute (Fig. 3a).

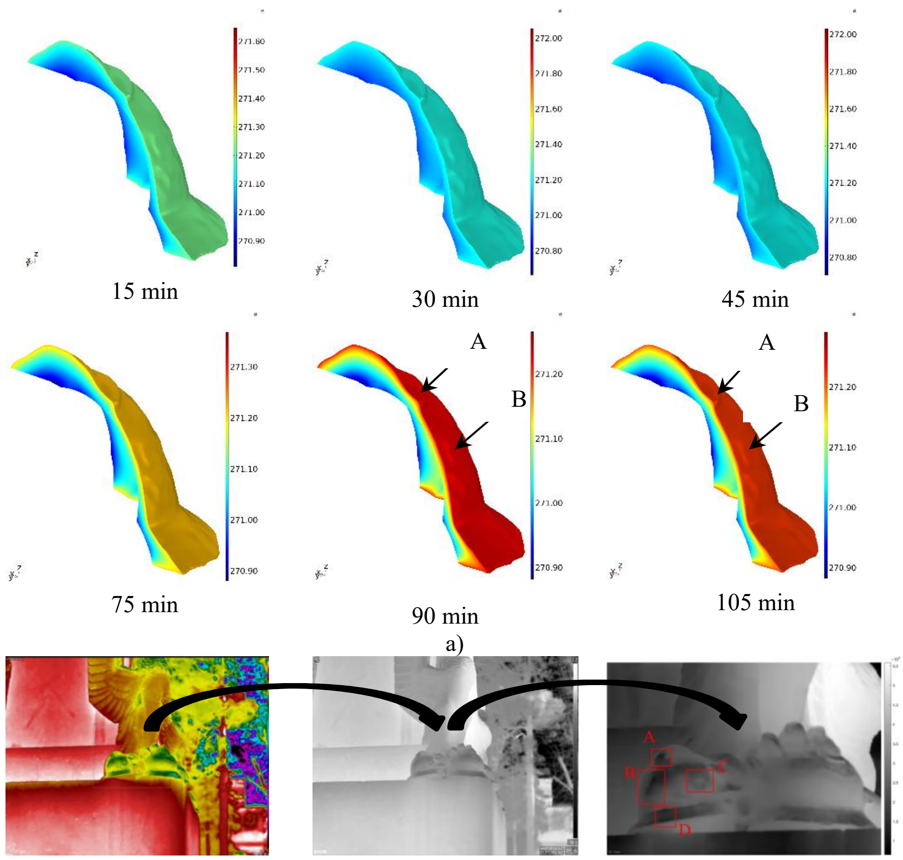

Fig. 3: a) Numerical simulation of the helmet showing the external and internal thermal fields along a selected cross-section: frame rate of 15 min, multiplying by three as was done during the 2007 thermographic test; b) Conversion of the RGB images into single-channel grayscale images, cropping and normalizing procedures of the 2024 thermographic test.

The effect of complete radiation on the SUT is also evident in Fig. 3b, that is related to the 2024 thermographic test. The numerical model approximates the thermal field in a satisfactory way (Fig. 3a), highlighting the slight temperature gradients on the surface. This demonstrates that pitting was computed thanks to local gradients. As evident in Fig. 3a, no shadows on the back of the model are present at the first light of dawn (sunrise starts at 06:45 AM [11]). The increase of solar irradiance and the relative evolution of the thermal field manifest themselves along the depth of the helmet cross-section starting from 90th minute. *A* and *B* defects indicated in Fig. 3a (at 90th and 105th minute) are detectable in Fig. 3b (experimental result), too. Defects *C* and *D* haven't been included in this part of the numerical modelling due to computational reasons.
This step allows defining the correct parameters to be imposed at the magnetic induction heater to obtaining a similar thermal contrast on a small part of the SUT whether compared to the one facing the sun. The working principle of a magnetic induction heater is very different with respect to a common electric resistance. Everything originates from an oscillator, that is an electronic circuit capable of generating waveforms whose amplitude can be modulated. Amplitude modulation, for energy conservation, generates frequency variation. The electric current flowing out of the oscillator is, therefore, frequency-modulated. If this current is allowed to flow through a solenoid, then the coils will generate a circular electric field. If the current is alternating, the electric field and the magnetic field are orthogonal to each other. Therefore, a circular electric field (due to the coils of the inductor) will bring an orthogonal magnetic field to the main axis of the winding. An oscillating current in the solenoid (*i.e.*, a variation in the direction of the electric current vector) leads to an oscillation of the induced magnetic field (*i.e.*, a variation in the direction of the magnetic field vector). This effect excites the particles of the material to be heated, causing the spin of the electrons of which the matter is made to continuously change. This continuous change generates a *Joule effect* that causes the thermal load in the material under inspection.
The *Beta 1852 R* heater designed for this application has a 50Hz fixed frequency circuit, therefore, to vary the heating effect the user can act only to the working time or distance between the coil and the

component. This choice was dictated to generalize the experiment, allowing application also through common and non-dedicated equipment.

Given the high computational cost that would arise in *COMSOL Multiphysics®* for coupling *Heat transfer in solid* and *Magnetic field* functions, a separate numerical model was adopted for such a large mesh. The aim was to evaluate the thermal imprint released on a flat bronze plate considering a frequency of 50Hz by varying only the working time and the heater-sample distance. The governing equations of the modelling are the following [12]:

$$E = -j\omega A \tag{5}$$

$$\nabla \times \boldsymbol{H} = \boldsymbol{J} \tag{6}$$

$$\boldsymbol{B} = \nabla \times \boldsymbol{A} \tag{7}$$

$$\boldsymbol{J} = \sigma \boldsymbol{E} + j\omega \boldsymbol{D} \tag{8}$$

With $\boldsymbol{E}$ electric field *[V/m]*, ω angular frequency *[rad/s]*, $\boldsymbol{J}$ current density volume *[A/m²]*, $\boldsymbol{H}$ magnetic field *[A/m]*, $\boldsymbol{B}$ magnetic flux density *[T]*, $\boldsymbol{A}$ magnetic potential (vector) *[Wb/m]*, σ electrical conductivity, and $\boldsymbol{D}$ electric displacement or electric flux density *[C/m²]*.

Fig. 4a) shows the model generating information vectors used in the final modelling. The coupling of these two models allowed us to obtain the thermal behavior occurring at a 10 mm distance between the solenoid and the SUT at different times (see Figs. 4b), c), d), e), and f)).

The choice of 10 mm distance was dictated by a series of numerical tests; it was assessed that for shorter distances, the heating effect is too sudden, *i.e.* in the order of hundredths of a second, while for greater distances, the bronze is affected by a very slow magnetic field. Figs. 4 b), c), d), e), and f) also show how the user has the possibility of choosing the working time to obtain an appropriate thermal contrast for the *in situ* thermographic measurements. The authors will consider equipping the electrical connection of the heater to a programmable time switch to control the evolution of the thermal imprint; this is the future perspective of the present work.

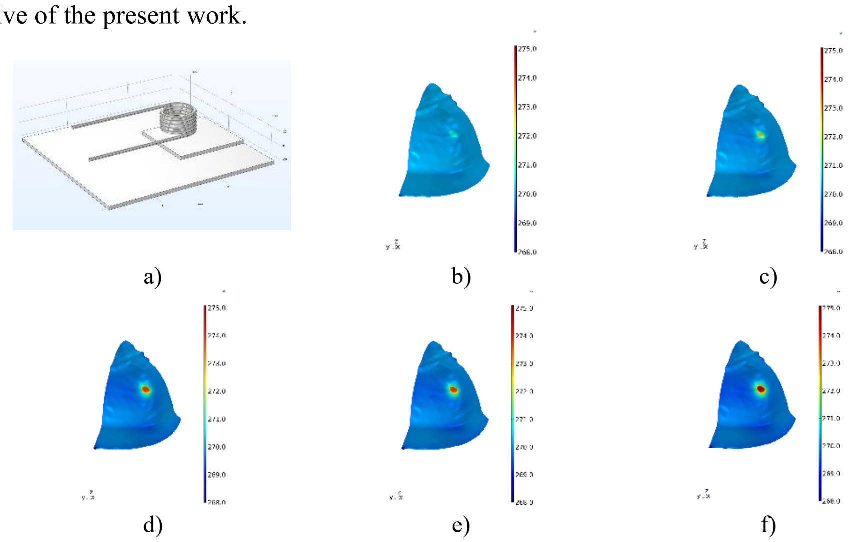

Fig. 4. Numerical model of the magnetic analysis coupled with *heat transfer in solid* and subsequent application of the coupling results to the original model for the study of the local thermal contrast: a) modelling of the active inductor for the study of the imposed thermal contrast; b) local effect of the heater on the bronze helmet using a magnetic inductor working for 0.2 s; c) 0.4 s; d) 0.6 s; e) 0.8 s; and f) 1 s.

4 Conclusions

In this work, thermal imprints retrieved in an ancient helmet via a complex numerical analysis involving the use of an advanced 3D laser scanner were evaluated by setting thermophysical parameters and boundary conditions inherent to specific years.

In the years 2007 and 2024, thermal images were indeed recorded and their comparison helped to understand the evolution over time of the corrosion process.

With a view to a future thermographic inspection aimed at analyzing with greater detail the corrosion in the helmet, it was considered of interest to evaluate whether the thermal load, usually provided by the passive thermography approach in artworks facing the sun, could be replaced by an equivalent one given by an inductive heater. The analysis led to satisfactory results, allowing the obtaining of appropriate

thermal imprints using a commercial and non-dedicated inductive heater, leaving the probe working time as the only parameter to be controlled.
In the future, an *in-situ* induction thermography analysis supported by such a numerical procedure will be performed to validate our preliminary results.

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Study of Indoor Air Quality Impact During Building Demolition: A Case Study of the 2009 L'Aquila Earthquake Reconstruction

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I. ABSTRACT

This study focuses on the 2009 earthquake in L'Aquila, Italy, as a case study. A user-friendly household monitoring method was adopted for systematic data collection, aiming to enhance the comprehensive understanding of particle pollution. Multivariate statistical methods, such as principal component analysis and partial least squares regression, were implemented for data analysis. Additionally, a deep learning model is developed to predict the diffusion patterns of dust around demolished buildings. By combining traditional statistical techniques with advanced analytical tools, it is expected to gain deeper insights into the complex dynamics of air quality during the building demolition process.

II. INTRODUCTION

L'Aquila, known for its seismic vulnerability and rich historical heritage, suffered considerable damage from the 2009 earthquake. The subsequent building demolitions during the reconstruction process in the affected areas led to increased concentrations of particulate matter in the air, potentially causing health issues. Consequently, effective monitoring of these particles is essential. Monitoring and mitigating airborne pollutants during demolitions is particularly crucial for the holistic safeguarding of communities, which is important to informing resilient and sustainable reconstruction plans. Previous studies have convincingly demonstrated the link between air pollution and climate variables [1, 2]. In this study, in-home monitoring was conducted in houses adjacent to demolition sites. The analysis specifically examined the relationship between weather parameters and suspended particulate matter.

III. DATA COLLECTION AND ANALYSIS METHODOLOGIES

For this study, data collection was carried out using the Particle Counter PC220, manufactured by Trotec. This instrument was placed on the windowsill opposite a building being demolished due to earthquake damage, as depicted in Figure 1. It was designed to capture particle sizes of 0.3μm, 0.5μm, 1.0μm, 2.5μm, 5.0μm, and 10μm, thereby facilitating the measurement of suspended particulate matter in the atmosphere. In addition to this, the instrument simultaneously monitored environmental parameters such as atmospheric temperature (AT), relative humidity (RH), dew point (DP), and wet-bulb temperature (WB). Wind speed (WS) was also measured, utilizing the central control system located in proximity to PC220. This setup provided a comprehensive overview of the environmental conditions prevailing during the demolition process.

Fig. 1. Target building and instrument setup

Four key techniques were employed for data analysis in this study: principal component analysis (PCA) [3], partial least squares (PLS) [4] mutual information (MI) analysis [5], and deep neural networks (DNN) [6]. PCA is a widely-used multivariate statistical method for reducing dimensionality. It transforms data into uncorrelated principal components (or scores), arranged so that the initial

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components retain most of the variations from the original variables. The coefficients, known as loadings, link the original variables to the scores and offer insights into the data's structure and relationships. PCA is particularly effective for exploratory data analysis. PLS, on the other hand, is a linear regression technique well-suited for situations with highly collinear variables. MI analysis, meanwhile, measures the information one variable contains about another, quantifying the degree of dependency between variables. This tool is especially valuable for identifying nonlinear correlations among variables. DNNs are sophisticated machine learning models composed of multiple layers of interconnected neurons. These networks are capable of learning complex data patterns. In this research, a fully connected feedforward neural network was utilized, selecting the rectified linear unit as the activation function.

IV. RESULTS AND DISCUSSIONS

The collected data, including five climate parameters and the particle amount for six different particle sizes, were subjected to the PCA method for dimensionality reduction. The results are presented in Figures 2(a) and (b). Specifically, the loading plot shows that climate parameters and amounts of suspended particles are nearly orthogonal, indicating the particle amounts cannot be accurately predicted with a linear model. This finding aligns with the results of the PLS model, which uses climate parameters as input variables and outputs not only the total quantity of particles but also the specific amounts for each of the six distinct particle size categories. The prediction outcomes for both the training and test sets, as illustrated in Figures 2(c) and 2(d), demonstrate subpar performance. The R2 values, indicating prediction performance, were less than 0.15, with even negative values observed in the test set. However, the MI values for climate parameters in relation to total particle amount are 5.09, 5.78, 4.38, 4.46, and 4.52, respectively, indicating that the variables may be nonlinearly correlated. Therefore, it is reasonable to adopt a DNN model. The initial findings are shown in Figure 3. The R2 values for the total particle amount in these datasets, at 0.36 and 0.31 respectively, indicate a moderate level of predictability. This outcome might stem from limitations in the data collection methodology, particularly oversights in parameters like local wind direction around the monitoring site, leading to an incomplete assessment of atmospheric disturbances. However, this presents opportunities for future research to enhance the dataset collection process.

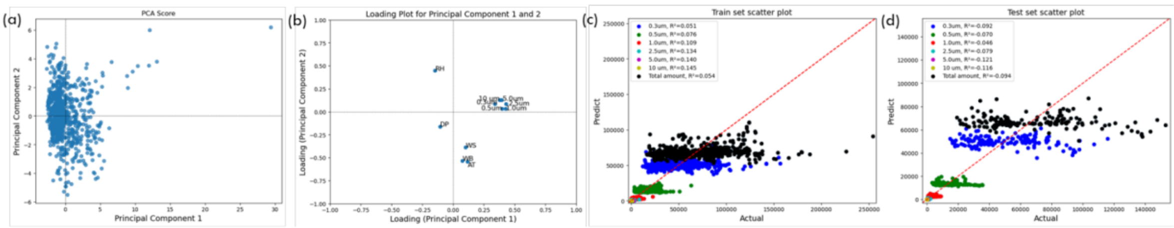

Fig. 2. (a) PCA score plot, (b) PCA loading plot, (c) PLS training set predictions, and (d) PLS test set predictions.

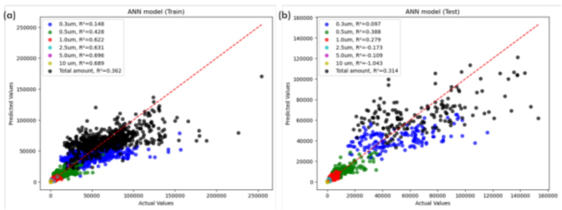

Fig. 3. DNN model predictions: (a) training set, and (b) test set

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Materials characterisation and damage assessment of the ancient kiln of Kirra, Greece

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I. EXTENDED ABSTRACT

The aim of the study was the development and implementation of a methodology for the characterization and damage assessment of the building materials of a prehistoric kiln excavated at Kirra, Greece. Northeast of the center of the modern settlement of Kirra is the archaeological site where the kiln was found. The kiln was excavated in 1984 and 1989 by the French School at Athens and is dated to 1450-1400 BCE [1]. The kiln is of the updraft type, and it's mainly constructed by mudbricks (Fig. 1). Based on Hasaki's typology, it's classified as a type Ie kiln since it is circular with three parallel walls on the long axis [2,3].

Fig. 1. The kiln as it is preserved today **Fig. 2.** 3D reconstruction of the kiln with depth measurements

Mud brick structures are dramatically susceptible to water as it triggers different deterioration phenomena, the results of which are clearly visible in the many decay features on site. For this reason, the excavation is temporarily covered by a typical "Dexion" type canopy for protection from rainwater. A pump is also installed near the entrance of the combustion chamber to pump out groundwater and restrain rising damp.

Although mud brick has been used in different structures worldwide since the early Neolithic times and is therefore encountered in many archaeological contexts, there is no consensus on the best practice for its documentation, analysis, and preservation. Because of the significant efforts necessary to preserve inherently unstable earthen structures, as well as the significant costs of the development and

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implementation of sustainable conservation and maintenance methods, the preservation of ancient mud brick architecture remains a challenge and is still not standard practice.

A methodology was developed and applied in this work to characterize the building materials, to examine the preservation state of the kiln, and to document its pathology in order to design conservation treatments:

- Photogrammetry was used to create 3D models of the kiln before any interventions (Fig. 2).
- Environmental monitoring was performed by collecting climate and microclimate data with the use of a data logger. The data logger measured the air temperature (T) and the relative humidity (%RH) in hourly intervals and stored the data. For the macro scale, climate conditions data were collected from meteorological stations near the archaeological site.
- Sampling was carried out from different parts of the kiln to characterize the building materials and to study the weathering phenomena. Samples were studied with Optical Microscopy (OM), Scanning Electron Microscopy coupled with X-ray Spectroscopy (SEM/EDS), and X-ray Diffraction (XRD).
- Non-Destructive Testing (NDT) was applied by using infrared thermography to investigate the sources of moisture, a hygrometer to measure the moisture content, and a penetrometer to estimate the compressive strength of the building materials.

The structural elements of the kiln show extensive and irregular weathering. Advanced loss of material has been observed, which has resulted in a gradual change in the shape of mudbricks and mortars. The weathering of swellable clays gradually leads to the collapse and loss of the kiln's building materials. Aqueous solutions transfer soluble salts which, depending on the conditions, crystalize near the surface, causing deterioration. Furthermore, aluminosilicate minerals and clays can induce significant "hygric stress".

The ways in which mud bricks and clay mortars can become contaminated with salts are the soil, from which salts may be carried into the kiln's building materials by rising damp, and sea-salt particles blown by the wind. Salts cause damage to mud bricks in several ways. The most important is the growth of salt crystals within the pores of an element, which can generate stresses that are sufficient to overcome the brick's tensile strength and turn the brick to a powder.

There is evidence that another important decay mechanism is related to what is called "differential stress." This decay mechanism includes the effects of clay swelling, differential hygric stress, and stress from differential expansion rates of material in pores (such as salts). The general idea is that treatments, salts, water films, —anything that causes the building material's surface to react differently than the interior— can result in a shear stress, and, eventually, surface parallel detachment (e.g., flaking). For example, significant shear stress is generated when, during an increase in relative humidity, the surface of clay-containing brick swells while the interior of the brick remains dry. Osmotic swelling (salt-activated clay swelling) is probably another significant decay mechanism in the case of Kirra's kiln.

Conforming to the internationally agreed principles for the protection and management of archaeological heritage, foreshadowed by Flinders Petrie in 1904, earthen structures should not be left exposed after excavation if provision for their conservation, maintenance, and management is not guaranteed.

The preservation of mudbrick structures is relatively complicated and expensive. Research has focused on the circumstances that enable preservation and the influence of climate and weather over time. Conservation treatments should address these two processes as soon as possible after exposure of the structures. Our assessment of a range of conservation methods leads to the conclusion that reburial is among the least objectionable methods of preservation, despite its drawback of returning the excavated buildings to a situation where they are invisible to both researchers and the public.

Reburial can be proposed as a temporary emergency treatment or as a means of providing long-term protection. Although it hides the original elements from view, the procedure is reversible, allowing future study or additional conservation treatment. Besides any necessary treatment before reburial, the method is non-invasive and greatly reduces the immediate need for detailed conservation as well as long-term maintenance.

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Part V

Thematic Area 4 - Natural and Anthropogenic Damage Hazards

The conservation plan for Morosini fountain: an opportunity for reflection and redefinition of the norms

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Abstract. The Morosini fountain is a Venetian monument located in Crete; it is a symbol for the city of Iraklio and the pride of the local society; it is a work of art, an enigma for historians and archaeologists, a tourist attraction, and a meeting point. But most of all, it is the bearer of a long history narrated by its patina. Our duty as conservators and our approach as members of a central public organisation, the Directorate for the Conservation of Ancient and Modern Monuments of the Hellenic Ministry of Culture, is to ensure and empower the continuation of this narrative.
Undertaking the task of planning the conservation strategy for the four stone lions and the reliefs with scenes from the sea world was the equivalent of one word: complexity. The monument's preservation state lead the way; its location in an urban and marine environment and the previous interventions it has undergone, were determining to our approach; an approach based upon optimum documentation and understanding of its deterioration signs and mechanisms, towards the formation of several alternatives for long term sustainable conservation and management.
Our quests evolved around the three elements that define the fountain's current state: the impact of water, the urban environment, and the interventions of the past. The project was developed in three axes: thorough documentation, analytical techniques, and historical and archival research on its history and past conservation. Collaboration with the Department of Conservation of Antiquities and Works of Art of the University of West Attica assisted the Directorate's commitment to an interdisciplinary approach to the conservation plan.
With this paper we wish to address the issues that we were engaged with during the project and our overall perspective, to highlight the dynamics of interdisciplinary collaborations for the purposes of conservation plans, and perhaps to insinuate a transposition in future priorities, approaches and norms of the conservation plans and the proposed solutions.

Keywords: Relocation, 3D documentation, previous interventions

1 Introduction

The Directorate for the Conservation of Ancient and Modern Monuments (DCAMM) undertook the task of developing a conservation plan[1] for the Morosini fountain, a Venetian monument in Crete, in response to the request of the Iraklio Archaeological Ephorate. The key factors for the plan's methodology were the complexity and the monument's critical preservation state. Macroscopic evaluation of its current pathology highlighted the urgency for its thorough documentation. Therefore, the conservation plan methodology evolved into three main strands:

1. Archival research in search of data related to past conservation interventions. The archives of the Iraklio Archaeological Ephorate, the Directorate of National Archive Management (Historical Archive of Antiquities and Restorations), and the DCAMM archive were studied.
2. Archaeometric analyses on stone and mortar samples. A stage deemed necessary as it would contribute significantly to the documentation and detection of the deterioration processes causes, thus

[1] Conservation plan or study: document on the conservation of ancient, historic and modern monuments aiming to ensure their integrity and make them accessible to future generations. It focuses on the conservation of the monuments' surfaces and decorative details, not their structural state. According to international literature, conservation plans in other countries encompass guidelines for overall site management [in Greece: management plan (διαχειριστικό πλάνο)] providing instructions for conservation in technical reports. Further reading: Teutonico, J.M. Palumbo, G. Management Planning for Archaeological Sites, The Getty Conservation Institute, Los Angeles. (2002); Conservation Plan. A Guide to the Preparation of Conservation Plans, Heritage Policy …Safeguarding Built Heritage, Historic Scotland. (2000).

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fulfilling a critical aspect of the study. Non-destructive and destructive techniques were employed aiming to investigate the external layers –natural and anthropogenic– and the conservation materials used over time. Analysis was conducted in collaboration with the Architectural Conservation Laboratory of the Department of Conservation of Antiquities and Works of Art at the University of West Attica and Assistant Professors Alexis Stefanis and Georgios Mastrotheodoros.

3. A 3D documentation of the monument by means of close-range photogrammetry and laser scanning. The 3D documentation was assigned to the Department of Conservation of Antiquities and Works of Art at the University of West Attica and led by Associate Professors Dimitris Makris and Leonidas Karampinis and the Conservator of Antiquities and Works of Art and PhD Candidate Christina Sakellariou.

2 Description of the fountain

Fig. 1 Morosini fountain
[Source: https://aboutheraklion.com/sightseeing-in-heraklion/fontana-morosini/ last accessed 23-05-2024]

The Morosini fountain is located in Iraklio, the largest city and port of Crete[2]. It was constructed in 1628 during the prosperous Venetian times (1211-1669)[3] by General Proveditor, Francesco Morosini (1619-1694) as part of a grandiose aqueduct that provided the city with water. Despite the technical difficulties, the aqueduct was constructed with funds from public representatives, the clergy (Latin and Orthodox), and a small contribution of the public treasury [Spanakis, 1981: 58-60, 68][4]. Morosini was proud of the major project and placed the elaborate fountain in the central square of Candia –as Iraklio was then called– the Piazza delle Biade [Spanakis, 1981: 85-86].

The fountain's decorations have been attributed to the sculpture workshop of brothers Thomas, Michalis, and Mathios Benetos, also known as Frabbenetos, from Rethimno (Kazanaki-Lappa, 2009: 752)[5] as is made known to us by poet Marinos Tzanes Bounialis (1620-1685) in his poem: *Cretan War - The Rivalry of Candia and Rethimno*. [Ξηρουχάκης, 1908: 584][6]. The decorations' theme was inspired by Morosini and Venetian-Cretan scholar and amateur engineer Zorzi Corner (1583-1647), who was also a supervisor of architectural design and construction [Hrisohoou & Vincent, 2001: 370][7]. The reliefs'

[2] «Iraklio Crete », https://ellinismos.gr/istoria-ellinismoy/topikes-istories/irakleio-kritis/ last accessed 2024/04/04.
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[6] In the poem the personification of Rethimno speaks of the artists who work in Candia but come from Rethimno: «[...] I gave you the Frabbenetos and they honoured you and made your Gigante and adorned you beautifully [...]» («Τση Φρα Μπενέτους σου 'δωκα κ' εκείνοι σ' ετιμήσαν κι εκάμε [sic] το Τζιγάντε σου και εύμορφα σε στολίσαν […]») [Xirouhakis, A. O Kritikos polemos (1645-1669). I silogi ton elinikon piimaton Anthimou Diakrousi, Marinou Zane, tipis tou austriakou Loyd, en Tergesti (1908)].
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profound differences in terms of their details quality are a strong indication that it was the work of different individuals; it has been assumed that Thomas Benetos created the now missing statue of Poseidon or «Gigante» (giant)[8] and the reliefs and lions were distributed among all three brothers [Kazanaki-Lappa, 2009: 756].

The fountain is a free-standing structure consisting of a stepped platform, an octagonal basin with eight lobe-shaped ends, an octagonal central pedestal with four fully sculpted lions on the backs and tails of which is a small circular basin where once stood the supernaturally sized statue of Poseidon. Water was poured through the lions' mouths, and four holes in the basin, and the eight deep lobed-shaped ends increased the circle's circumference to serve more people [Spanakis, 1981: 73-74]. Twelve marble basins among the lobes were for watering animals [Varthalitou, 2021: 107, 114-116] [9]. The octagonal basin consists of 32 limestone panels joined together by a thin layer of mortar. The relief decorations depict a sea-themed procession with a multi-faceted composition of marine beings and other marine mythological creatures symmetrically developed with eight crests of Venetian officials [Spanakis, 1981: 74, Isychaki-Fatourou, 1991: 664· Kazanaki-Lappa, 2009: 845]. The monument has engaged scholars with questions regarding its original composition. What happened to the statue of Poseidon remains unknown and historical testimonies are contradicting[10]. It has also been claimed that the lions are not inherent to the original structure but constitute a later addition substituting the statue of Poseidon [Spanakis, 1981: 70, footnote 131]. Morosini's report, however, compiled the day after its inauguration, refutes any such speculation [Gerola, 1932: 52][11].

The Turks, who conquered Candia after the Venetians, rechannelled water in the aqueduct (they had disrupted it during the siege); Defterdar Ahmed Pasha converted the church of St. Mark into a mosque (Defterdar Mosque) and to facilitate worshippers, he opened holes in the lobes of the basin [Stavrinidis, 1969: 1][12]. In 1847 the divan (council) of Mustafa Naili Pasha (1798-1871) decided to enclose the fountain with marble columns and a marble top band adorned with golden Turkish letters and renamed the fountain «Abdul Mejid Fountain» in honour of the Sultan, who would visit Heraklion in 1850. The additions were removed by decision of the Municipal Council on May 29 1900. In 1924, archaeologist Stefanos Xanthoudidis (1864-1928) wrote to the Municipality about the condition of the fountain: «[...] a container of waste at risk of destruction, as detachment and total loss of a piece from the marble frame of the basin were recently observed [...]» [Spanakis, 1981: 97].

3 The monument's current preservation state

3.1 Sources of deterioration

Today, the fountain of Morosini is a listed monument bearing the values of age, history, art, and modern economic value for the local community as a major tourist attraction. Most of all, it is the legacy of future generations, and the responsibility for its protection and overall management has influenced our perspective during the project. While studying the monument in the context of its conservation plan, the first step was to define and comprehend the main sources of the deterioration that determine its preservation state. These are:

Previous conservation interventions They have been documented by archival data and archaeometric analysis, and it is a factor considered to have had a great impact on the monument, with long-term,

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[8] The medal struck to honour the event, had Morosini on one side and the fountain on the other with the statue of Poseidon. The lions are not discernible and in the sky Zeus is depicted pouring water from a vessel accompanied by the phrase: GAVDET FLUMINE NON FULMINE (Jupiter is pleased with water, not with lightning) and the inauguration date (MDCXXVIII-1628) [Spanakis, 1981: 85-86].

[9] Varthalitou, St. Peritehnes krines me glipto diakosmo. Sto: Vakondiou, M. Gratziou, O. (epim.) I gliptiki sti Venetiki Kriti (1211-1669).Tomos protos: Meletes, 105-141. Panepistimiakes Ekdosis Kritis, Iraklio (2021).

[10] According to General Proveditor Isero Civran, in 1639 the statue had not been destroyed, it may have been temporarily removed and later reinstalled [Spanakis, St. I ekthesi tou genikou provlepti Isero Civran (1639). Kritika Hronika (21), 365-458, EKIM: Iraklio (1969)]. 17th century Turkish traveller Evliya Çelebi, (1611-1682), was present in Candia's conquest (1668). He mentions he had seen the statue but not its «mutilation». He recorded everything he saw in his notes which in his old age he turned into a ten-volume travelogue (*Seyahatnâme*), a rare source of information for the period even though his reliability has been questioned [Dimitriadis, V. Mnimia tou Irakliou kata ton Evliya Çelebi», Ariadni (56), pp. 213-219. (1993)]

[11] Gerola, G. I monumenti Veneti dell' Isola di Creta. Ricerche e descrizione fatte dal dottor Giuseppe Gerola per incarico del R. Istituto Vol. IV, Istituto Veneto di scienze, lettere ed arti: Venezia. (1932)

[12] Stavrinidis, N. I filanthropikes krines tou M Kastrou. Efimerida Patris, 15/11, p. 1. Iraklio. (1969)

perhaps even irreversible causing of decay. Archival research and examination of administrative correspondence and technical reports, confirm conservation interventions since the mid 1970's[13].

1976. Execution of the first hands-on conservation program. The 13th Byzantine and Post-Byzantine Ephorate[14] contacted the Directorate of Antiquities and Restoration, listing the problems of the fountain (extensive stone cracks, oxidation of iron joints, fractures, and loss of material, and deposits of atmospheric pollutants) and requesting guidance for its conservation[15]. The Directorate's conservation proposal, signed by architect Anastasios Portelanos, was approved and implemented, and it included filling deep cracks with a marble adhesive and superficial ones with a silicone product (trade name PRODOIASTIC SK 93), replacing iron joints with stainless steel ones, removing deposits with solution of a cleaning agent (the trade name D-SPLENDO)[16] and thorough scrubbing. For protection against peeling, a silica product (trade name TEGOVAKON H) was recommended[17].

1980's. In the mid-1980s, efforts for the conservation of the monument intensified. In 1983 dates the first written communication of the local authorities with the Directorate of Antiquities Conservation (DAC) (today DCAMM)[18]. The Ephorate requested an inspection by an expert, which was conducted by sculptor and marble conservator Ioanna Stipsianou. Following her inspection, Stipsianou submitted a report with her proposal having taken into account the conservation program that had been implemented seven years earlier and recommended removal of deposits by mechanical means emphasizing: «[...] without any use of chemical materials to avoid further erosion and destruction of the monument [...]», and use of a solvent-free silicate product (trade name STEINFESTIGER) for preventive protection[19].

The DCA proposal was never implemented because the Ephorate characterized it as empirical, comparing it to an approach being developed by the Ephorate and the Stone Institute, the latter represented by chemical engineer Nikos Beloyannis (1951-2020). In a report of 1987 signed by the Ephorate and Beloyannis, biological colonisation, chemical decay due to water, salts, and atmospheric pollutants manifested by scaling, were registered. The report stressed the significant role of salts in the decaying processes and correlated it to materials from past conservation. The main deterioration agents, apart from water, vibrations, human presence, and the stones' natural properties, were mentioned. The conservation proposal comprised preventive and remedial measures, such as the use of filters in the water, protective vegetation walling to prohibit access to the monument, removal of biological formations with a combination of chemical agents [Desogen, hydrogen peroxide, Vancide 51, Primatul-CIBA were mentioned], removal of salts and deposits with compounds such as acetone, chloroform, EDTA, trichloromethane, and mediums such as sepiolite and micro-abrasion). Consolidation was recommended,

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[13] The earliest activity on the monument's conservation is registered in 1969 through correspondence of the Ephorate and the Municipality for estimation of the costs for its conservation (Iraklio Ephorate Archive, F. Morosini Fountain, Prot. N. 1437/21-12-1969). In 1971 there was public disclosure in the local press of vandalism incidents and misuse of the monument by locals and tourists, a phenomenon that was not dealt with until the mid-1980's after having tried many solutions such as railings, plants and a water-barrier. The latter was established and remains until today. (Iraklio Ephorate Archive, F. Morosini Fountain, Letter of Robert Paters, director of a travel agency «Mediterranean Travel System» to the Municipality on 21-08-1971. I Krini Morosini. Efimerida Mesogios, 27-05 και 28-09 (1978)· Letter of Ephorate to the Directorate of Antiquities and Restoration, 30-10-1984).

[14] 13th Ephorate of Byzantine and Post-Byzantine Monuments Ephorate will be referred to as «Ephorate».

[15] Iraklio Ephorate Archive, F. Morosini Fountain, Request of Ephorate to the Directorate of Antiquities and Restoration of the Ministry of Culture and Sciences, No Prot. N. 27-02-1976.

[16] During research no further information on the material was found.

[17] Two-component organic silica gels widely used in the 1970's for consolidation and waterproofing of sandstones combined with other agents. Depending on the chemical nature of the catalyst they were unstable and exhibited cracking. TEGOVAKON H's catalyst was acid which made it more stable compared to other formulations [Brus, J. Katlik, P. Cracking of organosilicone stone consolidants in gel form. Studies in Conservation (41), pp. 55-59. (1996); Wheeler, G. Alkoxysilanes and the consolidation of stone. Research in conservation, The Getty Conservation Institute: Los Angeles. (2005); Nano-cathedral, Document on historical/architectural/environmental knowledge of buildings (2016)]. Iraklio Ephorate Archive, F. Morosini Fountain, Directorate of Antiquities and Restoration of the Ministry of Culture and Sciences, «Cleaning and conservation of Morosini fountain. Technical description » Prot. N. 13-04-1976. Iraklio Ephorate Archive, F. Morosini Fountain, Prot. N./12427/1121/19-04-1976, Prot. N. 720/08-06-1976.

[18] Iraklio Ephorate Archive, F. Morosini Fountain, Prot. N. 1302/15-04-1983.

[19] «[…] χωρίς καμμία [sic] χρήση χημικών υλικών για να αποφευχθεί η παραπέρα διάβρωση και καταστροφή του μνημείου […]». Stipsianou had consulted sculptor Stelios Triantis (1931-1999) before forming her proposal (DCAMM Archive, Box 13th Ephorate of Byzantine Antiquities, F14 – Iraklio, Prot. N. 644/11-08-1983 (Iraklio Ephorate Archive, F. Morosini Fountain, Prot. N. /F/14/917/65612/06-12-1984). On STEINFESTIGER: https://www.caparol.de/caparol_pim_import/caparol_de/products/ti/95767/TI_1039_EN.pdf last accessed26-04-2024).

conditions for its execution were mentioned (penetration, sweating, thermal expansion, aesthetics, and reversibility) but not elaborated, and an acrylic medium (trade name PARALOID B72) in an organic solvent was suggested. Finally, as an imperative preventive measure against atmospheric pollution and water action, the application of a «…special invisible film…» [sic] was recommended. The material had to be reversible, aesthetically compatible, hydrophobic (allowing stone to breathe), dust repelling, and have a penetration coefficient similar to that of the stone. A chemical agent (trade name FOMBLIN Y MET)[20] was noted, which, according to the report, had been used for conservation at the Palazzo Pitti in Florence and at the Palazzo Piccolomini d' Aragona in Siena.

In a supplementary report, Beloyannis proposed use of EDTA patches enhanced with ammonium bicarbonate, hydrogen peroxide or Desogen and mentioned the need to remove materials from previous interventions –to which he referred as «exfoliating varnishes»– that had decayed by «…scrubbing with a very hard sponge…» and use of «…NITROMOS[21] [sic] or dimethylformamide...». As a preventive measure, he suggested channeling water directly into the basin, thus minimizing the formation of new deposits and discoloration, by installing ceramic drains at the mouths of the lions and a water barrier to prohibit access. The conservation proposals of 1987 were implemented in 1988, and according to a technical report on the conservation of reliefs, surfactant soap (trade name TEXAPON) and EDTA patches with carboxymethyl cellulose (CMC), sodium, and ammonium bicarbonate were also used [22].

1990-1991. Documents dated 1990 and 1991 on works prompted by the fracture and detachment of a fragment from one of the lions provide information on the replacement of cement insulations with a lime mortar, removal of pollutants with organic solvents and sepiolite, and impregnations with silicic esters, calcium and barium hydroxide for reinforcement. For reinstatement and adhesion of the fragment onto the sculpture, acrylic resin Paraloid B72 in toluene was suggested, with titanium or steel elements[23].

2002-2008. Detachment occurred again on the same lion head in 2002 but this time on the other side of its face. The Ephorate decided to deal once and for all with what was proving to be the main deterioration source: salts. The representative conservator of the 28th Ephorate of Byzantine Antiquities based in Rethimno proposed dismantling of the entire monument and transfer of its elements to the Ephorate's laboratory in Rethimno, claiming it was the only place with availability of personnel with the necessary expertise and adequate spaces and facilities for desalination of the fountain[24]. The proposal was approved, and in 2002-2003, the extensive interventions that would last until 2008 began, with the dismantling and transfer of the standing monument.

A conservation plan was approved by all competent authorities in 2003, according to which the issues that had to be addressed were biological colonization, cracks and fractures caused by vandalism, vibrations, operational interventions, loads, unsuitable materials and mortars, and oxidised metal joints, and chemical damage due to a combined action of atmospheric pollution, salts, and the wind. Gypsum and black encrustations were also reported, most likely mistakenly, since proposals for their addressing were not approved by the DCA [Troullinos, 2003: 58-62]. Also, five different mortars from previous interventions were macroscopically identified, but no further details on their composition or provenance are provided [Troullinos, 2003: 55-56]. Conservation proposals included mechanical means for cleaning because, as it was specifically noted: «…it is the only fully controlled method». The only chemical method concerned the removal of rust, a solution of thioglycolic acid, and neutralization with ammonia. For consolidation, impregnations with calcium hydroxide were recommended, along with a compound with polyvinyl alcohol, water, tris hydrochloride (tromethamine), and glycerine (trade name GELVATOL)[25] on all surfaces, and a vinyl acetate emulsion (trade name Mowilith)[26] in acetone, placed in subsequent layers. Finally, thorough consolidation of impregnations with calcium hydroxide was proposed

[20] Fluoride agent, water-permeable, reversible, but with serious drawbacks due to concurrent use of chlorofluorocarbon solvents, and its low surface tension that encouraged migration of its components in the stone structure [Pasetti, A. Fomblin Y Met: un nuovo protettivo corticale. In: Atti Convegno Riabitat, Ed. Sagep and Piacenti, Genova. (1984); Matteoli, R. Tiano, U. Manganelli Del Fa, P. Fratini, C. Scala, A. New protective agents for stone materials. International Congress for Deterioration and Conservation of Stone, Lausanne. (1985)].

[21] Paint stripper with the trade name «Nitromors», an agent containing solvents and bleaching agents [https://cdn.shopify.com/s/files/1/0604/7380/2968/files/NPV375_NITROMORS_AP_PAINT_VARNISH_REMOVER_16-082021.pdf?v=1653398023 last accessed 24-04-2024).

[22] Iraklio Ephorate Archive, F. Morosini Fountain, Report of M. Troullinos, Prot. N. 446/1100/28-03-2002.

[23] Iraklio Ephorate Archive, F. Morosini Fountain, Prot. N. F105/53412/2516/18-12-1990.

[24] Iraklio Ephorate Archive, F. Morosini Fountain, Prot. N. 446/1100/28-03-2002.

[25] «GELVATOL MOUNTING MEDIUM RECIPE» (https://imb.uq.edu.au/files/5303/GelvatolMountingMediumRecipe_1.pdf last accessed 28/04/2024).

[26] «Mowilith» (https://adhesives.specialchem.com/selectors/tr-mowilith last accessed 28/04/2024).

[Troullinos, 2003: 187-194]. After the fountain was returned to its original place, the upper basin was insulated with a lead sheet, a biocide agent was used for preventive purposes, and calcium hydroxide was used as a consolidation medium[27].

Works ended in July 2008[28] and since then conservation has been based on the approach of minimum interventions of preventive nature, such as systematic removal of birds' excrements and loose deposits, and minor consolidations without any new materials being introduced.

2017. In 2017, remedial works were carried out by the conservators of the Ephorate, according to a report by the head of the Ephorate's Conservation Department, Konstantinos Patedakis, in May 2016[29]. The works aimed at improving the state of the monument by addressing issues that originated from its inner core and affected the entire structure. Detection of water leakage from the upper basin onto the lions, the pedestal, and the reliefs, and intense development of biological colonization, salt efflorescence, and scaling, revealed that the lead sheet no longer served its original purpose. When the lead sheet was removed, cracks were revealed, water leakage in the interior of the basin was verified, and it was ascertained that the cracks had been sealed with synthetic resins of unknown composition, and stainless steel joints were connecting the basin to its base. The following works were characterized as critical and executed urgently: waterproofing of the basin with lime mortar reinforced with fiberglass mesh and synthetic fibres to channel water directly to the lions' mouths and insulated with a mortar of white cement, marble dust, and an acrylic emulsion in water (trade name Primal), mechanical removal of salts and biological deposits with biocides, consolidation of scaling with mortar through micro-injections, and sealing of cracks with lime mortar

Evaluation of the recorded conservation works of the past Analysis of data from the archives of all relevant organisations has confirmed that over a period of 51 years (1976-2017), at least 36 different materials were applied to the monument, which, in conjunction with its dismantling and transfer, determined its current preservation state to a degree that may never be fully comprehended and reversed. Evaluation of the conservation approaches of the 1980s and 1990s must consider the challenge that the serious decay phenomena of the monument must have been for the people who were called to treat them and ought to be done under the light of the era's trend in conservation which shows a clear preference to chemical methods. The conservation programs of 1988 and 1990-1991 provided solutions to the problems and were relevant to the general context of practical conservation in Greece at the time.

As far as the conservation programme of 2002-2008 is concerned a change in the approach is clearly noticed. The relatively conservative remedial approach that Stipsianou had proposed in the early 1980, which had then been considered empirical, was later preferable and valued as controlled. The dismantling and transfer of the monument to another location by putting forward desalination as the main argument for the decision was, in our perspective, an unfortunate and unnecessary action. Dismantling a standing monument may only be justified if it forms a permanent solution; if the conditions under which a unique monument exists trigger such a high decay rate that its relocation to a controlled environment and its replacement with a replica is the only way to be safeguarded. In such a case, thorough desalination may also be justified, otherwise desalinating a standing monument, and indeed one so heavily burdened by previous interventions without treating the salts' original source, is a futile and dangerous process after which the monument becomes even more vulnerable than before to any source of decay.

The systematic and stable, conservative approach with preventive character of minimum and absolutely necessary interventions that the Iraklio Ephorate has maintained since 2008 seems to be the only option until a radical and final solution is developed.

Presence of water (and salts) The impact of water has been minimised to some extent, but it has not stopped; Iraklio Ephorate restored insulation of the upper basin and stopped the prolonged water leakage inside the structure. The fountain as a standing monument is, by definition, exposed to water from natural processes –rainwater and the underground water table. Also, water is still circulated within the structure

[27] Iraklio Ephorate Archive, F. Morosini Fountain, «Technical report on he works that were executed in June 2004 on the Morosini fountain », Prot. N. 3484/25-08-04.

[28] According to the reports, works would be documented but the documentation that should have been submitted to the Ephorate was not located during our research. The only photographs documenting dismantling of the monument were taken by the Ephorate (Iraklio Ephorate Archive, F. Morosini Fountain, Prot. N. 7513/06-11-2003, and Technical report: «Conservation project of the Morosini fountain», 02-10-2003).

[29] Iraklio Ephorate Archive, F. Morosini Fountain, Technical report: «Preservation state of Morosini fountain and urgent conservation works», Prot. N. 52204/10-05-2016.

since it is still being used to provide water (attempts made to end this did not prosper due to public reactions). Occurrences of rising damp and water-related decay phenomena, such as biological colonization on its surfaces, are limited but not eliminated.

The presence and action of salts remain a major problem; it is clearly visible and detected by simple macroscopic observation and confirmed by examination of its pathology and by the compelling data derived from the analysis of the stone and mortar samples. The high salt concentration is directly linked to the presence of water in the monument but also with materials and practices from past conservation treatments; the irony is that those treatments' purpose had been primarily to deal with salts. As far as the extensive presence and action of salts on the monument, the role of previous conservation treatments, heterogeneous chemical agents, and harsh mechanical cleaning methods should not be underestimated. Many of the consolidants and cleaning agents might have left behind residues that contribute to salt crystallisation. The reactions of the chemical compounds among them and with the stone, combined with the impact of environmental factors, encourage the development of salts that accumulate on the stone's surfaces and in its pore micro-structure, forming efflorescence and cryptoflorescence. Finally, radical chemical and mechanical cleaning processes have damaged the patina and exposed the stone's pores to environmental salts, indirectly contributing to their crystallization

Location in an urban environment, at a sea crossroads, on a windy island The fountain is located in the urban centre of Iraklio and at the meeting point of two main streets that lead to the seafront at a very close distance from it. In the early 2000s, the area surrounding the monument and the two streets were pedestrianised. This contributed to a lowering of high concentrations of atmospheric pollutants from cars transmissions, and the accumulation of deposits due to this type of air pollution on the stone surfaces is not extensive, but it is apparent.

The other two characteristics of the fountain's location, proximity to the sea, thus exposure to a marine environment, and its temporal exposure to the strong winds, a frequent phenomenon in Crete, are combined, forming a major source of decay. Strong winds transfer salt from the sea, which deposits and accumulates on the stone surfaces and penetrates its pores, while at the same time, they gradually weather the stone surfaces, the relief, and the carved decorations.

Human presence and increasing consumption as a symbol and a tourist attraction The fountain has always been interwoven with people's everyday lives. In the course of its history, it has undergone many alterations, the most significant one being that of its role: a source of water for the community, a place of gathering, a tourist attraction, a monument. The transition has not been smooth. Collective memory changes very slowly, as do mentalities and the habits that go with them. The fountain's role as a social gathering point and its function as a source of water endanger the monument. Members of the local community and tourists need to be informed so that they become aware of the special requirements of this monument. Until recently, potentially destructive incidents of vandalism or misuse were isolated, which was encouraging for the future. Unfortunately, on May 29th 2024, during festivities for an athletic event, a very disturbing incident of vandalism took place, which caused partial breakage and collapse of one of the lions' s faces.

Finally, the monument's consumption as a main tourist attraction with serious economic and social repercussions affects its preservation state indirectly through actions such as denial to prohibit water circulation within its structure, fearing it would make it less attractive to the eyes of the visitors. We must bear in mind that the fountain's original purpose was to provide the town with water –just like many other fountains of Iraklio, none of which have water circulating in their structures today. This function, which was simultaneously a value of the fountain, was abolished the moment it became a listed monument. Before this moment, however, it was neither merely a decorative work of art nor a place for entertainment. Nevertheless, because water is, in one way or another, intertwined with the monument, its circulation must be done under specific conditions, with systematic monitoring and regulation.

3.2 Pathology and decay phenomena

The factors mentioned before function in a complementary manner, causing the following decay and weathering phenomena[30]:

- Fractures/Detachments/Cracks,

[30] Identification of the decay phenomena was done in accordance to the: Illustrated glossary on stone deterioration patterns, Monuments and Sites XV, ICOMOS. Ateliers 30 Impression, Champigny/Marne. (2008)

- Blistering (correlated with salts and materials from previous interventions),
- Disintegration (occurs in depth even though it starts from the surface),
- Scaling (fish scale-shaped detachments),
- Peeling (linked with materials from previous interventions),
- Perforation/Alveolization/Cavitation (punctures, holes, cavities with various shapes and sizes caused by wasps, marine organisms, chemical residues, wind erosion and salts),
- Erosion (leaves behind smoothly-shaped surfaces),
- Mechanical damage (mainly randomly formed abrasions by tools, transfer etc).
- Pitting (due to biological and chemical factors and harsh mechanical means of cleaning),
- Crust (mostly on the pedestal and the lions. Coherent, of various colours, homogenous thickness, strongly adhered to stone surface, drifts stone material),
- Deposits (accumulation of dust, pollutants, salts),
- Discoloration (extensive, very hard to distinguish and categorise, affects the stone in depth. Linked with salts, microorganisms, rising damp, water evaporation, materials from previous interventions),
- Efflorescence and Cryptoflorescence,
- Biological colonization,
- Mortars from previous interventions.

Photographic documentation of decay

Fig. 2 Relief depicting triton waving fish [Source: DCAMM 2023]

Salts
Discolorations
Alveolization and cavities
Mortars from past interventions
Erosion
Weathering
Disintegration
Biological colonization
Mechanical damage
Peeling
Scaling

Fig. 3 Relief depicting female triton playing the violin [Source: DCAMM 2023]

Salts
Discolorations
Alveolization, perforations, cavities
Mortars from past interventions
Erosion
Biological colonization
Mechanical damage
Pitting

Fig. 4 Relief depicting Aphrodite's birth [Source: DCAMM 2023]

Salts
Discolorations
Perforations
Mortars from past interventions
Erosion
Mechanical damage
Pitting
Fractures
Cracks

Fig. 5 Lions and upper basin [Source: DCAMM 2023]

Salts
Discolorations
Perforations
Disintegration
Mortars from past interventions
Erosion
Pitting
Fractures
Cracks
Crust
Peeling
Biological colonization

4. Reflection and redefinition of the norms (instead of an epilogue)

A conservation plan is expected to develop a conservation proposal, a strategy to provide solutions to the problems raised and scientifically documented in its preliminary stages. The proposal comprises preventive and remedial methods and approved materials that will treat and restrain the decay phenomena. The DCAMM's members are entitled to develop conservation plans, to implement them, and to evaluate conservation proposals developed by third parties, with one and only goal: to ensure that the cultural capital of the country, which is not indefinite, will be preserved and passed on to future generations of humanity in the maximum of its integrity.

The task sounds fairly simple in our time since legislation on cultural heritage protection is clear, and applied heritage conservation is ruled by specific guidelines that have emerged through long and painful theoretical processes, practical failures, and scientific breakthroughs. In reality, however, case studies such as the one that was discussed in this paper demonstrate the complexity of the task and the burden of our responsibility. During examination of the monument through collaboration with our colleagues and scientific partners, two questions arose that we must answer: is a typical conservation proposal, as we know it, adequate for the Morosini fountain? To what extent can a conservation plan consider previous interventions for developing effective conservation strategies?

Is this the time to think outside of the box? For the conservation of the fountain and only during the period from 1976 to 2017, for which there are available records, at least 36 different materials were used for cleaning, consolidation, reinforcement, and waterproofing. Moreover, an extremely intrusive intervention was implemented, the dismantling, transfer, and reinstallation to its original place after conservation, an approach that should have been beneficial for the monument but failed to confront successful decay and degradation.

Is this the time to use conservation material number 37? Is this the case to propose more chemical compounds to remove deposits, mortars to consolidate scaling and fill cavities, provide guidelines for another extensive desalination programme, or a methodology for smoothing out discolourations? Can we move forward without making changes to the conditions under which this monument is kept? In forming our approach for intervention we wondered what would be effective, appropriate, or even ethical according to the principles of the scientific field we serve, to tackle the problems of a monument that has been through so much.

Can a non-interventive conservation approach be adapted? Is it worth considering cutting strong winds by planting vegetation at a distance from the fountain, which could prove to be beneficial to salt formation processes on the stone surface? Or perhaps, consider the still experimental yet promising method of imposing magnetic fields to reduce salt crystallization[31]? Upgrading water quality combined with regular maintenance could reduce decay, be beneficial for the monument, and become an opportunity for the community to participate actively in taking care of its heritage. A public awareness campaign could inform the local community and the tourists in order to effectively communicate the needs of the monument and possibly make them part of the solution rather than part of the problem. Is this feasible? Or should a more radical solution be adopted?

Relocating and substituting The genuine and inevitable concern as far as what more can be done to care for and protect this traumatised monument lead to a broader perspective, to consider and discuss an approach of relocation to an indoor environment and its replacement by a replica, even though a full conservation program will also be provided[32]. Relocation and replacement by a replica is a practice that has been adopted in other cases[33] and an approach often considered for the protection of outdoor stone sculpture. Nevertheless, the fact that the original monument is removed from its original context remains the strongest argument against it. In the Charter of Athens (1931), removal of monuments is discouraged, and in-situ preservation is prioritized, yet the practice of relocation and replacement is accepted under specific circumstances when the copy becomes the means of saving the original monument, particularly when this has been irreversibly treated in the past. Relocation is also mentioned in the Venice Charter (1964), which considers it «[…] admissible if the monument can no longer be preserved at its original location if it cannot be protected in any other manner[34]».

Although it is a practice with a fairly long history for stone sculpture, it does not have vast applications in relation to the monuments in danger. A decision towards this direction is influenced by both ethical and practical issues. First, a dialogue with the local community is necessary in order to understand and accept the decision. Then, a series of practical factors ought to be designed, such as the relocation process and site preparation, the suitable new space for the original monument, the extent to which the copy will duplicate the original in terms of morphology and materials, assurance that the technique adopted for the creation of the replica does not have a negative impact on the original monument. Last but not least, it must be considered that after relocation, the original monument must undergo conservation, and the root causes of its decay should be addressed so that it is stable.

The complexity of the situation and the difficulty in decision-making is easily perceived. In our understanding,, the only way to go is teamwork –not only for decision-making but at every stage of the process. Provisions are made for the replica's morphology and accuracy in order to avoid any negative impact on the original monument by building collaboration with a scientific team of high expertise from the University of West Attica. Modern technologies –close-range photogrammetry and laser scanning– are used for the service of conservation. Our final proposal for sustainable and effective conservation and management of the Morosini fountain will provide a variety of conservation and management options, along with the necessary scientific argumentation for scientists, professionals from all relevant fields, and representatives of the community to consider before a final decision is reached. Conservators, archaeologists, architects, engineers, artists and museum professionals, and the representatives of the local community will provide their input, and the most sustainable decision under the circumstances will be reached.

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[31] Magnetic Water Treatment (MWT): an area of research on prevention of scale formation in water systems. It proposes influencing the behavior of dissolved salts potentially altering their salt crystallization processes, by applying magnetic fields. As a process it is affected by water chemistry (mineral content, pH and temperature levels), reproducibility of salts, regular monitoring and maintenance etc. Further reading: Mosin, O Ignatov, I. Basic concepts of Magnetic Water Treatment. European Journal of Molecular Biotechnology, 4(2), pp. 72-85. (2014) [DOI:10.13187/ejmb.2014.4.72]; Coey, J. M. D. Cass, S. (2000). Magnetic water treatment. Journal of Magnetism and Magnetic Materials, 209(1-3), pp. 71-74. [DOI: 10.1016/S0304-8853(99)00322-5]

[32] The conservation plan currently being developed will be flexible to provide a number of options and will not only be limited to relocation and substitution by a replica.

[33] The most characteristic case in Greece is that of the Caryatids from Erechtheion but also the lions from Delos, the statue of Hermes holding the infant Dionysus from the Temple of Hera in Olympia and others. Other cases include the bronze Lion of Venice from St. Mark's Square, the marble statue of David by Michelangelo from the Palazzo della Signoria (Palazzo Vecchio) in Florence etc.

[34] Venice Charter for the Conservation and Restoration of Monuments and Sites. Article 11. (1964)

To learn about the past is to prepare for the future. Conservation plans in Greece follow certain norms that have been established to dictate their contents. A key component, among others, is the detailed assessment of a monument's current condition by describing the main decay phenomena detected, the impact of the environment, and previous interventions on its preservation state. The case study of the Morosini fountain brought to prominence the factor of previous interventions and made us reflect upon the extent to which we, conservation professionals in this country, go deep in our research to gain knowledge of previous interventions and consider their instrumental role in the development of sustainable conservation strategies. The experience derived from the role of DCAMM in developing and evaluating conservation plans has shown that although this parameter is not neglected, it is underestimated considering its significance, often constituting only a reference insufficiently correlated to the monuments' preservation state.

In Greece, we are now counting approximately 180 years of heritage conservation practices –since the first approaches of Xavier Landerer (1809-1885) and Othon Rousopoulos (1856-1922)– and specifically in Crete, we are counting almost 120 years with the first applications of the empirical conservators who acted even before the foundation of the Cretan State (1912)[35]. Recent historical research has enriched knowledge on previous interventions, materials, techniques, and approaches, being a real asset, enabling us to provide optimum documentation of the monument' s current state in relation to its history and to improve our conservation strategies.

Lack of organized records, limited access to existing ones, and the often unpleasant experience of the practical aspect of archival research –archives are sometimes neglected and forgotten, kept in moist and dusty spaces and in a state of chaos– are all discouraging conditions that make it hard for us to even consider going into this effort. Luckily, scientific analytical techniques and the advancements made in the field of archaeometry are another way to find out more about previous interventions. This opportunity was utilized in the case of the Morosini Fountain and combined with the examination of archives and past records so that the goal of thorough documentation was reached.

Despite all the difficulties in the process, it is worth investing time and effort in the selection of data relevant to past conservation works that may prove to be catalysts for a conservation approach and for the monument's future. Taking into consideration the time passed and the materials used on monuments, it becomes easy to comprehend the magnitude and significance of documentation of the monuments' preservation state in relevance to previous interventions.

5. Acknowledgments

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Revisiting the Mosaic of the Masks on Delos: A Comprehensive Condition Survey

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Abstract. A condition survey was conducted on the 'Mosaic of the Masks' located in the homonymous Hellenistic house on Delos to reassess its condition twenty years after its conservation. This mosaic adorns the central symposium room and comprises a central geometric carpet with a 3D cube pattern, along with figurative bands featuring theatrical masks and floral motifs. Extensive and drastic conservation treatment was applied to the central carpet, involving its detachment in sections and reinstallation on a new, purpose-built setting bed, while the peripheral sections were preserved in situ. The particularly poor state of preservation necessitated thorough research into the weathering processes and the factors affecting its condition. Investigation into the archival records, the original constituents, conservation materials, and past conservation interventions were conducted to better understand the deterioration processes. Photogrammetric methods were employed in the study and documentation of surface geometry, while the cohesion of the substrate was examined through acoustic tapping. Environmental monitoring throughout a full year provided insights into the weathering factors at play. SEM-EDS and XRD analyses enabled the characterization of constituent materials, manufacturing techniques, and weathering products, offering clues about the deterioration processes.

Keywords: Hellenistic mosaics, Delos, condition survey, documentation, photogrammetry, SEM-EDS, XRD.

1 Introduction

The "Mosaic of the Masks" adorns the floor of the central room of the homonymous house at the World Heritage Site of Delos in the Cyclades, Greece, and exhibits a diverse range of materials and techniques. The 'House of Masks' was excavated in the 1930 [1] and dates to the late 2nd - early 1st century BC [2]. It stands out as one of the most luxurious buildings at the site, with figurative mosaics of the highest quality in all its rooms. Restoration of the building was undertaken in the 1950s, which involved reconstruction of the walls to their estimated initial height and the addition of a reinforced concrete slab roofing. The mosaic floor underwent extensive conservation treatment in the late 1970s which involved the detachment of the central, geometric panel in sections, their remounting in custom-made supports, and reinstallation on a new foundation. The rest of the mosaic was preserved in situ.

2 The mosaic of masks: materials and techniques.

The mosaic under study measures 9.12 x 7.09 meters and features a central geometric pattern composed of '3D cubes,' a recurring motif in Hellenistic mosaics. This design is characterized by the arrangement of cubes to create a three-dimensional effect. The central pattern is bordered by a decorative band of waves, with two lateral bands on the east and west, each showcasing five theatrical masks, interwind with floral motifs. The outer band is plain, giving the illusion of a big carpet on the floor (Fig.1).

Fig. 1. Orthophoto of the mosaic of the Masks, 9.12 x 7.09 meters (by C. Maris)

A variety of materials and fabrication techniques are employed. The sides of the cubes are set in *opus segmentatum*, characterized by the random setting of irregular red and black tesserae with wide and irregular interstices (Fig. 2). In contrast, the top of the cubes is set in *opus tessellatum,* characterized by a well-organized *andamento*, using white tesserae of approx. 1 cm side arranged in concentric lozenges [3]. Additionally, lead strips [4,5] are used to define the sides of the rhombuses that form the three-dimensional cubes and the outlines of the waves. *Opus vermiculatum* is used in the masks, and *opus tessellatum* in their background, the floral motifs, and the rest of the decorative bands. Glass tesserae are used in a few details of the masks while the rest of the mosaic is made of stone tesserae.

Fig. 2. Detail of the 3D cube pattern of the central mosaic carpet (left) and the masks (right) (photo and drawing by S. Minetou).

The outer part of the floor (approx.1 m wide), is paved with a course *opus segmentatum* consisting of marble fragments in the order of 5-6 cm. The remains of a surface coating consisting of a fine red plaster colored with iron oxides are preserved on the periphery of the opus segmentatum, indicating that the entire area of the outer band is covered in colored plaster. Moreover, evidence indicating the '*giornata'* (the portion of the work produced in a day) is apparent in this outer band [6,7]. A monochrome (white) *opus tesselatum* section is found in front of the entrance steps, alluding to an entrance carpet. The color pallete consists of pink, brown, green, orange, blue, white, grey, and black. Information about the mosaic's stratigraphy is retrieved from the archival records indicating the following layers from the bottom up: *statumen*, charcoal layer, *rudus*, *nucleus*, setting layer (or *supra nucleus*), and the tessellatum.

3 Condition Survey 2021-2023: objectives and methodology

The condition survey undertaken on site aimed at the documentation and the assessment of the current state of preservation of the mosaic, the identification of the prevailing weathering factors, the evaluation of previous treatments, and finally, the development of a methodological approach towards its conservation and protection. The investigation began with archival research followed by field surveys and laboratory analyses. The field survey included macroscopic observation, photogrammetric documentation, acoustic tapping, the detection of metal reinforcement, environmental monitoring, and measurements of surface and substrate moisture content. Finally, the color pallete was defined using the Munsell Rock Color Chart. Sampling and laboratory analyses focused on the study of surface depositions and the characterization, the original and restoration mortars, and the surface coating that is preserved on the opus segmentatum.

3.1 Archival research

The conservation interventions undertaken between 1978 and 1994 were retrieved through archival research conducted at the Archaeological Ephorate of Cyclades [1]. After the detachment of the central carpet mosaic in the 70s, the project was abandoned, and 16 years later, the sections were remounted in new mortar reinforced with aluminum frames and galvanized mesh (chicken wire). A new foundation was constructed on-site for the reinstallation of the mosaic sections. This foundation comprised of a layer of loose stone gobbles, two iron bars set diagonally above the gobbles, and a final layer of cement mortar. To mitigate the risk of rising dumps, a polyethylene sheet was laid on the ground before the new foundation was set [1,8], thus isolating the reinstalled mosaic section from direct contact with the ground. This approach prevented the infiltration of moisture and condensation water and encouraged salt crystallization cycles to occur primarily within the layers of the new foundation and the re-laid mosaic sections especially at their interface. The alignment of the mosaic sections was challenging due to the loss of legibility of the initial records. As a result, their joins appear disruptive.

3.2 Macroscopic observation

The entire mosaic was covered by loose deposits originating from the disintegration of the wall plasters, and the masonry, concrete, and iron fragments collapsed from the roof, as well as biological depositions. Acoustic tapping indicated the loss of cohesion between the mosaic surface and the substrate across the entire floor, in particular on the previously detached area. Extensive disintegration of the interstitial mortar was observed at the *opus segmentatum* of the outer band, especially in the northern and western parts of the floor, leading to loss of adhesion and often to detachment of tesserae. Cracks, bulges, and rises were concentrated in re-laid areas. Salt efflorescence covered the northern side, which kept reoccurring shortly after their removal. The green tesserae are extensively eroded, often partially or completely pulverized. The ceramic tesserae on the north and west sides show cracking, exfoliation, erosion as well as biological and microbiological colonization (Fig. 3).

Rainwater seepage from the north side of the roof and walls favors salt migration and biological colonization on both the masonry and the mosaic floor. Soluble salts and iron corrosion products originating from the restoration materials are leached and transported to the mosaic floor. Severe corrosion of the metal bars is observed at the northern part of the roof, causing the detachment of small fragments of the concrete slab and rendering the mosaic inaccessible to visitors. The incorporation of incompatible intervention materials into the new substrate further contributes to the continuous degradation of the mosaic. In addition, the action of insect swarms, which create colonies inside the masonry, intensifies the degradation of the wall plasters, resulting in their gradual collapse on the mosaic surface. It is evident that the severe condition of the mosaics is largely owing to the detrimental effects of the past restoration practices. When comparing the detached portion of the mosaic with the part that remained in situ, it becomes evident that the detachment has led to enhanced deterioration. In addition to the severe deterioration of the mosaic substrate and surface, the misalignment of the re-laid sections compromises the aesthetic values of the mosaic floor, also affecting the broader architectural context.

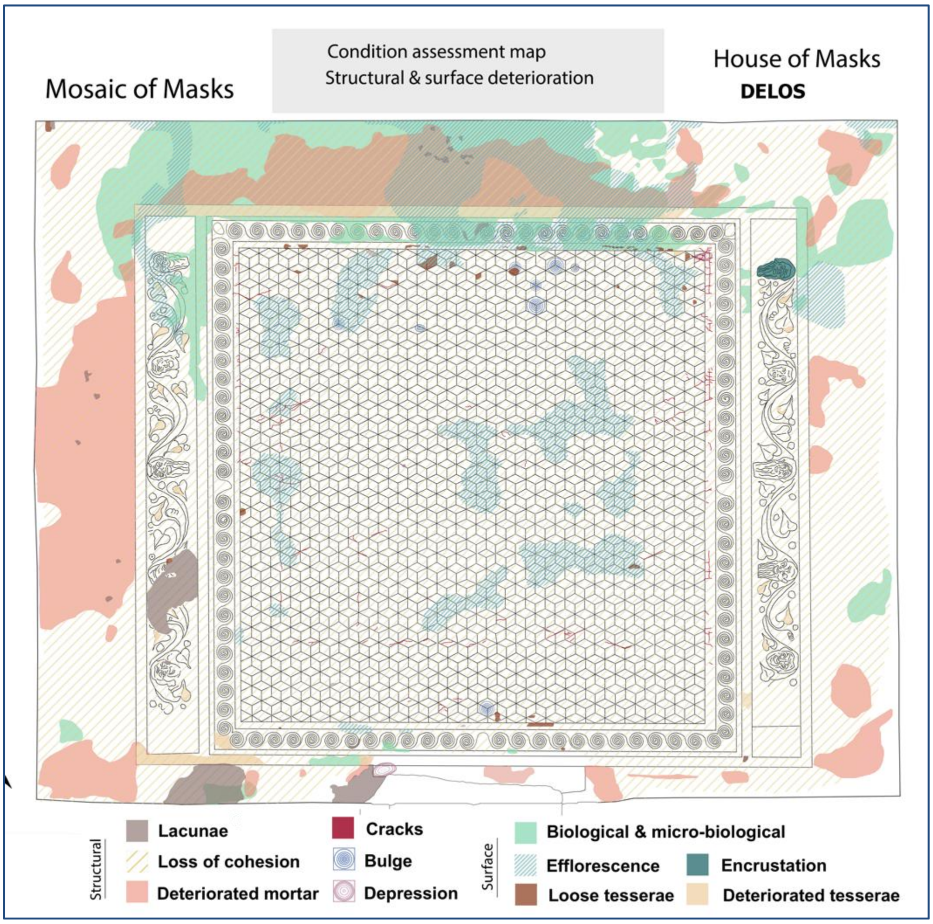

Fig. 3. Condition map, showing the prevailing surface and structural conditions (by S. Minetou).

3.3 Surface and substrate examination

A portable digital microscope was used on-site to examine and document surface weathering features and depositions. However, the limitations of the low depth of field and the high relief of examined surfaces led to unsatisfactory results. The examination of the surface with a portable GMS metal detector confirmed the presence of metallic elements that were used as reinforcement in the mounting system of the detached mosaic sections and allowed us to locate them and correlate them with the loss of cohesion and the bulges occurring on the surface. In addition, moisture distribution maps were drafted based on comparative measurements acquired with a microwave humidity sensor, providing information from the subsurface up to a depth of 30cm. Measurements were taken on 80 points distributed in a 1x1m. Grid over the entire floor. The average of 3 measurements on each spot was plotted to create the moisture distribution map, showing a wide variation of moisture content across the mosaic floor with values ranging from 40 to 99. The obtained data were correlated with the occurrence of salt efflorescence, indicating that salts crystallized on the surface in areas where moisture content values ranged from 62 to 93.

3.4 Photogrammetric documentation

Both handheld digital cameras and drones were utilized to capture images. A first set of 974 images were acquired before cleaning, followed by a set of 857 images after dry cleaning. The first two sets of images were shot from a height of approx. 0,5 m, with a 70% overlap, a rather time-consuming and labor-intensive process. Image processing was similarly challenging due to the large number of images. A third set of 187 images were acquired with a drone from a steady distance of 3 m. The 3D model, the orthophotos, and the digital elevation model (DEM) provided metric information and enabled the study and documentation of surface geometry alterations related to natural deterioration and previous conservation treatments. The orthophotos served as a base for accurately mapping surface and structural conditions, while the point cloud and the DEM provided the basis for monitoring subsequent changes in the geometry of the mosaic, allowing for the assessment of the evolution of decay (Figs 1, 4).

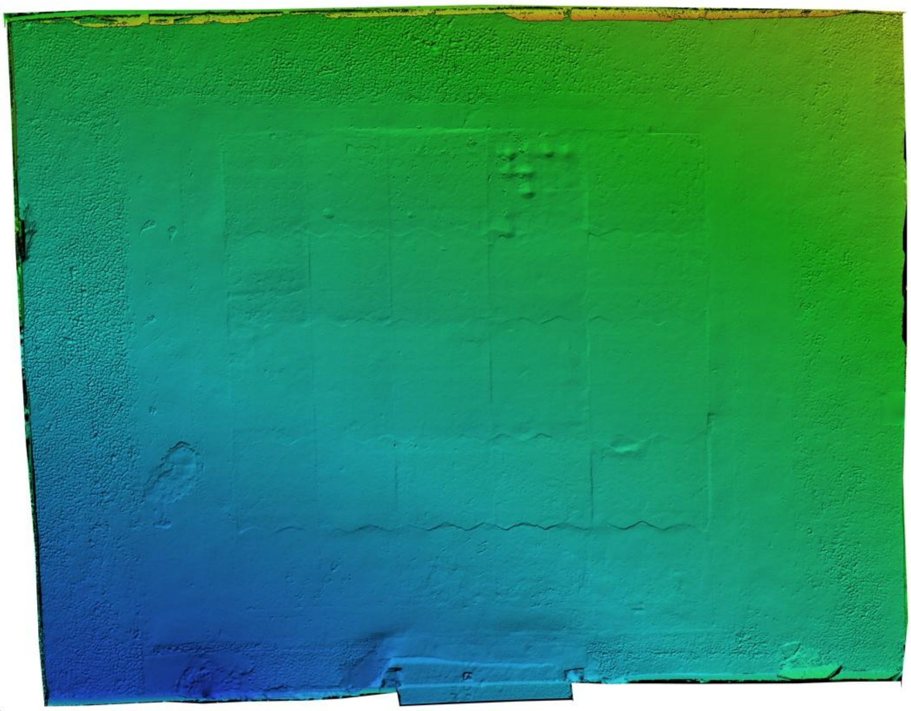

Fig. 4. Digital Elevation Model (DEM) of the mosaic floor generated using Agisoft Metashape v1.7.3. The blue tones indicate the lower areas of the floor, sloping towards the water drain exit (by S.Chlouveraki).

3.5 Environmental monitoring

Temperature (T) and relative humidity (RH%) values were recorded via a Tiny-tag data logger placed inside the room for a period of 10 months and 2 weeks, from November 1st, 2018, to September 15th, 2019. The data acquired reveals consistently high relative humidity levels, with average values reaching

76,6% during the winter months and 65,3% during the summer months. Due to the lack of outdoor monitoring equipment on Delos (the nearest weather station is on the nearby island of Mykonos), it was not possible to evaluate the effectiveness of the shelter in terms of mitigating the impact of the environmental parameters. However, the research by Prokos [9] offers environmental data for different areas of the archaeological site, including the prevailing humidity and temperature inside the room where the mosaic under study is situated. The findings of this study suggest that marine aerosols are the primary source of salt affecting the architectural remains of Delos, both in sheltered and outdoor environments.

3.6 Sampling and laboratory analyses

Sampling was concentrated on the heavily deteriorated areas and the surface deterioration/corrosion products, targeting fragments that had already detached. All samples were initially examined and documented with an optical stereoscope Olympus SZ61 using the Infinity Analyse & Capture software. Cross sections of the original mortars, which included the surface red layer and the main body of the setting mortar, as well as samples from the lower layers of the mosaic bedding stratigraphy and the lead strips (used to outline the geometric motifs), were prepared for study under the SEM-EDS. Additionally, samples were taken from surface salt efflorescence of two different morphological types and one of a biological deposition with a leafy structure.

Scanning electronic microscopy (SEM-EDS)
The study of the samples was carried out on a JEOL JSM6510LV Scanning Electron Microscope (SEM), accompanied by an Oxford Instruments x-act type X-ray Energy Dispersive Spectrometer (EDS/EDX) with the use of INCA program. The intensity and radius of the analyzer were maintained at BEC 20kV, with Spot Size 34-35ss and 40ss. The distance of the sample to the analyzer was kept steady at WD 15 ±1. The samples were not carbon-coated. Between 6 and 12 point-analyses were obtained from each sample depending on the complexity of its composition.

X-Ray Diffraction (XRD)
The X-ray diffraction method was used to investigate the crystal structure of the salts present on the surface of the mosaic and identify the mineral composition of the aggregates used in the original mortar. The study of the samples was carried out using the Inxitu - BTX 262 model with a cobalt tube, and the analysis time of each sample was 75 minutes.

4 Results

The analyses provided insights into the manufacturing technology of the Hellenistic mosaics of Delos and the information required for proposing the optimal conservation methodology and materials for future interventions. The examination of the red mortar that is preserved in the interstices of the *opus segmentatum* showed that it comprises a thin layer (404 - 613μm thick) of lime mortar, with fine aggregates of pure quartz and ceramic powder, which is responsible for its color. The mortar beneath the red layer consists of lime mortar with crushed ceramic, with maximum particle size in the range of 2,95 mm, and natural aluminosilicate aggregates with a chemical profile of Si 27%, K 10%, Al 8.46%, and Na 1%. The grain size ranges from ~1.37mm to ~2.48mm. The aggregates exhibit a greyish hue and a rounded shape. In addition, the use of lead strips was affirmed with a composition of Pb 41.09 wt%.
Two different types of intervention mortars were sampled from lacunae and were examined by SEM-EDS, which show a composition that corresponds to lime mortars. Similarly, the crystal phases of the intervention mortars identified by XRD do not appear to contain cement compounds. The silicate and calcite aggregates used show great variety in colour, structure, grain size, and composition and, in some cases, are found rich in Ti (av. 14.72wt%). Grain size varies from 305μm-2.483mm, with the majority in the order of 550-750μm. The analysis of salt efflorescences shows the presence of Na combined with high percentages of S. Specifically, the average weight of the two samples examined shows percentages of Na 24.93%, S 19.15%, Ca 1.35%, and Al 0.6%. A low Cl of 0.45 wt% was identified only in one analysis. The main crystal phase identified in XRD analyses showed primarily Thernadite (Na_2SO_4) with crystal phases of Gypsum, Calcite, Coesite, Quartz, and Halite. The salt contents examined in the current survey point out that salt efflorescences primarily originate from the leaching of sulphates form the restoration materials surrounding the mosaic, with minimum amounts of halite. The biological organisms

could not be identified at this stage of research, but they were extensively documented through electron microscope images for future research purposes.

5 Conclusions

The condition survey of the *'Mosaic of the Masks'* on Delos, conducted twenty years after conservation, has provided valuable insights into its current state of preservation and the factors affecting its deterioration. The investigations conducted so far have led to the conclusion that the deterioration of the mosaic is primarily attributed to the drastic interventions of the past, along with the absence of systematic maintenance for both the mosaic floor and the modern concrete roof forming its current architectural context. When comparing the detached portion of the mosaic with the part that remained in situ, it becomes evident that the detachment process has led to enhanced deterioration. These observations underscore the intricate interplay between natural and anthropogenic factors shaping the mosaic's evolution of decay. Photogrammetry, environmental monitoring, SEM-EDS, and XRD analyses have enriched our understanding of the deterioration processes as well as the materials and manufacturing techniques.
Moving forward, it is imperative to implement targeted mitigation strategies to safeguard the *'Mosaic of the Masks*' against further deterioration. This may include new conservation treatments targeted to the detached area after further research and pilot on-site applications.
It's evident that immediate action is necessary to address these issues. Proper maintenance is essential to prevent further damage and ensure the safety of both workers and visitors. This may involve repairing the roof, improving drainage systems to prevent water seepage, and implementing measures to control moisture and biological growth. Additionally, steps should be taken to make the mosaic accessible to visitors once again, as it's an important part of the building's heritage.
Furthermore, the lessons learned from the conservation and preservation efforts of the *'Mosaic of the Masks*' serve as a valuable case study for similar cultural heritage sites worldwide. By sharing our experiences and best practices, we can collectively strive to ensure the long-term preservation of our shared cultural heritage for future generations to appreciate and enjoy.

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Ancient Sanctuary at Kalapodi, Fthiotis, central Greece. Presentation of Restoration Works and the implementation of Triquetra Programme.

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Keywords: Kalapodi Fthiotis, Restoration, Conservation, Triquetra

1 The site

Fig. 1. Kalapodi. Fthiotis Greece (2023). The ruins of the site after presentation works. Photo: M. Papanikolau, DAI Athen.

In central Greece, in today's Fthiotis, where in antiquity Phokis bordered eastern Lokris and Boeotia, there is a sanctuary that is one of the most important of ancient Phokis [1]. The sanctuary was in the same region as the famous pan-Hellenic oracle of Apollo of Delphi. According to the excavators, the sanctuary, too, was possibly an oracle of Apollo, the famous one of Abae. Systematic excavations were carried out again in the sanctuary only in the second half of the 20th century, under the direction of the German Archaeological Institute; they continue to this day [2] (seeThe pilot sites are Kalapodi, Greece; Ventotene, Italy; Aegina Island, Greece; Choirokoitia, Cyprus; Epidaurus, Greece; Roseninsel, Germany; Argilliez, Switzerland; Smuszewo, Poland).

According to the Kalapodi project, data collection, data evaluation, documentation, implementation, monitoring, and publicity activities will take place.

In more detail, the following activities will take place:

1. Analysis of materials (sample collection, petrographic and petrographic analyses from the Kalapodi monuments) / in order to create a comprehensive database/archive of analyses

2. Data such as meteorological data - Collection of satellite images of the wider area -Collection of data on the seismicity of the area - Assessment through modelling of climate change impacts - Risk assessment. Testing of geophysical techniques consisting of passive seismic measurements to output effect related to stratigraphy as well as geo-structural setting on local seismic response

3. Application through the digital twin technology project in the archaeological site with detailed documentation of the existing state of the monuments. Creation of a GIS of the archaeological site

4. Construction of infrastructure for the implementation of the program on the archaeological site

4.1 Preliminary earthworks

https://doi.org/10.12681/monubasin.8325

4.2 Installation of underground power line to the project site
4.3 Construction of a base/plate of lightly reinforced compatible mortar for the project implementation within the archaeological site at a location at a distance from the monuments
5. Construction of an exact replica of the steps and stylobate of the Northern Tempel (exact copy with the application of CNC - Computerized Numerical Control). The replica will be made with a similar material to the original
6. Placing on the implementation base of different types of stones that have been used in the monuments of the site and which have no archaeological traces
7. Application of nanotechnology with a coating product to protect the materials (stones) from water on stones that do not bear archaeological traces
8. Application of active protection of materials against frost. Installation on the stones of the pilot project of a net of heated electrodes which will be activated when the temperature in the archaeological site approaches 3° C. The temperature of the materials will be recorded, and the behavior of the system during snowfalls will be recorded by a camera over a 24-hour period. The technique has been applied experimentally on stones with the same quality as the stones of the site in the settlement of Kalapodi in 2019, with data recording.
9. A permanent exhibition of information material about the archaeological site is to be set up in the old school in the modern village of Kalapodi. There, the contribution of the Triquetra project to the issue of protecting the monuments from the effects of climate change could be mentioned through posters. It is proposed that information material on the programme can be placed in the context of the project.
). The results of the excavations were impressive, especially on the issue of the continuity of worship from prehistoric times to the Roman era. The architectural remains were also significant for the evolution of ancient Greek architecture. Temples of different periods, with various types of structure and materials, testify to the gradual development of ancient Greek temple architecture over time, from the humble brick structures of prehistory to the intention of the monumentality of the Geometric period, later to the transitional character of the Archaic period and finally to the systematic mode of expression based on the rules of the Classical period. The ruins of these cult buildings are arranged in two parallel monumental units: north and south. For years, the ruins had been protected either under embankments (northern monumental unit) or under a low and temporary roof (southern monumental unit). Many excavated sections were backfilled. Even the ruins that were under the protective canopy were virtually inaccessible, partly because they were under geotextiles and partly because the canopy itself was particularly low and dangerous to the personnel and the scientists (see Fig. 2).

Fig. 2. Kalapodi. Fthiotis Greece (2017). The ruins of the site before presentation works. Orhophoto: DAI Athen.

2 Presentation Works

In 2017 German Archaeological Institute had started working on a plan for the cultural heritage management and the presentation of the southern temple complex. From the autumn of 2018, the maintenance and presentation works are almost completed. In 2023, the temporary presentation of the northern temple was also completed. The shape of the soil was restored, and the ruin of the archaic temple now emerges naturally from the soil, just as was the case in Greek archaic architecture [2].

Going beyond the narrow limits of the archaeological site, the architectural study proposed the idea of linking the monument with its wider environment in an interdependent relationship, so that they form an indivisible unity. In this way, the monument marks equally its rare scientific content and its aesthetic value as a ruin that is projected in the sunlight against the background of the natural environment. The older and deeper layers, which consisted of delicate materials (raw bricks, stonework made of small-sized crude stones), were decided to be backfilled. In addition, the maintenance of large pits in the ground for the sake of viewing, even within a canopy, would, in the long term, cause issues of continuous maintenance of the soft limestones of the archaic temple, as the study of these stones showed since rising damp would constantly undermine the cohesiveness of these materials. The loss of the view of the geometric adyton due to the backfilling of this particular level was compensated by the restoration of the classical adyton directly above the geometric one in its original position, which, in any case, was a condition imposed by the Ministry of Culture for the approval of the dismantling, for the sake of excavations which took place in 2009 (see Fig. 3). It should be pointed out that the architectural significance of the classical adyton constructed purely by reusing architectural parts of an archaic building is superior to that of the simple brick geometric sanctuary. According to the study, four phases remain visible and intertwine with each other, shedding considerable light on the historical evolution of the sanctuary from Geometric times to the Roman era. Indeed, with the work of marking the Geometric temple proposed with replicas of raw bricks, for the first time the scale of this great temple is so well understood. The pediment was proposed, after its systematic research, to be exhibited as an exhibit of major importance at the place where it was found. The stones of the pediment on the ground at the place where they fell are a valuable historical document of the burning of the archaic temple by the Persians, as ancient resources testifies. The passage from the initial idea to the preparation of the specific studies, to their approval by the competent authorities, and finally to their implementation was not a simple process. It required the timely management of the funds credited by the German Archaeological Institute and the Pestalozzi Foundation and the cooperation with the Ministry of Culture of Greece, especially with the local Ephorate and the director E. Karantzali. The restoration project was a request of the local community for years [3], and its implementation is the result of the vision of the director of the German Archaeological Institute, K. Sporn [4].

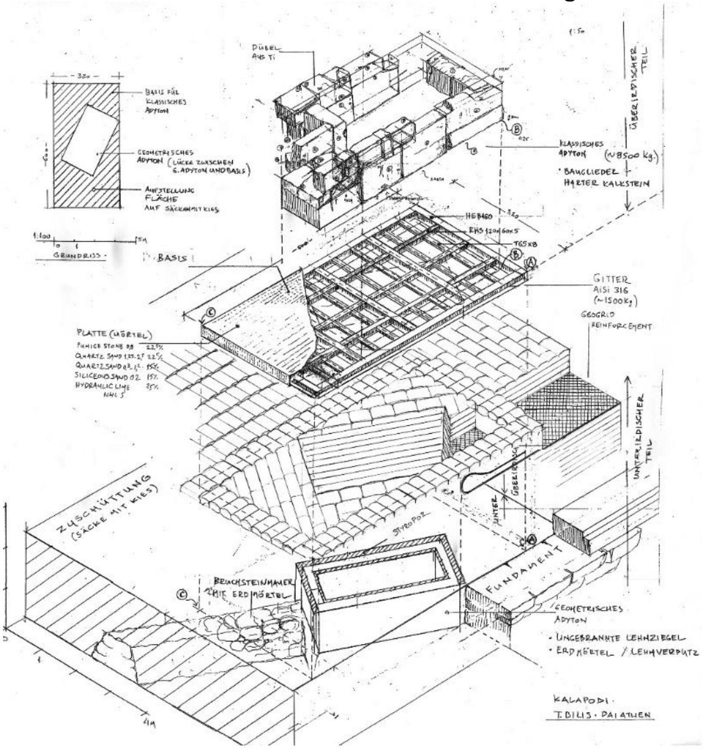

Fig. 3. Kalapodi. Fthiotis Greece. Structural analysis of the proposal of the restoration of the classical adyton directly above the geometric one, in its original position. The restoration of the classical adyton was a condition imposed by the Ministry of Culture of Greece for the approval of the dismantling for the sake of excavations, which took place in 2009. Sketch: Th, Bilis, DAI Athen.

3 Triquetra Programme

Fig. 4. Kalapodi. Fthiotis Greece (2021). The ruins of the site are protected during winter by seasonal covering with geotextile and insulation panels. Photo: Ch. Vaporakis, DAI Athen.

The phenomenon of frost poses a constant danger to the site's materials, which, in combination with the vulnerable structural materials, causes decay problems. Currently this is solved by seasonal covering with geotextile and insulation panels. Due to climate change, in the future all these problems will become intense. The site participates as a case study for the TRIQUETRA program that started on 01/01/2023 and will last for 3 years. As part of the program TRIQUETRA, an integrated methodological model to protect archaeological remains at Kalapodi from frost, is proposed.

According to the official website of the program: «...The TRIQUETRA project aims to create an evidence-based assessment platform that allows precise risk stratification and creates a database of available mitigation measures and strategies, acting as a decision support tool for efficient risk mitigation and site remediation. Triquetra's overall approach is based on three distinct steps: 1. Risk Identification 2. Risk Quantification 3. Risk Mitigation. This "trifecta" approach (hence the name Triquetra) creates a framework of risk assessment and risk mitigation so as to tackle as many of these risks as possible in the most efficient way available. A total of 21 organizations from 7 countries participated in the project, including 8 universities and research organizations and 6 cultural heritage authorities. The project started on 01/01/2023 and will last for 3 years. TRIQUETRA project is funded by the EU HE research and innovation programme under GA No. 101094818...» The TRIQUETRA project (EU HE research and innovation program under GA No. 101094818)...»[5]. The sites participating in Triquetra reflect a wide variety covering almost all cases from natural environments such as Continental - rural areas, submarine sites, and coastal areas. The pilot sites are Kalapodi, Greece; Ventotene, Italy; Aegina Island, Greece; Choirokoitia, Cyprus; Epidaurus, Greece; Roseninsel, Germany; Argilliez, Switzerland; Smuszewo, Poland.

According to the Kalapodi project, data collection, data evaluation, documentation, implementation, monitoring, and publicity activities will take place.

In more detail, the following activities will take place:

1. Analysis of materials (sample collection, petrographic and petrographic analyses from the Kalapodi monuments) / in order to create a comprehensive database/archive of analyses

2. Data such as meteorological data - Collection of satellite images of the wider area -Collection of data on the seismicity of the area - Assessment through modelling of climate change impacts - Risk assessment. Testing of geophysical techniques consisting of passive seismic measurements to output effect related to stratigraphy as well as geo-structural setting on local seismic response

3. Application through the digital twin technology project in the archaeological site with detailed documentation of the existing state of the monuments. Creation of a GIS of the archaeological site

4. Construction of infrastructure for the implementation of the program on the archaeological site

4.1 Preliminary earthworks

4.2 Installation of underground power line to the project site

4.3 Construction of a base/plate of lightly reinforced compatible mortar for the project implementation within the archaeological site at a location at a distance from the monuments
5. Construction of an exact replica of the steps and stylobate of the Northern Tempel (exact copy with the application of CNC - Computerized Numerical Control). The replica will be made with a similar material to the original
6. Placing on the implementation base of different types of stones that have been used in the monuments of the site and which have no archaeological traces
7. Application of nanotechnology with a coating product to protect the materials (stones) from water on stones that do not bear archaeological traces
8. Application of active protection of materials against frost. Installation on the stones of the pilot project of a net of heated electrodes which will be activated when the temperature in the archaeological site approaches 3° C. The temperature of the materials will be recorded, and the behavior of the system during snowfalls will be recorded by a camera over a 24-hour period. The technique has been applied experimentally on stones with the same quality as the stones of the site in the settlement of Kalapodi in 2019, with data recording.
9. A permanent exhibition of information material about the archaeological site is to be set up in the old school in the modern village of Kalapodi. There, the contribution of the Triquetra project to the issue of protecting the monuments from the effects of climate change could be mentioned through posters. It is proposed that information material on the programme can be placed in the context of the project.

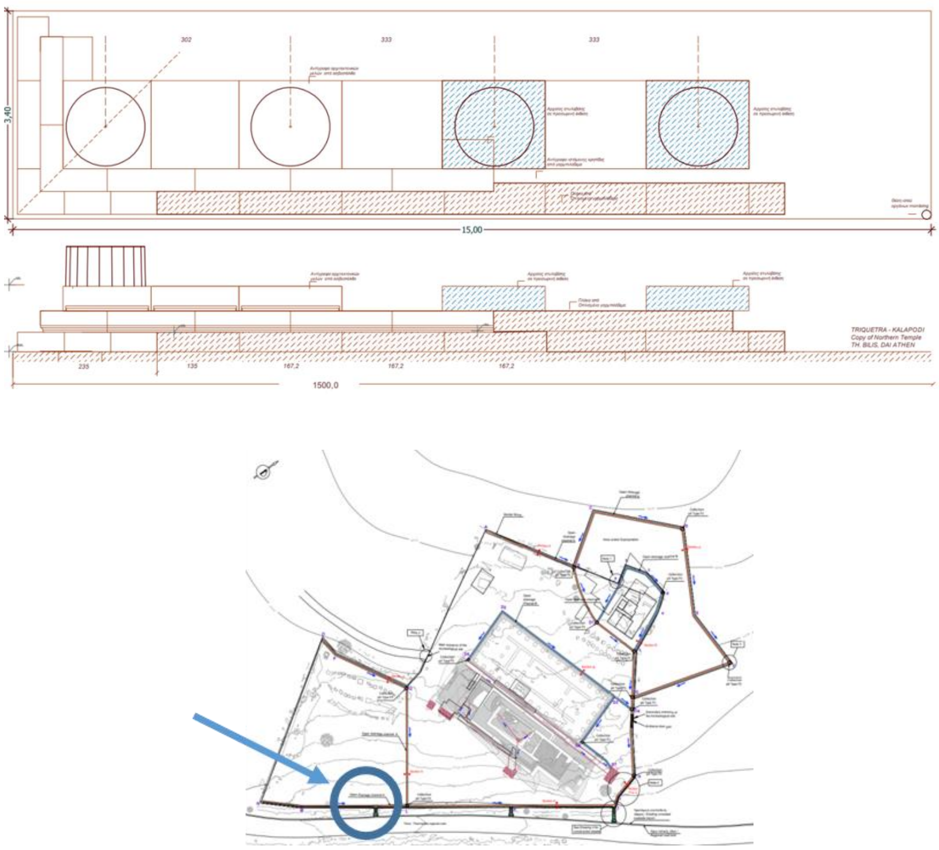

Fig. 5. Kalapodi. Fthiotis Greece. Implementation of the Triquetra program at the site of Kalapodi. Drawing of the construction of an exact replica of the steps and stylobate of the Northern Tempel (Above). The position of the structure is on the site plan (Below). The replica will be made with a similar material to the original for the application of nanotechnology with a coating product to protect the materials (stones) from water on stones. Drawings: Th, Bilis, DAI Athen.

Fig. 6. Kalapodi. Fthiotis Greece. Photo: K. Sporn, DAI Athen.

4 Conservation works and analyses of building materials

Along with the restoration and presentation of the southern temple complex of Kalapodi, systematic conservation works were carried out on the building materials of the monuments. This was prior to the approval of a conservation study by the Greek Ministry of Culture [6]. The study included physicochemical analyses of the structural materials of the temples and proposals for new compatible restoration mortars. A total of 15 samples were studied, which included limestones from the classical and archaic temples, mudbricks, and building mortars, while the new mortars designed (10 in total) had hydraulic lime as binder and aggregates in appropriate grades. In addition, accelerated aging experiments on frost and soluble salts were carried out on the limestone samples. From the results of the analyses, important conclusions were drawn about the building materials, such as the low frost resistance of the limestone used in the archaic temple.

The systematic conservation works were aimed at the structural strengthening of the various materials, and included cleaning of members, welding, sealing, grouting, consolidation and aesthetic restoration works. They were carried out in different phases from 2018 to 2021 by both external conservation crews and DAI's specialized staff (see Fig. 7, 8).

From observations of the conservation interventions and maintenance work so far, we can conclude that the materials used withstand the harsh conditions successfully. The annual covering of the temple from October to mid-April with ground cover fabric and insulation materials has contributed to this, as well as the frequent monitoring of the site by DAI staff who acts with small-scale conservation works where necessary.

Fig. 7. Kalapodi. Fthiotis Greece. During conservation works. Photo: T. Bilis, DAI Athen.

Fig. 8. Kalapodi. Fthiotis Greece. During conservation works (left), before and after conservation of a limestone from the archaic temple (right). Photo: E. Stamou (left) A. Sotiropoulos (right), DAI Athen.

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Hypotheses for a scientific glossary for restoration in the age of new climatic and anthropogenic risks

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Abstract. The proposed contribution aims to foster reflections and considerations on the hypothesis of a scientific glossary for restoration projects in response to new climatic, natural, and anthropogenic risks. The ongoing changes increasingly push for multidisciplinary approaches involving the entire scientific community to define the most appropriate actions for the protection and conservation of cultural heritage. Hence, here is born the study of a common language that allows communication among the actors involved in the restoration project. The contribution specifically analyzes the Italian context from the 1970s with the unique example of the NorMaL Commission. Its multidisciplinary work led to a series of "recommendations" on the study of unified methodologies for the safeguarding of stone materials and architectural artifacts in their entirety, contributing to the development of regulations at the Italian and, subsequently, the European levels. The commission's work shows that, for a better definition of safeguarding actions for heritage, it is necessary to equip oneself with specific tools that allow dialogue among researchers from different scientific fields. This is highlighted in the first document produced by the Commission concerning the definition of a series of lemmas, *NorMaL 1/80 - Alterazioni macroscopiche dei materiali lapidei: Lessico*, subsequently updated. From here arises the question of whether it is necessary to update the tools available today to improve dialogue within the scientific community in defining the discussed intervention methodologies, considering new anthropogenic natural risks and climate change.

Keyword: Climatic and anthropogenic risk, Scientific glossary, NorMaL Commission, UNI-NORMAL.

1 Scientific glossaries and new risks to heritage. Some Reflections

New natural and anthropogenic risks and climate change stimulate further research in the field of cultural heritage protection and conservation. This aspect has led to a necessary and continuous revision of the most appropriate actions to be taken for safeguarding.

Temperature variations, precipitation, increased atmospheric humidity, wind intensity, catastrophic events, and air pollution were recognized by the *United Nations Educational, Scientific and Cultural Organization* (UNESCO) [1] in 2007 as the main threats to the safeguarding of cultural heritage sites. UNESCO's policy documents, in addition to recognizing the threat of climate change, provide a framework for the Member States of the World Heritage Convention to develop and implement effective mitigation and adaptation strategies, to promote international cooperation and to improve the involvement of local communities.

More recently, in 2019, a report published by the *International Council on Monuments and Sites* (ICOMOS) [2], summarized the main climatic stress factors and their impacts on various materials and categories of heritage. The report highlights the need to update heritage safeguarding actions, starting from the necessity of new multidisciplinary approaches in areas such as vulnerability documentation, conservation, education and training, as well as the presentation methods of heritage sites to visitors [3].

The multidisciplinary approach is fundamental in defining a correct restoration project, particularly in analyzing the influence of new climatic stress factors on different types of architectural artifact degradation. Numerous studies show how increased precipitation and humidity, combined with warmer temperatures, influence the growth of microorganisms on stone and how variations in wind speed and direction affect the transport of atmospheric pollutants, sand, and salts, accelerating the corrosion mechanisms of materials [3,4,5]. Considering the risks that threaten the integrity of heritage today, it is evident that a

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necessary and continuous revision of the most appropriate actions to be taken for the protection and conservation of cultural heritage is required. This can be achieved through an increasingly integrated approach, which also involves the search for a language shared by the entire scientific community.

In view of the aforementioned risks, a worthwhile new project regarding the research of a common language is urgently required to facilitate the dialogue among researchers from different scientific fields and among the various actors involved in the restoration. A first consideration of the tools available today, such as scientific glossaries translated into different languages [6,7], could be, for example, the limitation of the categories of materials considered, mostly stone materials, excluding other entries related to different material categories, such as reinforced concrete. This aspect implies the exclusion of forms of degradation found in twentieth-century architecture, which is also strongly influenced by new risks. The literature highlights the terminological inconsistency existing in the field of restoration projects and in the description, classification, and representation of the various forms of degradation, which are closely linked today to the effects of climate, natural and anthropogenic changes.

The research traces the events that led experts and researchers to early international discussions for defining a common lexicon for restoration, with the intent of resuming the line of studies initiated in the last century and expanding the research to areas of investigation not previously analyzed. In particular, the study focuses on the activities of the NorMaL Commission, initiated in the 1970s, delving into the fundamental role it played in identifying common methodologies for studying the alterations and degradation of stone materials and particularly in defining a shared lexicon for restoration. It is also interesting to analyze the influence of the Commission in drafting Italian technical standards and, subsequently, those of the European standards in the early years of the twenty-first century.

2 The first experiences in the definition of scientific glossaries

2.1 The Italian context: the NorMaL Commission

The identification of the most suitable actions for the conservation of cultural heritage has been the focus of numerous meetings and debates, which have seen the comparison between theorists, treatise writers and protagonists of the discipline of restoration. In the twentieth century, the debate took shape starting from the drafting of the first *Carte del Restauro*, which was born as a methodological-operational tool to address interventions on heritage [8]. It was also during this period that many institutes and laboratories were established at the international level. In 1938, with the establishment of the *Istituto Centrale del Restauro delle opere d'Arte* (ICR), it was finally recognized the importance of integration between different disciplines, technical and scientific, for heritage conservation [9].

The debate about the preservation of the historical-artistic heritage and the new conservation issues was extended in the 1960s [10], following the damage caused by the disastrous floods in Florence and in Venice, in November of 1966. These events have led scholars from various scientific fields to undertake research on new techniques of intervention, supported also by instrumental investigations in relation to the environmental issues that were emerging [11].

In the same years, among the national bodies for scientific research for the conservation of heritage, a fundamental role was played by the National Research Council with the three centers in Milan, Florence and Rome. The aim of the research centers was to develop specific methodologies of cognitive investigation and intervention on surfaces and structures, starting from basic knowledge of chemistry, biological physics and engineering [11].

In this scenario, a group of researchers from the *Istituto Centrale per il Restauro delle opere d'Arte* (ICR) and the *Consiglio Nazionale della Ricerca* (CNR) presented in 1975, at the *International Symposium on Conservation of Stone Mate-rials*, held in Bologna under the auspices of the *International Institute for Conservation of Historic and Artistic Works* (IIC), the methodological proposal *Artistic «Stone» Works. A proposal for the unification of the methods of studying stone decay and of controlling stone conservation*, on behalf of Giovanna Alessandrini, Carlo Manganelli del Fà, Paola Rossi Doria, Marisa Tabasso, Sergio Vannucci [12]. The proposal arose from the need to apply common methods of control and analysis to the study of works of art, focusing on the degradation that afflicted stone materials and the consequent control of the effectiveness of products used in conservative treatments.

The initiative led to the creation in 1977 of the NorMaL Commission, recognized and sanctioned on 19 July 1984 by the Decree of the Ministry of Cultural and Environmental Heritage [13]. Its formation had the main purpose of creating stable, unified methodologies for the study of alterations that afflicted stone materials used in arches-roof and sculpture and to investigate the effectiveness of conservative treatments on the historical-artistic heritage [14]. In addition to natural materials, such as marble and stone, the expression "stone materials" was also used to examine materials derived from earlier processes, such as stucco, mortars and ceramic products.

The investigation of common methodologies of intervention not only concerned the characteristics of the material constituting the artifact, but investigated globally the architectural elements, paying particular attention to the climatic and environmental conditions to which it is exposed. The research was based on the experimentation of materials and conservation techniques, involving specialists from different scientific disciplines.

It is interesting to underline that the organization of the research activity is based on the multidisciplinary nature of the actors involved. The work was divided into groups and sub-groups organized into specific disciplines, into the different types of material and into the different conservation problems [15]. The harmonization of the activities of the individual Groups was managed by the General Coordinator, who had the task of maintaining the relations of the groups with the offices of the Ministry of Cultural Heritage and Environment and the CNR. The General Coordinator, together with the Coordinators of the individual groups, formed the Executive Committee, which was responsible for defining the general guidelines of the Commission's activities. The appointment of members and the formalization of the working groups were regulated by a circular of the Ministry of Cultural and Environmental Heritage, with annual updates. The Commission's work benefited from the free collaboration of academics, industry representatives and self-employed experts in the various relevant research fields.

Although initially, the activity of the working groups was limited to the study of stone materials, it was later extended, in the early 1990s, to the study of metal and wood [16]. The investigations concerned the study of intervention methodologies and heritage monitoring techniques, taking into account the characteristics of the surrounding environment. In particular, the search was carried out to find the definition of a common language for restoration. A selection of lemmas was identified by the research groups for the drafting of the Commission's first document, *NORMAL 1/80 - alterazioni macroscopiche dei materiali lapidei: lessico* [17]. A first update occurred in 1988 with the publication of *NORMAL 1/88 - alterazioni macroscopiche dei materiali lapidei: lessico* [18], where the need for a graphic (and photographic) correspondence to the description of the corresponding term was highlighted.

"Questa seconda edizione aggiorna, sostituendolo, il documento NORMAL 1/80.

Per alterazione si intende una modificazione del materiale che non implica necessariamente un peggioramento delle sue caratteristiche sotto il profilo conservativo; mentre il termine degradazione implica sempre un peggioramento.

Nella definizione dei singoli termini ci si riferisce esclusivamente a ciò che viene osservato visivamente, prescindendo dalle cause di alterazione e degradazione.

L'elencazione dei termini, ampliata rispetto alla precedente edizione, è basata sull'ordine alfabetico e non su criteri di classificazione o di collegamento dei fenomeni descritti.

Nell'attuale edizione ogni termine è illustrato da una documentazione fotografica significativa, ma non esauriente, e corredato di un simbolo grafico." [18]

For each item, the Commission applied the same analysis scheme, developed in five main points [19]: definition, graphic representation, detailed photo of degradation, origin and cause, and, finally, a selection of examples.

It is important to underline how this structure, enriched by graphical representations, favored a more immediate identification of the typologies of alteration and degradation, limiting the possible misunderstandings of the examined terms.

In the early 1990s, Commission documents, initially published only in Italian, were translated into other languages [20]. This has led to encourage consultation by scholars and professionals from other countries and it has also left room for different interpretations in the identification of different forms of degradation and alteration, due to language differences.

These first documents formed the basis of the research activity of the individual groups that converged in the publication of a series of "recommendations", documents marked by the NorMaL acronym, followed by a serial number and the year of edition.

The publication and dissemination were managed exclusively by the *Istituto Centrale per il Restauro delle opere d'Arte* (ICR). The Institute was responsible for distributing the documents to the various superintendence, bodies, organizations and laboratories in the sector, as well as selling them to freelancers, universities and companies at the Technical Secretariat [21]. In the early 1990s, the need to formalize the recommendations produced up to that time became increasingly apparent, and especially a recognition of these as Italian Standards in order to regulate the conservation interventions carried out without precise criteria until then.

2.2 The European context

On 19th June 1996 the Convention between the *Ministero per i Beni Culturali e Ambientali* and the *Ente Nazionale Italiano di Normazione-UNI* was signed, recognizing the documents produced as Italian Standards, with the acronym UNI-NORMAL [22,23].

In the early 2000s, UNI forwarded to the *Comité européen de normalisation* (CEN) the proposal to activate a European Secretariat dedicated to the standardization of cultural heritage, so as to allow a single and unique "language" among the subjects operating in Europe, which led to the birth of *CEN TC 346 - Conservation of Cultural Heritage* [24].

The initial Business Plan included five working groups [25]:

- alteration lexicon (WG1)
- macroscopic description of the state of conservation through a "condition report" for movable property or a "condition survey" for real estate (WG2)
- Characterization of materials constituting movable and immovable property (WG3)
- characterization of the environmental parameters of the microclimatic surroundings of the object (WG4)
- evaluation of products and methodologies used in conservation intervention (WG5)

The periodic revisions of the work programs were kept at the base of the search for guidelines for the definition of terminology.

It is interesting to note that the tools available today follow the working structure of the NorMaL Commission.

3 Conclusions

These first notes on the search for a definition of a lexicon for restoration highlight the importance of multidisciplinary work and the need to identify a common terminology fundamental for the protection of cultural heritage.

In addition, in the light of the dangers to which the heritage is subject today and the related conservative risks, it is therefore necessary to update the scientific glossaries with the inclusion also of terms referring to new forms of degradation and alteration due to changes climate and natural and man-made risks.

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Monitoring the Effects of Climate Change on Microclimate and Building Materials of Monuments – the approach of "Herisktage" Research Project

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I. EXTENDED ABSTRACT

I. Why Herisktage?

In its most recent report, the Intergovernmental Panel on Climate Change (IPPC) illustrates a rather dire picture of the state of our current and future climate, recognizing that -beyond nature and people's livelihoods- climate change has caused and will be causing *"..cultural losses, related to tangible and intangible heritage, threaten adaptive capacity and may result in irrevocable losses of sense of belonging, valued cultural practices, identity and home.."* [1]. While this is not breaking news for the heritage community, this explicit statement indicates the level of urgency. The nexus between climate change (CC) and cultural heritage (CH) has gained significant attention over the past 25 years at global and European level, with primary focus on assessing the potential impacts to outdoor and indoor heritage places and artefacts [2-4]. Yet, issues regarding assessment tools, implementation of adaptation plans and integrated measures for risk reduction and management at national and regional levels remain a central concern [5-6].

II. The context of Herisktage project

For the Hellenic Ministry of Culture, the nexus of CC and CH has been identified as a key priority area for concerted action. In light of this, a number of high-level policy initiatives and research actions have been instigated at national level. The present work aims to outline the "Herisktage" research project, its objectives and methodology, as well as report on its ongoing research activities and share insights derived

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from recent analyses. “Herisktage – Recording Systems for the Monitoring of Climate Change Impacts on Monuments’ Microenvironment and Heritage Building Materials”, in its full title, is a state-wide initiative undertaken by the Institute of Nanoscience and Nanotechnology (INN) and Institute of Nuclear & Radiological Sciences & Technology, Energy & Safety (INRASTES) at the National Centre for Scientific Research "Demokritos" in collaboration with the Directorate of Conservation of Ancient and Modern Monuments (DCAMM), to serve the priorities of the Hellenic Ministry of Culture. The project is funded by the Recovery and Resilience Facility-Greek National Recovery and Resilience Plan Greece 2.0, under the action: Protection of Cultural Monuments and Archaeological Sites from Climate Change (Action ID 16433) and financed by the European Union.

III. Aims & Objectives

Herisktage investigates the impacts of CC to CH across the Greek territory through real time data collection, climate modelling, and in situ & laboratory-scale tests on building materials. It aims at developing a digital resource, integrated in an IoT platform, for the monitoring of the microclimate of cultural heritage monuments, through which associated risks can be identified and prioritized in selected CH sites of Greece. In particular, its key goals include:

- The development of a wireless sensor network for continuous recording of monuments’ microclimate in real-time,leveraging Internet of Things (IoT) technologies. Collected data will be plotted onto high-resolution climate maps,considering the five Shared Socioeconomic Pathways (SSP) as outlined by the IPCC.

  The development of algorithms for predicting the risk and probability of degradation of the building materials of monuments in various geographical regions, based on the data from climate maps and heritage-tailored climate indicators.
- The design of a risk management tool for assisting the prioritization of conservation/preservation actions, the selection of appropriate interventions and the mitigation strategies against CH impact on monuments.

IV. Methodological approach

Herisktage focuses on slow, progressive and cumulative decay-induced events, invariably linked to environmental parameters (e.g. salt-crystallization, freeze-thaw, swelling of clay minerals) and air pollution (e.g. surface recession, soiling, biomass accumulation). Although not acute, and intensive as most of extreme events, such typology is often overlooked (risk blinding/masking) since their results become noticeable only after a long period of exposure, after an advanced stage of material degradation has already taken place. In the framework of Herisktage, cumulative decay-induced mechanisms are studied at multiple levels: at territorial level through hazard/risk mapping (macro level), at site/building level (meso and digital level) through assessment of selected case studies, at building material level (micro level) through laboratory tests. More specifically:

- **At macro level:** A series of high resolution (5X5 km2) maps plotting a selected number of heritage climatology indicators for the Greek territory (hazard/risk mapping) is produced based on historic data (1980-2004), as well as climate modelling for near (2025-2049) and far future (2075-2099) under Representative Concentration Pathways (RCP) 4.5 and 8.5.
- **At meso level:** A geographically and typologically representative number of monuments in high priority areas are selected as case studies for in depth assessment based on state-of-the-art, field- & time-tested risk management methodologies.
- **At digital (cloud) level:** As part of the site/building level assessment process, autonomous IoT sensors for indoor climate monitoring and control are developed and installed in situ.
- **At micro level:** Laboratory tests on a range of representative porous building materials (e.g. stone, mortars, mudbrick) are undertaken, including their chemical, mineralogical and morphological characterization, assessment of physical and mechanical properties, and evaluation of durability against decay mechanisms through accelerating aging tests.

V. Obtained results, ongoing research and expected outcomes.

CC does not affect the manner in which heritage materials weather; rather, it affects the pace at which weathering mechanisms take place [7]. With that in mind, the hazard/risk mapping provides broad but telling brushstrokes on the pace at which a decay mechanism unfolds. This is particularly insightful for porous building materials, which are heavily influenced by phase transitions- induced stresses.

Interpretation of historic and projected (through models) climatic data for areas of dense heritage and their correlation with phase transition decay mechanisms (i.e. salt crystallization, and freeze-thaw) illustrate an overall decline in the number of events/cycles, with some geographical variations. Given that the rate of phase changes (cycles/events) is not linear to the accumulation of decay, thorough analysis and interpretation of additional parameters, such as mineralogy, pore-space characteristics, and mechanical properties on building materials is underway. Moreover, the advantages of nanotechnology-based materials for functionalized properties and bacteria-based interventions for long-term, autonomous, and eco-friendly treatments are being evaluated.

In overall, as resources become increasingly scarcer, insights from the analyses of the Greek heritage climatology and the study of new conservation approaches will enable more targeted actions, and an evidence-based prioritization of prevention strategies for local heritage authorities and the centralized administration (DCAMM). It is also a unique opportunity for a significant shift from real-time monitoring to real-time response through smart actuators; in other words, from sensing for monitoring, to sensing for managing indoor climate based on the specific requirements of each monument.

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Part VI

Thematic Area 5 - Decorative Architecture Design, Planning and Cultural Heritage Management

Tears in the Rain. Street Art Conservation in a City that is Constantly Changing

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Abstract. Street art has become a worldwide phenomenon over the past few decades, especially in major cities, serving as a form of urban activism that reflects the current socio-political landscape. These ephemeral artworks are vulnerable to deterioration due to outdoor exposure and human intervention.

The conservation of street art is a growing field that has gained the attention of international organizations, academics, and professionals. Since 2009, the Department of Conservation of Antiquities and Works of Art at the University of West Attica has been at the forefront of exploring the ethics, documentation, and research related to street art conservation. The department has been actively involved through lessons, educational programs, and voluntary efforts.

The alteration, extensive deterioration, and potential loss of street art create a different value and interpretive context. The deterioration and losses can enhance or even extend the meaning of the artwork. Deterioration becomes an integral element in the dynamic interpretation and understanding of the artworks, transforming the role of conservation from merely decelerating deterioration to actively interpreting it.

The conservation of street art has brought forth profound questions and challenges that prompt a reconsideration of the broader perspective and ethics of conservation. To this end, documentation and educational initiatives serve as proactive measures in the preservation of street art as a contemporary city's patina and living heritage.

Keywords: Street Art, Conservation, Graffiti, Public Murals, Urban Art.

1 Introduction: The Dynamic Landscape of Street Art

Street art, public murals, and graffiti are vibrant forms of visual expression flourishing in the urban environment worldwide.

Over the past few decades, street art has evolved into a global phenomenon, particularly prevalent in major cities, serving as a form of urban activism that reflects the current socio-political landscape.

Street art is characterized by the creative use of public space, its ephemeral nature, the intention to communicate with the public, and the utilization of various techniques and substrates. Unlike traditional art forms, street art encompasses a wide range of techniques—from stencils and posters to installations and performances—emphasizing its ephemeral nature and its close interaction with the public.

Art in public space has always been at the heart of movements for social justice and social change [1]. In Greece, street art has emerged as a powerful form of protest during the socioeconomic crisis, providing a voice for the marginalized and serving as a mirror of social struggles.

Public murals are large-scale paintings on urban surfaces that often reflect the local community's history and political activism, serving as a powerful communication tool. They have a long history dating back to prehistoric cave paintings and extending to iconic movements like Mexican muralism and contemporary political and community murals in places such as the USA, Ireland, Palestine, Greece, and elsewhere. They have played key roles not only as aesthetic contributions to public spaces but also as tools for social activism and collective memory.

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Graffiti is an unauthorized visual expression using inscriptions and characters through scratching, writing, or spraying on urban surfaces. Its origins range from ancient wall scratches to the graffiti culture of the 1970s in the USA, evolving into an iconic form of underground expression that reflects subversive narratives and countercultural dialogues. Despite its unsanctioned nature, graffiti challenges conventional boundaries of art and public space, making it an integral part of contemporary visual culture.

Street art and graffiti have garnered attention from a range of academic disciplines, including sociology, anthropology, geography, criminology, art history, conservation, and linguistics, each offering a distinct perspective on these forms of expression [2].

These artworks face significant challenges due to exposure to uncontrolled outdoor conditions and human interventions such as overpainting and tagging, making them ephemeral and susceptible to complex and extensive deterioration [3,4,5,6,7].

From a conservation standpoint, street art provides a valuable opportunity for scientific investigation into the identification of materials, mechanisms of deterioration, and conservation treatments. Most importantly, it presents a challenging ethical framework that has sparked ongoing discussions for the preservation of artworks that might vanish before the discussion can reach a resolution.

2 Fading Surfaces: The Ephemeral Life of Street Art in the Urban Environment

The pathology of street art presents examples of the behavior of complex systems rarely observed in other kinds of artworks. These unique characteristics do not have been previously studied. Thus, they need a novel approach, focusing on the phenomena that either trigger or retard deterioration mechanisms -a field that is still in progress.

The environment in which street art exists is very different from the controlled and stable environment of a museum. For example, a public mural in Athens receives direct sunlight for 269 days (about nine months) a year, with some exposure reaching over 40,000 Lux, including high quantities of UV radiation. Additionally, the mural endures rain for about 102 days annually, with huge variations in humidity and temperature [8]. These harsh conditions lead to the rapid degradation of materials, resulting in deterioration that is rarely seen in other types of paintings. Consequently, these works often vanish before preservation decisions can be made, significantly reducing their lifespan (Fig. 1).

The alteration, extensive deterioration, and potential loss of these artworks create a unique value and interpretive context (Fig. 2). Street artists may intentionally incorporate deterioration into their works or highlight it subsequently.

Deterioration and loss can connect or even extend the artwork's meaning. In all cases, deterioration becomes an integral critical element in the dynamic interpretation and understanding of the artworks, shifting the role of conservation from merely decelerating deterioration to actively interpreting it.

The use of already corroded metal substrates, such as old doors, is quite widespread in street art. The water-based glue of the paste-ups obviously activates corrosion mechanisms and consequently results in aesthetic alterations of the surface of the artwork. The rust stains of a paste-up on a corroded metal door are incorporated as a part of the artwork that adds a dramatic effect to the painting as, in the case of artworks by Dimitris Taxis and Wild Drawing.

Especially during the crisis period, the deteriorated support adds importance and extends the meaning of the artwork.

An example that illustrates this hypothesis is Wild Drawing's "5 €uro" (2014), at Exarchia, where the collapsing support of the artwork, the anxious face, and the symbol of the euro, falls apart long with the decomposed render of the substrate.

In this case, the ongoing material loss of the support creates a lively continuity of the artwork which although it is gradually destroyed, it strengthens its meaning very with a dramatic way.

All the above are proving that the deterioration can have a devastating effect and, on the other hand, can add value to the artwork.

The rate of decay and the potential for ultimate loss are crucial for estimating the state of preservation of an artwork. Gradual deterioration is generally accepted until it reaches the critical threshold of potential loss and transformation to something new.

For street art, the most significant aspect is the loss of connection with its environment and the loss of its meaning, while physical degradation is an ongoing process usually accepted by artists. Street art is time-based contemporary art because of its inherent ephemeral nature, openness for interventions, and interaction with the constantly changing city's environment. The degradation might add value and extend meaning with criticism and skepticism in dealing with the crisis, as demonstrated by Wild Drawing's (WD) artwork at Exarcheia (fig. 3).

Visibility and invisibility in public spaces during a crisis raise ethical and political issues [9] that shape the framework for documentation and preservation decisions. Street art often arises from communities in distress, reflecting their struggles and resilience. As such, the conservation of street art preserves not only the physical artwork, but also the socio-political context it represents.

Fig. 1. The impact of extreme, uncontrolled outdoor environmental conditions and human interventions, leading to the rapid deterioration of street art.

Fig. 2. Deterioration of street art.

Fig. 3. Since decay and ephemerality are intrinsic elements of the time-based artwork what do we want to preserve? Mural by Wild Drawing (WD), 2014.

Fig. 4. The artwork as an ongoing process: creation, additions, extensions, overpainting, whitewashing. Plaka, Athens, 2009-2024.

Fig. 5. Interventions in the urban space: from creation to overpainting,

Fig. 6. WD's mural adapted to the building concerning its historical and social value and intervention by city authorities.

3 Conservation in a Changing Landscape

The conservation of street art is a relatively new and growing field that has garnered increasing interest from international organizations, academics, and professionals [10, 7, 11].

From a conservation viewpoint, we start by considering that street art characterizes the face of the contemporary city that we ought to -at least- document. Conservation interventions are rarely and occasionally carried out on artworks with social, scientific, and educational - apart from artistic – value [7].

The study of urban surfaces as a palimpsest uses losses and gaps to detect and interpret layers and signs (Fig. 4). Archives, photographs, and stories are used to synthesize narratives composed of evidence and hypotheses. As Orbaşli (2017) [12] mentions, "conservation is a way of interpreting through material remains informed by the meanings and values of the present." However, in-depth documentation does not mean a neutral perspective. Conservation has proven with the plethora of publications in the field that it does not stand on the grey side of the street. We preserve legally protected heritage while accepting that the contemporary face of the city -like it or not- belongs to the heritage of today.

Since 2009, the Department of Conservation of Antiquities and Works of Art (C.A.W.A.) of the University of West Attica (UNI.W.A.) has been at the forefront of exploring the ethics, documentation, and research related to street art conservation. The department has been actively involved through lessons, educational programs, and the voluntary efforts of Street Art Conservators (St.A.Co.), a team of students and academics dedicated to the documentation and rescue conservation of street art [7].

During this period, a large amount of documentation material, experience from in situ interventions, theses, and surveys of students and the public emerged, reflecting the experience of monitoring artworks from creation to destruction.

At the same time, in an age where the most consistent archive of information is social media, part of the documentation of art projects the public counter-reaction arises from this data, proving the public's interest and enthusiasm.

This was evident with WD's mural "Knowledge Speaks, Wisdom Listens", and Stelios Faitakis' mural on the history of the olive tree on Pireos Street, where the public strongly reacted to tagging interventions and supported the cleaning of murals and the extension of their existence through conservation/restoration treatment. The public's call for preservation shows how certain artworks become part of the city's cultural heritage. In both of these cases, the conservation/restoration effort symbolized not only the technical challenge of tagging removal but also the ethical issues of how to maintain the integrity of a piece that exists within the changing, living fabric of the city.

By documenting these interventions, we gather knowledge that contributes to the evolving practice of street art conservation, where the ephemeral and the permanent must find a harmonious coexistence.

More effective in the rapid disappearance of street art is the special authority's service that offers its contribution to the appearance of the city (Fig. 5,6).

The appearance of a city looks intricately linked to the way of life it represents. A city with flawless surfaces may not necessarily be ideal, as imperfections and losses create opportunities for communication and intimacy. The city is our common social ground and small losses and gaps are the starting points for questions and research that -in a way- allow something new to emerge and flourish.

Connerton [13] noticed that “Today it is we who observe the birth and death of objects; whereas, in all previous civilizations, it was the object and the monument that survived the generations.” The familiarization with consumable products being substituted by others has influenced art for decades. The end of the artwork as a physical entity is not the end of the artwork… As Lucio Fontana said in 1947, “Art is eternal, but it cannot be immortal. … It will remain eternal as gesture, but it will die as material (…).”

In today's world, the artwork as a consumable product and the graffiti as an alternate advertising message on the walls prepare for the acceptance of the end of the artwork. Since “Conservation is the process of managing change” [14], managing these alterations through documentation, research, and mild rescue interventions is the only feasible way. Understanding and accepting the inevitability of loss as a natural part of the life cycle of artworks, buildings, monuments, and cities can lead to creative solutions. These solutions can help prolong the lifespan of artworks and also aid in planning conservation strategies through documentation, education, and raising awareness. Given the transient nature of street art, traditional conservation often proves impractical for its protection. Thus, Conservation plays a crucial role in educating the public about appreciating and accepting the natural decay intrinsic to these artworks.

4 Conclusion: Street Art is Dead. Long Live Street Art

By understanding street art as a time-based ongoing process [15] in extreme environments, we can better manage its changes [14] and set a preservation strategy based on documentation, research, and educational activities. The practice of conservation cannot effectively reduce and forever the degradation process. The choice of more drastic interventions, such as detachment and transfer, affects its intrinsic characteristics and invalidates its nature and values. The transition from interventive conservation to a documentation for preservation strategy, keeping the instances/moments of its existence that were significant for the community or -even- of those that we happened to be there, is the real-life of conservation. This can help us set achievable and inspiring goals. Conservation in the streets is an influential performance. It also sets goals that extend to scientific and educational benefits that, in turn, broaden the significance of the artworks.

Documentation and monitoring are useful processes for conservation students who are thrilled to participate in these projects. Difficult outdoor conditions, complicated conservation case studies, and communication with the public make student engagement a very interesting experience that adds educational value to artworks. Additionally, the research on deteriorated surfaces is challenging and precious for conservation and adds scientific value.

Thus, the end of an artwork on the city's wall is an unwelcome but expected event that often signals the beginning of a new piece of art. By embracing the ephemeral nature of street art, we recognize its role as a dynamic and evolving component of urban culture, ensuring that its legacy endures even as its physical form fades. Documentation and educational initiatives serve as proactive measures to engage the public and mobilize experts in the preservation of street art as a contemporary city’s patina and living heritage. Street art is not formally under protection in a defined institutional framework but can be protected on a case-by-case basis and in ways that most often do not involve interventions on the physical object but rather their thorough documentation, public awareness, and educational programs.

In conclusion, the conservation of street art poses unique challenges and opportunities. While the physical preservation of these works may be limited by their inherent ephemerality, their documentation and the stories they tell can continue to inspire. Street art, as a living heritage, not only reflects the ever-changing socio-political landscape but also invites ongoing dialogue about the values and narratives we choose to preserve in our urban environments. Embracing this oxymoron allows us to appreciate its social value and its enduring impact on the cultural fabric of our cities.

Despite the colored surfaces being lost, much like "tears in the rain," to use the poetic phrase from Ridley Scott's film “Blade Runner” in its dystopian urban landscape, the memory of the space and the values associated with it persist as long as people recognize the urban space as common ground for social life and change.

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Scientific integration of 2D documentation sources for the digital representation of architectural monuments: its contribution to cultural heritage management.

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Abstract. The elaboration of 2D documentation sources, including all relevant historical, architectural, archaeological as well as artistic (textual and iconographical) data, are usually collected and evaluated, while an architect-engineer/conservator is conducting a restoration and rehabilitation project. In addition, all other relevant documentation may be used in a digital application, where 2D drawings and plans can be applied, for the virtual representation of heritage monuments, existing or non-existing ones (lost), either partially damaged or even having undergone severe deformations during the passage of time by nature or by man-made actions. The offered documentation and representation techniques vary, and of course, as digital technology develops, the related evolutionary steps can offer an important contribution to the faithful restitution of architectural monuments. Yet, what happens in other cases, where the architectural monuments and the complex of historic buildings, or the archaeological sites do not survive up to our times? The submitted paper will try to highlight relevant applied techniques as used in recent cultural heritage projects by means of their comparative analysis and presentation.

Keywords: 2D Documentation, Digital representation, Cultural Heritage Management.

1 Scientific architectural documentation through 2D sources.

1.1 Contribution of 2D documentation data for the representation of architectural monuments: case study of ancient buildings.

The architectural structural measured survey & the documentation of an architectural monument require a thorough knowledge of a building's construction, materials, as well as the state of its condition. Therefore, the process that takes place is usually the result of the interdisciplinary collaboration between specialists from various fields: architect engineers with specialized studies in Conservation, civil engineers, and topographers, while in many cases the contribution of archaeologists is quite helpful for the historical background and former use of a monument.

2D documentation sources include, therefore, all relevant historical, architectural, archaeological as well as artistic (textual and iconographical) data: their evaluation allows us to proceed to a structural reconstruction and representation of the monument, while this research is most important for the restoration and rehabilitation project. More specifically, in cases when a digital application of the building's reconstruction is elaborated, the conducted survey plans of 2D drawings for the virtual representation provide the basis of the project.

A similar procedure of architectural survey, a study of the monument's structure and materials is here applied, which assisted later in its restoration.

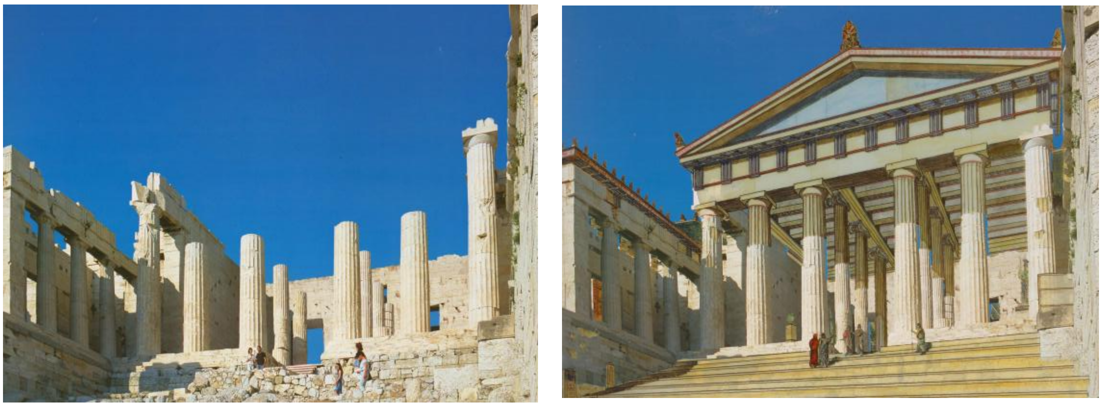

Fig. 1. Propylaia, Acropolis: elaboration of the monument's architectural survey and its graphic representation (G. Antoniou, 2008, Ancient Greece. The Monuments then and now, p. 12, Propylaia depicted before restoration works).

The monument has been architecturally surveyed and studied [1], as its restoration project was included in the major restoration and consolidation works to be carried out on the Acropolis hill by the Acropolis Restoration Service (YSMA). The conducted 2D drawings have been most useful, as in this case, the combination of the photographic material and formerly collected records were combined with free hand reconstruction and representation of all the missing parts of the monument.

The paper will focus on relevant applied techniques in cultural heritage projects by means of similar case studies, aiming at their representation and cultural management: the here selected ones are chosen due to the difficulties encountered.

2 The architectural representation of a monument.

2.1 Creating a digital representation (digitization) for recording and documenting an architectural monument: a case study of 18th c. buildings.

The application of various survey and documentation techniques –according to the technological knowhow, as well as to the overall budget of a project, may provide a faithful reconstruction of a monument: the use of architectural and archaeological Photogrammetry is one of these techniques, already applied in the previous decades; while 3D laser scanning gathers high quality records of the building's current state and document it by collecting millions of data points and its digital measurements from a project location, as technology is advancing rapidly; the recent use of digital twins, as applied in the simulation of a heritage site, uses modern technology and its tools enabling us to work on the accurate digital representation and digitization of cultural artifacts, architectural monuments, archaeological sites, and many other purposes, as an interaction between actual physical objects-the buildings, and their representation-their virtual image, can be produced; the insertion of augmented reality is also a newly applied option, as digital cultural content can be overlaid onto the physical entity of an architectural monument, (as well as of any physical artifact, sculpture, or archaeological find), creating a personal experience for the visitor.

The use of the above-mentioned techniques can be mostly applied in cases of existing buildings of importance and objects. Yet, there are many other cases where the architectural monument and the complex of historic buildings, or the archaeological sites do/did not survive up to our times, may even be found partially damaged or having undergone severe deformations during the passage of time by nature or by man-made actions. Since there can be no 2D documentation sources collected to be elaborated and scientifically integrated, the role of the restorer is mainly focused on the parallel study of other existing important data in order to represent the lost object.

2.2 The documentation of an Ottoman period architectural complex of monuments: the case study of Ottoman Corinth and its settlement.

The following case study will present relevant issues about Ottoman Corinth [3]: the urban expansion of the site and its monuments were recently thoroughly studied (2014-15). The Research Programme *COPIS: Corinth in the Ottoman Period through Interdisciplinary Study*, elaborated for the Department of History, Archaeology & Social Anthropology at the University of Thessaly (Volos), Greece, has produced new scientific research about the whole area of Ancient Corinth; Dr. Eleni Kanetaki conducted the architectural and historical study, while Dr. Seyyed Taghi Shariat-Panahi provided all historical data about the Ottoman manuscripts and their transcription.

During the course of 18^{th} c., the saray of the powerful Ottoman commander Kiamil Bey was constructed at the north end of the main road along a promontory at the lower terrace of Corinth, constituting another suburb, the Bey mahalla. The Saray (palace) of the Ottoman commander formed the political and administrative centre of the town. It was set at a well-selected location, overlooking the wide-spread gardens with fruit trees, the running water from the fountain of the so-called "*Baths of Aphrodite*", as well as the plain. Kiamil (Kâmil), the wealthy Ottoman Bey, who had governed the region and owned vast properties in the region and elsewhere in the Peloponnese, had well-chosen these northern promontories of Corinth for his seraglio: a remarkable complex built in a large enclosure with harems, baths, kiosks and gardens, exhibiting its oriental feature. Although it doesn't survive till today, the remaining parts of a damaged hammam/bath have been traced, as well as the monumental stone stairway at the site «*Loutra Aphrodite* (*Λουτρά Αφροδίτης, Baths of Venus*)», which must have led to the prominent palace). Its structure was documented in many 18^{th} c. engravings; among others, William Gell and Carl Haller von Hallerstein have depicted the monumental complex, which was also well described in the memoirs of European travellers who had had the luck of visiting it. Yet the elaboration of previously collected material, former topographical survey plans[1] by John Travlos -the Greek architect, architectural historian & archaeologist and the American School of Classical Studies- in the 1960's, as well as old photographs and engravings, along with in situ architectural survey drawings conducted by dr. E. Kanetaki, during 2014-15, provided important data for this remaining architectural feature (see Fig. 2).

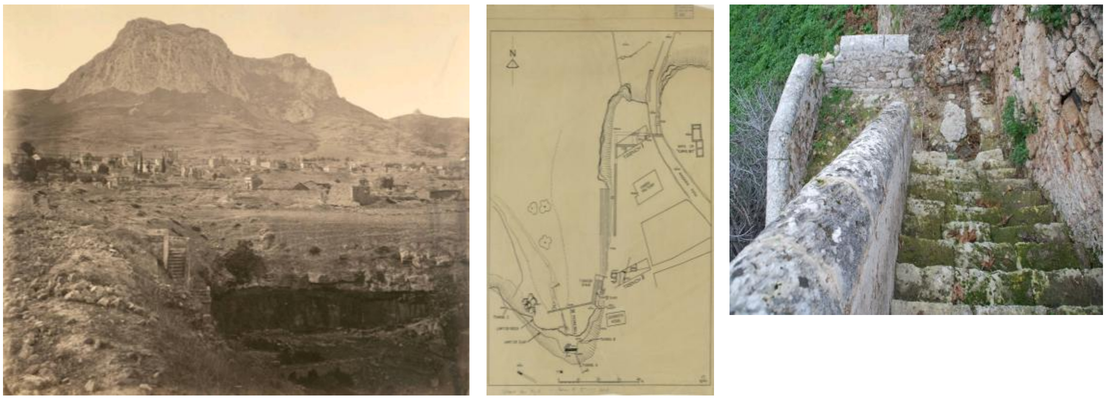

Fig. 2. Kiamil Bey Palace site: old photo (1869) by Granges, Paul Baron & archival survey plans by ASCSA- J. Travlos, with in situ conducted architectural surveys (E. Kanetaki, 2015).

2.3 The documentation of an architectural complex of monuments dated in the Ottoman period: the case study of 18^{th} and 19^{th} c. buildings.

The urban layout form of Ancient Corinth settlement and the urban transformations of its grid, during the Ottoman times, were both studied as part of the Research Programme *COPIS: Corinth in the Ottoman Period through Interdisciplinary Study* with the help of various technological equipment and data.

At the beginning of 19^{th} c. after the Liberation from the Ottoman Rule, the New Greek Governor Ioannis Kapodistrias commissioned the French military officer, geographer-engineer & cartographer Jean-Pierre-Eugène-Félicien Peytier (1793-1863)[2], member of the French Military Expedition in Morea, to draw the plan for the new city of Ancient Corinth. Peytier worked on the topographical survey map of Corinth ("*Plan de Corinthe"*/leve finissant l'hiver de 1829-1829, scale 1:2000, Dépôt de la Guerre) depicting the area in detail, as the urban fabric is drawn with great accuracy (in red ink and red watercolour). He also proposed a new street plan (in yellow watercolour). The topographical survey map records the names of three neighbourhoods, the Küçük mahalla, the Hadji (Haci) Mustafa mahalla and the Kalamata mahalla, along with the ruins of Kiamil Bey's palace with a tower and two baths; three ruined mosques (the market mosque was in use as a barrack and a gaol); churches; three public fountains; the temple of

[1]http://ascsa.net/id/corinth/drawing/223%20001?q=classification%3A%22%7C%20Corinthia%20%7C%20Ancient%20Corinth%22%20bath&t=&v=list&sort=&s=5).

[2] http://eng.travelogues.gr/travelogue.php?view=68&creator=952071&tag=8843.

Apollo and other ancient and Byzantine ruins. These neighbourhoods-distinct suburbs, were separated one from the other by fields of corn, as well as by gardens with lemon trees, cypresses and other fruit trees, and they were related to the main street connecting the mahallas. Small other secondary streets formed a net of irregular patterns, leading to private properties.

During the architectural and urban study of the area by Dr. E. Kanetaki for COPIS, quite interesting results were produced, as a comparative juxtaposition of Peytier's topographic plan was made in accordance to the modern urban fabric of Ancient Corinth village, using data from Google Earth.

The map (now in the Depot de la Guerre/Cartes/4.10.C.65.1.0057, 86x58,50 pencil drawing, ink, Paris, 1829) [6], was depicting important monuments of the area. A part of Peytier's plan was enlarged, and the "cut image" was overlapped on the extracted data from Google Earth, showing the modern urban fabric, producing stunning results[3]: the urban form of the village has remained quite unaltered, as the lines depicting small streets and plots of land were traced till our modern times (see Fig. 3).

Fig. 3. The central area of Ancient Corinth -Du Moncel, (Mosqué turque a Corinth, 1843). The topographical map by P. Peytier (1829) & the relevant overlapping of the under-study area with its important Ottoman monuments, using images extracted from Google Earth.

During the centuries that followed its establishment since antiquity, the urban fabric contour of remained the same due to the fact that its reproduction through the ages was merely a result of superimposed layers of buildings one over the other. Peytier's plan records the same layout division of the former Ottoman city, with small in extent neighbourhoods interspersed with fields and the centrally located market area (bazaar) with its dense urban fabric. The new city plan was mainly a proposal to straighten and broaden the streets, preserving and widening the existing streets of the city.

3 Contribution of various representation techniques for cultural heritage management by use of modern technology.

3.1 The documentation of two 19th c. urban mansions & their representation.

The twin Patsiadou urban mansions in southeastern Piraeus were constructed by the German architect Ernst Ziller (1837-1923) during 1894-95 in the (yet) undeveloped area of Alexandras square, Kastella facing the port of Zea, commissioned by Panayiotis Patsiadis, a wheat merchant of the time. They were in close proximity to the 7 mansions ("Villen-Colonie Ziller") constructed by E. Ziller as summer houses-villas, which he rented to wealthy Athenians of 19th c. -a site documented in the topographic map of Athens "Karten von Attika" by E. Curtius & J.A. Kaupert (1862-1897), a monumental cartographic work of high quality and accuracy displaying in 32 map sheets a huge amount of information, not only of archaeological heritage mapping but also of the landscape at the last quarter of the 19th c.

The smart technology digital application "*Piraeus Archwalks: virtual cultural itineraries for the historical city centre of Piraeus and its Neoclassical urban nucleus*" was elaborated by Aegean Solutions

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Company for Aik. Laskaridi Foundation, Piraeus, Greece, during 2022-23 and is currently offered for free [6]. Among the suggested itineraries, a research study of the Patsiadou mansions was presented in order to digitally represent and reconstruct the two buildings by combining all related documentation found: the original architectural plans, drawn in scale 1:50 by E. Ziller (1870), kept at the Ziller Archive of the National Gallery-Alexandros Soutsos Museum (Athens), numerous old archival photographs and other historical data, contributing to the digital renderings and the morphological restoration of the buildings' complex. Only one of the two houses exists, as the missing Patsiadou mansion was demolished in 1973 and a five-storey apartment building was constructed in its place. The 2nd mansion, although declared a listed building by the Hellenic Ministry of Culture, shows signs of decay [6].

During the elaboration of the digital renderings, it became necessary to conduct a comparative study of other Ziller's works in Athens since many architectural structural elements were not well defined -the watercolour plans in scale 1:50 were rather vague. Other projects were studied, such as the Ziller-Loverdou private house (Mavromichali 6 str., Athens), "Mpageion hotel" (Omonoia square, Athens city centre), as well as Sp. Metaxa mansion (Vas. Georgiou str., Piraeus), since similar architectural features found in these buildings were copied and applied. As an outcome, it seems that many of the drawn architectural morphological & decorative elements were either not realized or had been modified in later interventions (see Fig. 4).

Fig. 4. The twin Patsiadou mansions (1870), hand-drawn side façade design by Ernst Ziller -plan kept at the Ziller Archive at the National Gallery-A. Soutsos Museum, Athens and architectural elements deriving from other buildings designed by the architect, used for their detailed digital representation: i.e., a drawing for a Karyatide at Loverdou mansion façade in Athens, his home in late 19th c. & details from Sp. Metaxa mansion in Piraeus, depicting 4 male figures.

The results of this study have been incorporated in the digital application offering valuable architectural and historical documentation for 120 neoclassical and eclectic buildings of the 19th c. in Piraeus, as well as the archaeological sites of the city found along the proposed cultural routes. Dr. E. Kanetaki conducted the scientific architectural research. Digital renderings were produced by I. Plakotaris as a collaborator of Aegean Solutions Company.

3.2 The documentation of the 19th c. Piraeus Clock and its representation.

The Old Town Hall ("Roloi") of Piraeus, also known as the Town House of the city, was initially constructed in 1869-73 after the plans of city engineer Gerasimos Metaxas, housing later the Stock Exchange. The Clock that became the landmark of the area was erected in 1873. According to a few archival sources, the building functioned only for one year for these financial transactions. Later on, it hosted the city's Commercial Club for many years, and on its premises, balls and charity events were thrown. Also, since 1874, the Mavrokordatos Library was housed there. Since 1880, the ground floor was used as a coffee shop, while later, on its floors the municipal services of the city were installed. The building was demolished in 1968 by order of Mayor A. Skylitsis.

The digital application *Piraeus Archwalks: virtual cultural itineraries for the historical city centre of Piraeus and its Neoclassical urban nucleus*, included this listed building into the digital representations of Piraeus characteristic monuments [5], [6].

Yet there have been former attempts to digitally document and represent the Piraeus Clock, as almost 30 years ago (1994-6), the School of Rural & Surveying Engineering Department at the NTUAthens [2] had worked on the first attempt to digitally represent and reconstruct it: they used old postcards and amateur photographs, which they elaborated into photogrammetric data processing for the digital rectification and the reconstruction of the 3d model. Simple digital photogrammetric techniques were applied, resulting in the following representation as shown below[4].

Similar techniques were used for the digital app *Piraeus Archwalks* (see Fig. 5).

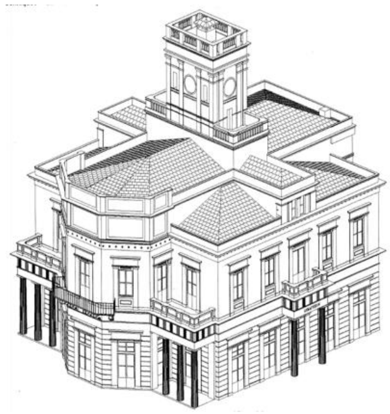

Fig. 5. 3D model of Piraeus clock (Ioannidis, Badekas, Potsiou 1994-6 & Plakotaris, 2023).

The Clock of Piraeus has been digitally represented, and a 3D model of its structural shell was produced, as no construction plans were found nor architectural survey plans were done due to its demolition in 1968. Although technology progresses quite quickly, the result of the 1996 photogrammetric representation model [2] appears most accurate and corresponds to old photos of the time, which were also used in the recent (2022-23) digital representation.

4 The contribution of various documentation techniques for the cultural heritage management of monuments.

The paper has tried to highlight a few applied techniques used in recent cultural heritage projects by means of multiple documentation data: existing monuments, metrically measured with a thorough documentation of their structure & state of conservation, as well as demolished buildings, with no survey plan to assist their reconstruction and representation. The management of cultural heritage requires novel approaches [5], for promoting & preserving architectural heritage and cultural artifacts.

Acknowledgements

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Scientific integration of 2D documentation sources for the digital representation of architectural monuments: its contribution to cultural heritage management.

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Abstract. The elaboration of 2D documentation sources, including all relevant historical, architectural, archaeological as well as artistic (textual and iconographical) data, are usually collected and evaluated, while an architect-engineer/conservator is conducting a restoration and rehabilitation project. In addition, all other relevant documentation may be used in a digital application, where 2D drawings and plans can be applied, for the virtual representation of heritage monuments, existing or non-existing ones (lost), either partially damaged or even having undergone severe deformations during the passage of time by nature or by man-made actions. The offered documentation and representation techniques vary, and of course, as digital technology develops, the related evolutionary steps can offer an important contribution to the faithful restitution of architectural monuments. Yet, what happens in other cases, where the architectural monuments and the complex of historic buildings, or the archaeological sites do not survive up to our times? The submitted paper will try to highlight relevant applied techniques as used in recent cultural heritage projects by means of their comparative analysis and presentation.

Keywords: 2D Documentation, Digital representation, Cultural Heritage Management.

1 Scientific architectural documentation through 2D sources.

1.1 Contribution of 2D documentation data for the representation of architectural monuments: case study of ancient buildings.

The architectural structural measured survey & the documentation of an architectural monument require a thorough knowledge of a building's construction, materials, as well as the state of its condition. Therefore, the process that takes place is usually the result of the interdisciplinary collaboration between specialists from various fields: architect engineers with specialized studies in Conservation, civil engineers, and topographers, while in many cases the contribution of archaeologists is quite helpful for the historical background and former use of a monument.

2D documentation sources include, therefore, all relevant historical, architectural, archaeological as well as artistic (textual and iconographical) data: their evaluation allows us to proceed to a structural reconstruction and representation of the monument, while this research is most important for the restoration and rehabilitation project. More specifically, in cases when a digital application of the building's reconstruction is elaborated, the conducted survey plans of 2D drawings for the virtual representation provide the basis of the project.

A similar procedure of architectural survey, a study of the monument's structure and materials is here applied, which assisted later in its restoration.

Fig. 1. Propylaia, Acropolis: elaboration of the monument's architectural survey and its graphic representation (G. Antoniou, 2008, Ancient Greece. The Monuments then and now, p. 12).

The monument has been architecturally surveyed and studied [1], as its restoration project was included in the major restoration and consolidation works to be carried out on the Acropolis hill by the Acropolis Restoration Service (YSMA). The conducted 2D drawings have been most useful, as in this case, the combination of the photographic material and formerly collected records were combined with free hand reconstruction and representation of all the missing parts of the monument.

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[3] I would therefore like to thank Georgios Antoniou, architect engineer NTUA, MA in Buildings' Conservation, IoAAS UoYork, for his help in the elaboration of the Google Earth data.

watercolour plans in scale 1:50 were rather vague. Other projects were studied, such as the Ziller-Loverdou private house (Mavromichali 6 str., Athens), "Mpageion hotel" (Omonoia square, Athens city centre), as well as Sp. Metaxa mansion (Vas. Georgiou str., Piraeus), since similar architectural features found in these buildings were copied and applied. As an outcome, it seems that many of the drawn architectural morphological & decorative elements were either not realized or had been modified in later interventions (see Fig. 4).

Fig. 4. The twin Patsiadou mansions (1870), hand-drawn side façade design by Ernst Ziller -plan kept at the Ziller Archive at the National Gallery-A. Soutsos Museum, Athens and architectural elements deriving from other buildings designed by the architect, used for their detailed digital representation: i.e., a drawing for a Karyatide at Loverdou mansion façade in Athens, his home in late 19th c. & details from Sp. Metaxa mansion in Piraeus, depicting 4 male figures.

The results of this study have been incorporated in the digital application offering valuable architectural and historical documentation for 120 neoclassical and eclectic buildings of the 19th c. in Piraeus, as well as the archaeological sites of the city found along the proposed cultural routes. Dr. E. Kanetaki conducted the scientific architectural research. Digital renderings were produced by I. Plakotaris as a collaborator of Aegean Solutions Company.

3.2 The documentation of the 19th c. Piraeus Clock and its representation.

The Old Town Hall ("Roloi") of Piraeus, also known as the Town House of the city, was initially constructed in 1869-73 after the plans of city engineer Gerasimos Metaxas, housing later the Stock Exchange. The Clock that became the landmark of the area was erected in 1873. According to a few archival sources, the building functioned only for one year for these financial transactions. Later on, it hosted the city's Commercial Club for many years, and on its premises, balls and charity events were thrown. Also, since 1874, the Mavrokordatos Library was housed there. Since 1880, the ground floor was used as a coffee shop, while later, on its floors the municipal services of the city were installed. The building was demolished in 1968 by order of Mayor A. Skylitsis.

The digital application *Piraeus Archwalks: virtual cultural itineraries for the historical city centre of Piraeus and its Neoclassical urban nucleus*, included this listed building into the digital representations of Piraeus characteristic monuments [5], [6].

Yet there have been former attempts to digitally document and represent the Piraeus Clock, as almost 30 years ago (1994-6), the School of Rural & Surveying Engineering Department at the NTUAthens [2] had worked on the first attempt to digitally represent and reconstruct it: they used old postcards and amateur photographs, which they elaborated into photogrammetric data processing for the digital rectification and the reconstruction of the 3d model. Simple digital photogrammetric techniques were applied, resulting in the following representation as shown below[4].

Similar techniques were used for the digital app *Piraeus Archwalks* (see Fig. 5).

[4] I therefore would like to thank Prof. Charalambos Ioannidis, Professor at the Lab of Photogrammetry, School of Rural & Surveying Engineering, NTUA, for providing me the relevant information about their former project and Congress publication.

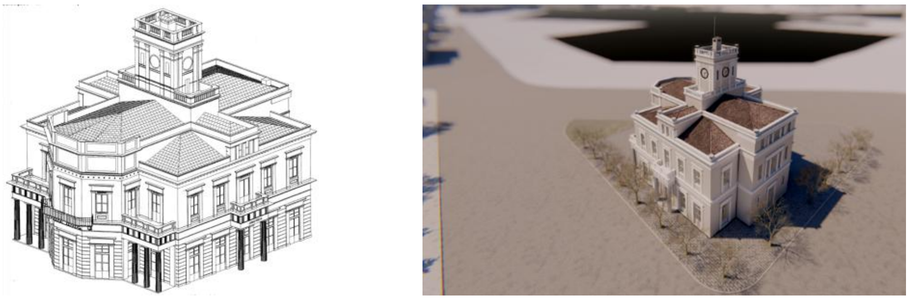

Fig. 5. 3D model of Piraeus clock (Ioannidis, Badekas, Potsiou 1994-6 & Plakotaris, 2023).

The Clock of Piraeus has been digitally represented, and a 3D model of its structural shell was produced, as no construction plans were found nor architectural survey plans were done due to its demolition in 1968. Although technology progresses quite quickly, the result of the 1996 photogrammetric representation model [2] appears most accurate and corresponds to old photos of the time, which were also used in the recent (2022-23) digital representation.

4 The contribution of various documentation techniques for the cultural heritage management of monuments.

The paper has tried to highlight a few applied techniques used in recent cultural heritage projects by means of multiple documentation data: existing monuments, metrically measured with a thorough documentation of their structure & state of conservation, as well as demolished buildings, with no survey plan to assist their reconstruction and representation. The management of cultural heritage requires novel approaches [5], for promoting & preserving architectural heritage and cultural artifacts.

Acknowledgements
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Planning for conservation: accessibility and management of cultural heritage

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Abstract. Cultural Heritage must today be the new centers of associated life, emotional spaces in which to feel part of a community that includes everyone. In Italy, the "Cultural Heritage and Landscape Code" defines the valorization of cultural heritage as those actions aimed at facilitating the use, knowledge, and conservation of the heritage. It is about creating a virtuous network of relationships that places cultural heritage at the center of a conservation circuit based on fruition and valorization. We are talking about a conservative model based on increasing visitor flows and not just on protection as an end in itself. The cultural and tourism industries intertwine, developing interactively: the former enhances the creativity of the latter while the latter provides a support platform and a catchment area for the former. The identification of a new user figure who can vary in age, geographical and social origin, cultural background, and physical or mental abilities is fundamental. Today, we can consider assimilating the concept that accessibility constitutes an integral part of the protection project in the broadest sense of "integrated conservation," which adds planning and management tools to conservation. If the decisive step from a legislative point of view was to review the concept of exemption from accessibility requests for historic buildings with the enactment of Law 13 of 1989, another significant watershed is undoubtedly the activation of the National Museum System, which places accessibility as an indispensable objective.

Keywords: Accessibility, Cultural Heritage, Conservation.

1 From Cultural Heritage to Cultural Tourism

Today, Cultural Heritage must be considered the new centers of associated life, places of collective events, emotional spaces in which one can feel part of a community that includes everyone. The valorization of cultural heritage in the "Cultural Heritage and Landscape Code" (Legislative Decree 42/2004) is guaranteed by indications to encourage use, knowledge, and conservation. These are actions aimed at creating a virtuous network of relationships that places cultural heritage at the center of a conservation circuit based on fruition and appreciation. It is a conservative model based on operations aimed at generating visitor flows and not protection as an end in itself. The monument remains alive as it is part of an emotional flow that affects multiple generations and all social classes. Enjoyment and knowledge are the basis of so-called cultural tourism, based on the desire to shorten the distances between oneself and the cultural heritage of a specific civilization. The term “cultural tourism” has been used since 1995 (Silberberg, 1995). The cultural and tourism industries develop in a mutual and interactive way: the former enhances the creativity of the latter while the latter provides a support platform and a catchment area for the former. The relationship between heritage and territory can generate countless possibilities, a very complex cultural offer system, and an important position for places from a tourist's point of view. This process tends to direct and increase the museum offering, acting as an immaterial multiplier of development (McKercher., 2002). The World Tourism Organization (WTO) states that “cultural tourism represents all movements of people motivated by cultural purposes such as study holidays, participation in live performances, festivals, cultural events, visits to archaeological sites and monuments, pilgrimages. Cultural tourism is also about the pleasure of immersing yourself in the local lifestyle and everything that constitutes its identity and character".

Cultural tourism refers to Cultural Heritage, including both material assets (monuments, churches, museums, castles, historical and archaeological sites, etc.) and intangible ones, in the broadest sense and in accordance with the definition of Intangible Cultural Heritage provided by UNESCO Paris Convention of 2003. The international charters on the rights of the environment and cultural heritage, starting from the declarations of UNESCO in 1972 and the Council of Europe in 1975 up to the latest European

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resolutions, define cultural heritage as the wealth of a nation, highlighting the role in the formation of the concept of a nation (Cucco, 2020).

2 The new visitor and visitors' journey

The starting point is the identification of a new, more complex figure of the user who can vary in age, geographical and social origin, cultural background, and physical or mental abilities but will have the common denominator of the desire to shorten the distance between oneself and the objects or places of knowledge. New users may be attracted by the usual cultural activities but also by the specificities of a territory, giving life to the so-called experiential tourism, which, as the word itself suggests, puts the visit experience at the center. The new concept of visitors' journey, borrowed from the customer journey (Douglas B. Holt, 1995), places users at the center of the research and makes known the process that determines the behavior of buyers/visitors inside the museum. Experience, integration, and classification are the dimensions of play he added. Knowing the visitors' journey helps the museum institution to understand and analyze the motivations and behaviors of users and to plan the route in order to eliminate any possible physical, social, sensorial, or cultural "obstacle."

This analysis, by studying the behavior of a potential visitor, aims to facilitate some basic actions such as:

- identify the museum in the area;
- choose the offer of a specific museum compared to that of other museums or other sporting and/recreational activities;
- plan the visit by identifying the time, physical, economic, and organizational resources.

The "path" of the users is not exclusively the one they have to take inside the museum once they have crossed the physical or virtual threshold. There is a before, a during, and an after. At first, we need to make the museum and its offerings known, stimulate the desire for knowledge, and facilitate the organization of the visit also for the wider audience mentioned above. Fundamental to the structure is the website, which constitutes the museum's business card and must, therefore, contain all the information necessary to organize the itinerary. To give an example, an autistic person may need to evaluate the level of noise in the rooms, the lighting, or the crowding. A mother with a pram may want to check the presence of steps, the possibility of letting her child play or crawl, or even the possibility of touching the works, given that children, as well as blind people, love tactile interaction. Everything that the museum declares must actually be present and usable during the visit. Any faults in the systems must be reported.

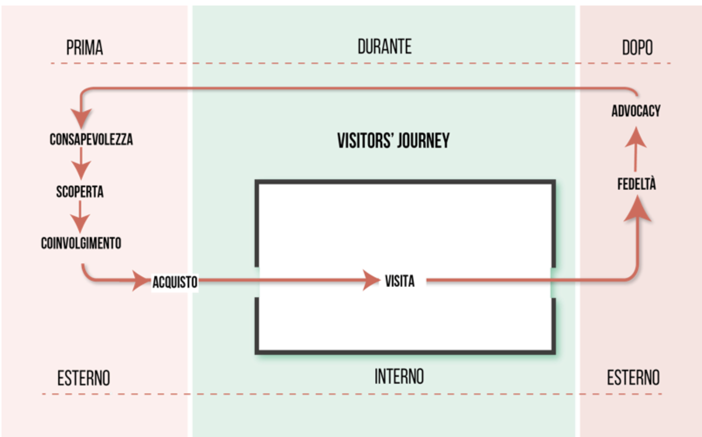

Fig. 1. Classification of the museum visitor path

The Museum acts as a guarantor of its services in terms of directions, accommodation, activities, accessibility, and any type of service indicated. During the visit, it is desirable that the visitor's expectations regarding the visit experience are confirmed – and perhaps exceeded – upon leaving the museum. In the post-visit phase, in fact, each visitor will share what they have experienced and will contribute to activating a virtuous circle, increasing visitor flows and the social effectiveness of the museum itself in the area.

3 Accessibility: from obstacle to project quality

The Cultural Heritage Code aims precisely at the concept of visit ability and to facilitate the use of cultural heritage through specific indications for the elimination of all those architectural barriers that prevent visits. The theme of accessibility began to spread only between the end of 1980 and the beginning of 1990, following the approval of law 13/89, which extended the obligation of regulatory adaptation to existing buildings if subjected to restoration works, and through the issuing of provisions implementing the regulation, Ministerial Decree. n. 236 of 14 June 1989 (Technical requirements necessary to guarantee the accessibility, adaptability, and "visit ability" of private buildings and subsidized and subsidized public residential buildings for the purpose of overcoming and eliminating architectural barriers). Article 3 establishes three levels of quality: accessibility, the possibility of a visit, and adaptability of the visit.

Accessibility is the highest level of quality because it allows everyone to enjoy all spaces open to the public. "Visit ability", on the other hand, corresponds to a level of accessibility limited to a more or less extensive part of the building, to also allow people with motor or sensory difficulties to live a basic visit experience, accessing the social spaces and to the toilets.

The possibility of visiting must be guaranteed except for some exceptions, expressly indicated in paragraph 3.4 of the decree. Finally, adaptability, i.e., adapting the museum visit to the user's conditions, represents a limiting condition with a reduced level of quality. It's important to underline that the legislative instrument specifies that the visit must be able to take place in conditions of absolute safety and autonomy. All those systems that allow everyone to move freely within the space without having to resort to the help of personnel or being directed along exclusive and segregating routes are therefore hoped for and recommended. In the Official Journal no. 114 of 16 May 2008, the Mibac (Ministry for Cultural and Environmental Heritage, now MiC) publishes the guidelines to allow everyone to access and use places of cultural interest in compliance with the principles of "Universal Design" for new buildings and in terms of breaking down barriers still present in historic architecture. It is not a simple "regulation" but rather a radical change in the concept of cultural heritage management that opens up to the needs of the public. Today, in the light of a fruitful debate, we can consider assimilating the concept that accessibility constitutes an integral part of the protection project in the broadest sense of "integrated conservation," which adds planning and management tools to conservation. These are sustainable development processes in historic areas aimed at ensuring and maximizing the long-term vitality of the tangible and intangible cultural heritage. The revitalization of this heritage includes multiple aspects, and the accessibility of places is perhaps the most innovative in the new meaning of resource and not a barrier or limit to planning. The adjective integrated, therefore, refers to active conservation, based on knowledge of heritage as a value and on the presence of an increasingly vast and heterogeneous public. Maximizing the use of a cultural asset, such as a museum, means, first of all, making it easy and accessible to everyone, even to those who suffer from a deficit in motor, cognitive, or sensory abilities for temporary or permanent periods. The commitment currently goes further, including the possibility of feeling represented and also included for the people (genderfluid or immigrants, for example) who permanently characterize our society. Cultural barriers are, in fact, also those linked to social representation (Ciaccheri, Fornasari, 2022), highlighted in exhibition choices or communication methods. Today, planning in the management of a cultural asset can no longer ignore social inclusion. New conditions of use are therefore specified: first of all, the democratic friction of the space, i.e., usable by anyone; flexible, adapting to different abilities; simple and intuitive, with an easy-to-understand distribution of functions; perceptible, which transmits and does not hide sensory information (lights, colors, sounds, textures); that minimizes risks or unpleasant or discriminatory actions and involves minimal effort; finally, careful use of measures to make the space accessible to all.

A concept of environmental comfort is therefore emerging that goes beyond the simple elimination of physical obstacles, referring to that feeling of autonomy and safety so desired by people with disabilities, i.e., the possibility of using spaces without limitations or alternative and discriminating routes. The current sensitivity is based on scientific research in recent decades, which has highlighted how making a place more accessible is an advantage from which multiple categories can benefit, and therefore not aimed exclusively at the disabled, understood in the classic sense as a person with a motor system or deficit sensory. A *Universal Design* that aims to create places that are easier to live in in all living conditions. The difficulties, temporary or permanent, can be motor, sensorial and perceptive, intellectual, linked to developmental age, language or chronic pathologies, physical characteristics, or specific dietary regimes. Accessibility goes from being a requirement to becoming an essential quality, which adds rather than removes freedom from the architectural project. For the management of museum assets, this new approach represents a great opportunity for the development of solutions aimed at guaranteeing the desired maximization of usability. The restoration project gives new life to the assets, reinserting them into the contemporary circuit. The intervention, therefore, constitutes the moment of returning the works to public enjoyment, aiming to "save them by allowing them to exist for as long as possible, as aesthetically and historically alive parts of our society" (Carbonara, 1996).

Museum spaces in Italy represent a significant part of the cultural heritage due to their social and educational value and, often located in historic buildings, are among the most complex to adapt in terms of accessibility. Thinking about the new users of the museum, the aforementioned expanded user base constitutes a basic issue for the correct development of a sustainable restoration project that aims to enhance the asset, guaranteeing maximum usability and usefulness.

If the idea of Universal Design spread in America starting in 1985, from a working group at North Carolina State University led by architect Ronald L. Mace, who was forced to move around in a wheelchair due to polio, the expression Inclusive Design was born in Great Britain, precisely by Roger Coleman, professor of the Royal College of Art, who used it for the first time in 1994. It's defined as a general design approach in which it's guaranteed that products and services meet the needs of the widest possible audience, regardless of age or ability. In 2001, the ICF approved a World Health Organization classification for creating quality environments, which provides a scientific basis for understanding the interaction between individual and context and the needs of the wider user. But usability alone is not enough to guarantee autonomy and dignity. The Design for All definition was developed in 2004 by the EIDD (European Institute for Design and Disability) on the occasion of the annual assembly held in Stockholm. It's defined as "design for human diversity, social inclusion, and equality," and its purpose is to facilitate equal opportunities for everyone to participate in every aspect of society. In 2006, the UN Convention on the Rights of Persons with Disabilities reaffirmed individual autonomy, including the freedom to make one's own choices, non-discrimination, and equal opportunities.

The countries that have adopted the Convention are committed to achieving accessibility by promoting research and development of universally designed goods, services, and equipment. Accessibility is understood as a principle (art.3 and art.9) and universal design as a general obligation (art. 2 and art.4). This is now recognized as an essential point for a correct multi-demand approach to planning in general and conservation in particular, which must be "inclusive." The transition from the medical (health) model to the social (human rights) model is fundamental, which leads to considering the person, with or without disabilities, a subject of law. Placing accessibility at the basis of planning for the conservation and enhancement of museums, therefore, means starting from the identification of the needs and difficulties of the wider user base.

4 The creation of the National Museum System

After much debate in Italy, the time had come to move from theoretical scientific research to the practical application of consolidated learning, not being able to entrust the functional adaptation of the structures open to the public to the individual sensitivity of the individual managers and specifically in this discussion, of the museums. If the decisive step from a legislative point of view was to review the concept of derogation from accessibility requests for historic buildings, with the enactment of L.13/89, another significant watershed is undoubtedly the activation of the National Museum System, which places accessibility as an indispensable requirement.

The transformation of state museums began with the Franceschini reform of 2014 (DPCM 171/2014, Ministerial Decree of 23 December 2014), which identified four functional areas, placing emphasis on relations with the public and management marketing. The museum stops being a self-referential place and opens up to the outside. We must wait until 2018 to begin the establishment of the National Museum System, indicated by the acronym SMN and regulated by Ministerial Decree No. 113. The operational document defines the uniform levels of valorization quality (LUQV) for museums and places of culture to which the art refers. 114 of the Cultural Heritage and Landscape Code. This can be considered the first act to transmit the minimum operating and organizational requirements that accredited museums must possess, previously different from region to region.

Article no. 2 specifies, among the objectives of the National Museum System, the strengthening of the use of cultural heritage through economies of scale aimed at «guaranteeing quality access for users and improving the protection of cultural heritage, through the definition of a homogeneous level of use of cultural institutions and places, of uniform and verifiable methods for the conservation and enhancement of buildings." The legislation specifies that museums that have already been recognized by a regional accreditation system based on quality levels comparable to national ones can be automatically included in the national system. The procedure also involves regions with special statutes and private museums through the sending of a voluntary request for evaluation. It should be noted that inclusion in the national museum system gives museums an edge, favoring requests for funding for modernization projects and, more generally, the economic management of the structures. The request is voluntary and is based on a self-assessment questionnaire where it's the museum requesting accreditation that has to demonstrate and highlight the degree of achievement of the minimum standards required.

The establishment of the National Museum System, therefore, aims to overcome the traditional management separation between the State, Regions, and local authorities in a unitary perspective, which also involves private bodies, and aims to achieve a unique quality standard throughout the national territory. All museums accredited to the National Museum System, regardless of their public or private nature, therefore share a unitary framework of reference inspired by the ICOM Code of Ethics. It is a professional self-regulation tool, translated into 38 languages and adopted since 1986, which sets minimum standards of professional conduct and performance for Museums and their staff. ICOM Italia has, in fact, actively collaborated in the definition of the National Museum System in the Study Commission (established with Ministerial Decree 1 June 2015) and in the various operational teams, working alongside ministerial managers and officials, sector experts, and representatives of the Regions.

5 Sicily and the case study of the "Antonio Salinas" Regional Archaeological Museum

Sicily has decided to join the national museum system (O.A. 35/GAB of 05.18.2021) and, pursuant to art. 5 of the Ministerial Decree. n. 113 of 21 February 2018, establishes the regional accreditation body, which is responsible for investigating the requests (D.D. 385, 16-02-2022) and whose results should be transmitted to the General Directorate of Museums of the Ministry of Culture for verification and validation by the relevant Commission.

However, the work of this commission has never started to date, and no museum in Sicily is included in the list of museums accredited to the SMN (Decree no. 604 of 17/06/2021|). The standards identified in the "Pilot Project for the Accreditation and Monitoring of Quality Levels and Standards of Regional Cultural Places" establish measurable and unambiguously definable quality levels. The objective of Sicilian museums from now on is not only to obtain accreditation and enter the national circuit but rather to aim for the general improvement of performance. In the self-assessment questionnaire, museums must examine eight areas: legal structure, financial structure, structures, security, personnel, management and care of collections, relations with the public, and relations with the territory. As regards accessibility, data relating to accessibility (relations with the public) were investigated, from the retrieval of information on the web to the actual carrying out of the visit.

The objective of the ongoing research is, in fact, to highlight the potential and shortcomings of Sicilian museums in relation to national standards and, more generally, in the light of Universal design for all. It is not simply a question of adapting places to allow access by disabled visitors, but of moving towards a general system of demolition of all those structural, cognitive, and sensorial-perceptive barriers whose scope falls, in different times and ways, on the entire museum users.

It should be specified that some requirements (for example, the structural conditions of the premises, some plant situations, etc.) do not fall within the scope of the direct responsibilities of the individual museum but refer to the owners of the premises, such as the Municipality, the Province, the Superintendency, the Diocese, and so on. However, accreditation allows relations between the owner bodies to be speeded up, withstanding requests, provided that the availability of the museum headquarters and collections is guaranteed for a period of at least 10 years to justify the costs of adaptation.

Many interventions necessary to achieve minimum quality levels are QZB or "almost zero budget," i.e., they do not require the outlay of money for the purchase of material goods but can be achieved through the reorganization of protocols and procedures.

The self-assessment questionnaire analyzes the structure in relation to the public, the collections on display, and the museum staff. In relation to the relationship with the public, the minimum standard requires, first of all, the free movement of physically disabled people. The museum must pay attention to the signs for approaching and entering the museum, the clarity of the orientation systems, the absence of architectural barriers, and the provision of toilets for the disabled. It must evaluate the actual usability conditions of the routes and verify the possibility of enjoying a good view of the collections even from a sitting position. By architectural barrier, we also mean a single step, a difference in height, or a gap that is too narrow, which may represent an insurmountable obstacle and be an impediment for wheelchair circulation, but also for an elderly person with a cane or families with a stroller. The accreditation procedure does not stop at the achievement of the minimum standard but provides margins for improvement (divided into two priority levels), which would guarantee the structure of the Quality Marks. Specific areas of improvement are represented by the provision of tactile information devices or those expressly dedicated to particular user groups, such as visit aids (audio guides, augmented reality, or multimedia supports) and educational and didactic devices (differentiated activities for different user targets, technological supports). The quality mark is also achieved with the presence in the structure of a director, a curator, and a security manager, and with the use of specialized reception staff capable of expressing themselves in multiple languages and in sign language, as well as of specific figures such as cultural mediators, responsible for communication and teaching, capable of significantly improving the museum's offering in terms of accessibility and use of the places.

In terms of safety, in addition to all legal obligations, specific training of staff to deal with emergency and disaster cases is desired at a higher level, even in the presence of disabilities. An illuminating example is the ineffectiveness of sound and flashing indicators for deaf-blind users, while a raised emergency route can more effectively guarantee reaching the exits.

Fig. 2. Large metopes of Selinunte, Salinas Museum, Palermo

As regards the collections, the minimum requirement provides for the coherence of the new acquisitions with the museum's mission, which is becoming increasingly inclusive and varied. In order to obtain "quality marks," it must be able to represent ethnic, gender, and social minorities. The museum can no longer ignore or underestimate its educational function and expertise towards its territory, positioning itself as an attractive pole. The accreditation highlights the need to rethink reception, both to achieve the minimum standard, guaranteeing 24 hours a week, and in the improvement phase, equipping the museum with a computerized ticket office and a booking service that can provide well in advance all the necessary information, also in other languages, including specifications for any disabilities. The museum's margin for improvement includes detailed analyses of the public in terms of customer satisfaction and, more generally, constant attention to detecting inclinations, preferences, and critical issues useful for planning activities and exhibition methods, according to the visitors' journey model already mentioned. When reaching the minimum standards is not possible, the individual structures can enter into a network and integrated offer system. This allows small museums to overcome the limits regarding particularly critical areas, such as logistical and management difficulties, maintenance and safety procedures, optimizing the supply of specialized personnel (such as a curator or an accessibility manager), and opening hours. Even if belonging to a network does not constitute an exception to compliance with the laws that apply to the individual museum. The establishment of the territorial network also allows for easier access to development policy consultation tables, adopting supply coordination strategies, and responding more efficiently to the cultural needs of the community. Particularly interesting is the possibility of creating hybrid networks that involve not only museums or cultural heritage but also tourist and economic operators, creating complex supply chains.

The research verified the standards of Sicilian museums, with the help of a check list in line with the SMN and with the Guidelines for overcoming architectural barriers in places of cultural interest (Ministry for Cultural Heritage and Activities with Ministerial Decree 28 March 2008). First of all, the four degrees of accessibility were examined: physical, perceptual, communication and experience.

I - The first degree examined physical accessibility and, in this case, the possibility for everyone to use the spaces in an equal, inclusive, and non-discriminating way. When conditions did not guarantee full autonomy of the visit, full accessibility was replaced by the concept of visitability of the property, with alternative solutions especially in archaeological areas.

II - The second degree considered sensorial-perceptive accessibility, i.e., that set of measures aimed at not creating discomfort. Think, for example, of the texture of a floor, the gratings, or the noise level of the rooms, which can cause disorientation in visually impaired or autistic people.

III - The third degree analyzed the communication of the museums, from the clarity of the website to the aids useful for planning the visit independently. In particular, access and quality to information, if this were available in a clear and reliable way, and if it allowed a self-assessment of one's visit possibilities.

IV - At the fourth level, wayfinding was evaluated (Vescovo, 2022), i.e., the possibility of enjoying the experience. The possibility for all museum users to simplify orientation, understand, and better enjoy the visit in an autonomous, fulfilling, and satisfying way was analysed. Just think of the captions of an exhibition, the brochures, the signs, the icons and the pictograms.

The research work then merged into a case study, the "Antonio Salinas" Regional Archaeological Museum in Palermo. Following the model of the SMN questionnaire, we begin with the analysis of the legal status and structure. The Museum can count on the availability of the headquarters and collections for the minimum required period of 10 years. It is named after the Palermo archaeologist and numismatist Antonino Salinas, who directed it from 1873 until 1914. The House of the Fathers of the Congregation of San Filippo Neri, home to the museum since 1866, underwent a final restoration and modernization of the exhibitions from 2009 to 2018. On this occasion, the exhibition space called Agorà was created in the third courtyard of the convent, and on the ground floor, a reception point and cafeteria with a wi-fi area. It houses one of the largest archaeological collections in Italy, ranging from prehistory to the Middle Ages. The collections and the mission of the institution are consistent with each other.

The management is regional, through the Regional Department of Cultural Heritage and Sicilian Identity, but it was a national museum until 1977 and since 1987 detached from the Superintendency. Since 2016 it has been part of the "Palermo regional hub for parks and archaeological museums with Salinas Museum," pursuant to the Prime Ministerial Decree. 29 August 2014, n. 171. It is equipped with signs for the approach and proximity of the entrance, although the number of signs could be increased and improved in terms of completeness and clarity. The structure is divided into three floors above ground. The exhibition, open to the public, is distributed on the ground floor and a part of the first floor where temporary exhibitions are set up. The Museum has a total of 49 exhibition rooms and two outdoor cloisters. There is no reserved parking. Physical accessibility to visitors with specific needs is guaranteed by lifts and stair lifts. On the ground floor, the museum claims 80% of spaces can be used directly but with the aid of stairlifts and/or dedicated staff and 100% accessibility to external spaces and services. A necessary intervention to increase the quality of services would be the creation of an entrance that can be used independently via an external ramp. The Museum is equipped with toilets suitable for all types of visitors. On the ground floor, there is an introduction and orientation space, but there is no staff capable of speaking three languages or sign language. The dining room staff also has the same deficit. Information devices for orientation, such as maps and signs, are there but not suitable for all visitors and not in Braille. The free printed information material is lacking and should be revised. The management and dining room staff section, in relation to accessibility, presents shortcomings with regards to those figures who can improve the offer and increase the degree of satisfaction of the individual experience, such as adequately qualified and formally identified curators capable of guaranteeing the mission of the museum and allow all categories of visitors to be adequately represented (presence of immigrants, socio-economic hardship, gender fluid), staff able to speak sign language and other languages besides Italian, responsible for the communication and teaching.

Fig. 3. Fountain with triton, outdoor spaces of the Salinas Museum, Palermo

The quality of the publications is commensurate with the reputation of the institution, and the dissemination of the results obtained from the research conducted could be improved. As regards relations with the public, the museum is open to the public for 49 hours per week, reaching and well exceeding the minimum requirement of 24 hours per week, including Saturdays and Sundays. An entrance ticket is issued, even if it is free, and entries are registered. The external tactile information panel with the full name of the Museum, opening hours, and access conditions is missing. The structure provides essential information for the recognition of works and finds and for understanding the collections, and it is possible to arrange special itineraries for school groups upon reservation. The Salinas Museum preserves documents, researches, exhibits, and communicates its cultural heritage. Over time, it has carried out various valorization activities such as exhibitions, conferences, conventions, extraordinary openings, training courses and internships, guided tours, workshops, and publications, stimulating the active participation of citizens and guaranteeing effective experiences of knowledge and public enjoyment. It promotes and carries out scientific research also in collaboration with Italian and international universities and institutions.

It's lacking in the section of the questionnaire regarding information material on the printed and digital collections, activities, and audio-visual aids for disabled people. With a number of annual visitors equal to approximately 64,000 units and 79,000 works inventoried, the institution could adapt the level of knowledge of its public and enhance the quantity of training offered and the provision of services, such as a children's area and activities for the disabled motor, sensorial or psychic. As regards communication on the web, the Salinas Museum has a website and is present on the main social networks; part of the communication and management of the ticket office, bookshop, and cafeteria are managed by the cooperative company COOPCULTURE. The website is being rebuilt; the information section is currently lacking, and the service map is accessible on the site but is not easily identifiable. The declared visit time is approximately two hours but it is not possible to plan the visit independently, especially if in a condition of even temporary motor or sensory deficit, due to the lack of a specific page and maps and graphic routes. From the analysis conducted, it can be seen that, with regard to accessibility, many of the actions necessary to facilitate the accreditation of the Salinas Museum to the National Museum System are at no cost and require the review and optimization of personnel and protocols. Some structural interventions would allow a significant strengthening of the structure's catchment area and the possibility for everyone to benefit from a very important social and territorial aggregation center.

6 Conclusions

The "right to accessibility" today has become an increasingly pressing right and duty on everyone's part. In fact, every city or town should equip itself with plans for the elimination of architectural barriers (P.E.B.A. introduced by Art. 32 of Law 41/86). It is no coincidence that any program or financing by the European Community must necessarily take into consideration two fundamental aspects: environmental sustainability and the prerequisites for achieving equal opportunities. The ultimate goal is to break down all the barriers but also all those clichés about accessibility. Too often, the topic is evaded by hiding in the shadow of the rules. We need to change the paradigm, moving from respecting regulations to questioning whether a space can truly be used autonomously and safely by people with different disabilities and specific needs. Enhancing a building by making it accessible is no longer expensive, nor does it lead to aesthetically ugly results; it is rather a design challenge and a social responsibility. Technical difficulties only denote a lack of knowledge of the topic. Today, more than ever, the architect must reject segregating solutions and promote integrated visions. This is not only possible but desirable as an added value capable of bringing new flows of visitors and promoting the economic sustainability of cultural heritage. Accessibility is a process that allows everyone to interact with cultural heritage through new multi-sensory modalities, promoting inclusive museums in which there are no special needs but only positive experiences for all visitors. The research highlighted good practices and underlined the introduction of a holistic approach to the challenge of making museums more accessible. For example, it is no longer acceptable to have museums for the blind and museums for "normal" people. The tactile experience can be useful to everyone and create new ways of relating to the work. Many European projects have developed from this inclusive perspective. Significant is the "Come-In Cooperare for open access to museums towards broader inclusion," which, in the wake of the slogan "nothing about us, without us", involves the museums of Italy, Austria, Croatia, Slovenia, Germany, and Poland. The structures involved collaborated with disability associations,

Fig. 4. Agora Hall, Salinas Museum, Palermo

academics, training institutions, and policymakers to define transnational standards aimed at improving the accessibility of museums. With a view to an approach that places the visitor at the center of the investigation, qualifying him as an active subject of change, a satisfaction questionnaire was developed so that users could express their opinions on the pilot museums.

The "Come-In" symbol was created with the aim of spreading the concept of accessibility as an added value throughout the world and guaranteeing the quality of the experience in certified museums. What matters is the transferability of research efforts beyond the specific field to the international level to achieve the desired universal level of inclusive planning for all.

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Part VII

Thematic Area 6 - Technologies for Damage Rehabilitation and Sustainable Preservation

Part VII

Thematic Area 6 - Technologies for Damage Rehabilitation and Sustainable Preservation

The Open Lab. Empowering Community Engagement and Knowledge in Conservation and Treatment Methods

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Abstract. From a conservation point of view, the final exhibition of an artefact within a showcase can be characterized as a multidimensional process from the initial diagnosis for possible intervention up to its eventual restoration. In this context, it used to be that museums were solely providing these conservation steps for treatment in a mere relevant community, keeping this kind of knowledge and practice within the walls of the museums. Novel perspectives in conservation at a worldwide level are pushing the limits to concepts and principles such as openness, stakeholders' participation, and collective problem-solving within the whole grid of conservation of museum artifacts. The Open Lab of the Museum of Modern Greek Culture in Athens embraces these concepts and values, opening its conservation and restoration knowledge both to the local community and to interest parties such as conservationists and humanities scientists such as folklorists and historians. The Open Lab presents a groundbreaking approach to biodiversity conservation with expertise in textile conservation and treatment, harnessing open-source principles, community engagement, and technological innovation. This paper introduces the pivotal functionalities of Open Lab, outlining its core components and discussing its transformative potential in conservation efforts. More specifically, the paper unfolds and describes all the steps for its development, namely the selection of space, the configuration, and equipment of the Open conservation Lab, the full utilization of the equipment within specific rooms such as the low vacuum table presentation room, the room with washing tanks and the room of painting presentation room and mechanical cleaning process. By fostering collaboration among scientists, conservationists, and local communities, the Open Lab enables the exchange of vital data, resources, and knowledge crucial for effective conservation and restoration actions. Through case studies and examples, we demonstrate the profound impact of the Open Lab in promoting inclusive and sustainable conservation practices both in the national and worldwide contexts. We conclude by highlighting future directions and challenges for scaling up the Open Lab to address urgent conservation needs in the face of rapid environmental change.

Keywords: open lab, conservation, restoration, textile, visitor engagement

1 Introduction

The Museum of Modern Greek Culture's Open Fabric Conservation Workshop (Open Lab) aims to challenge the traditional practice of conducting conservation and restoration processes behind closed doors. Launched in 2023, the Open Lab seeks to create a transparent, participatory conservation space, making these often-hidden processes accessible to a broad audience and educating visitors on the complex procedures involved in conserving fabric artifacts. This initiative responds to the growing movement within the museum sector to involve the public more directly in preserving cultural heritage **[1]**.

By inviting visitors into the conservation process, the Open Lab serves as an educational tool and a platform for fostering a deeper appreciation for cultural heritage preservation. The Lab's mission is to demonstrate contemporary conservation techniques for fabric objects and actively engage visitors through interactive experiences, catering to a diverse audience, including students, professionals, and the general public. This paper examines the Open Lab's visitor engagement methods and their impact on

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public understanding of conservation practices. It seeks to assess its effectiveness and identify areas for future improvement through analyzing visitor feedback, survey data, and social media interactions.

2 Related Background

Making museum processes accessible to the public is not entirely novel. However, it has gained significant momentum recently, mainly as museums aim to maintain relevance in an increasingly digital and participatory era. Velios **[2]** asserts that museums evolved from static spaces where objects are exhibited to dynamic environments where knowledge is exchanged and generated through interaction. This evolution has prompted the adoption of more transparent conservation practices, inviting the public to engage with the often-imperceptible processes of artifact preservation.

The Open Lab model falls within the broader framework of participatory museology, which emphasizes visitors' active involvement in the museum experience. Abdel-Kareem **[3]** underscores the effectiveness of such models in conservation work, where public comprehension of the intricate processes involved can foster greater appreciation and support for heritage preservation endeavors. In textile conservation, where materials are fragile and methods highly specialized **[4]**, public engagement can demystify the work and encourage deeper community involvement in safeguarding cultural heritage.

Research on visitor engagement has demonstrated that hands-on, interactive experiences significantly enhance learning outcomes, particularly in educational settings. Baglioni and colleagues **[5]** observe that students actively participating in museum programs are more doable to retain information and develop a lasting interest in the subject matter. For professionals, participatory conservation models present opportunities for knowledge exchange and interdisciplinary collaboration, potentially leading to innovative solutions in preservation practices.

The participatory approach of the Open Lab aligns with these trends by providing a platform where visitors can observe and contribute to the conservation of fabric artifacts. This model educates the public and serves as a space for professional development, fostering dialogue between conservators, researchers, and the public. These programs epitomize a forward-thinking approach to museum practice, emphasizing transparency, education, and community involvement **[6]**.

3 Methodology

The methodology for this study utilized a combination of qualitative and quantitative approaches to thoroughly assess visitor engagement with the Open Lab. Data collection spanned from September to December 2023 and was conducted using three primary methods, each designed to capture different aspects of the visitor experience.

Visitor Questionnaires: At the end of their tours, visitors were asked to complete a tailored questionnaire. These surveys were crafted to collect both qualitative feedback and quantitative data, aiming to gauge visitor satisfaction, the level of knowledge acquired, and recommendations for enhancing the experience. Similar methodologies have been successfully employed in other museum studies to measure visitor engagement and educational outcomes **[7]**. The questionnaires were customized for specific visitor categories, including the general public, students, and professionals, allowing for more nuanced insights into how each group interacted with the Open Lab. This approach aligns with research emphasizing the need for targeted evaluation to understand diverse audience interactions in museum settings **[8]**. Questions explored not only general enjoyment and understanding but also sought to uncover how visitors' perspectives on conservation might have shifted due to their engagement with the exhibits. Additionally, demographic information was collected to analyze any correlations between visitor backgrounds and their engagement levels.

Observational data: During guided tours, researchers made informal notes to document visitor behaviors, attention spans, and levels of participation. Observational methods are a widely recognized tool in museum studies, offering valuable insights into visitor behavior that are difficult to capture through self-reported data alone **[9]**. These observations included tracking which interactive exhibits or demonstrations drew the most interest, what types of questions were asked, and how visitors physically interacted with the space. Systematic but flexible, this observational approach allowed researchers to identify trends in visitor engagement, much like in previous studies that used observational data to evaluate interactive exhibitions **[10]**. By noting moments of heightened engagement or areas where attention waned, the researchers could assess the effectiveness of various interactive components and live demonstrations in conveying the importance of conservation practices.

***Data Synthesis and Analysis*:** After the data collection phase, all quantitative and qualitative data from the questionnaires and observations were compiled for analysis. Quantitative data were statistically analyzed to identify trends in visitor satisfaction, engagement, and knowledge acquisition across different visitor groups. Methods such as descriptive statistics and correlation analysis were employed, similar to approaches used in other visitor engagement studies **[11]**. Simultaneously, qualitative data from open-ended survey responses and researcher observations were thematically analyzed to identify recurring themes or insights regarding visitor engagement and perceptions of conservation. This thematic analysis aligns with established qualitative research methodologies that focus on identifying patterns in textual data **[12, 13]**. This mixed-methods approach provided a well-rounded understanding of how different visitor groups engaged with the Open Lab and highlighted which components were most successful in fostering curiosity, knowledge, and public interest in conservation.

This comprehensive analysis allowed for a deep exploration of visitor experiences and pinpointed areas for potential improvement. The findings offer valuable insights into how diverse audiences interact with conservation-focused educational programs, ultimately supporting the ongoing development of the Open Lab to better serve its mission.

4 Results

The Open Lab attracted a diverse audience, including students, professionals, and members of the general public, each of whom responded to the program in distinct ways:

Students: The Open Lab proved especially popular among students, particularly those studying conservation, museology, and related fields. Many expressed enthusiasm at the opportunity to observe conservation work firsthand, which offered practical insights beyond the classroom. For younger students, the Lab served as an introduction to potential career paths in conservation and heritage preservation, sparking interest in the field. More advanced students appreciated the detailed look into the complexities of textile conservation, often commenting on how it complemented their academic studies. Teachers reported that the Lab stimulated extended discussions in their classes, with many students eager to return for further visits. The immersive experience clearly played a role in bridging the gap between theory and practice, encouraging deeper engagement with conservation topics.

Professionals: The Lab also drew a significant number of museum staff, conservators, and other professionals involved in heritage preservation. These visitors were highly engaged with the technical details of the conservation process, frequently posing specific questions about the equipment, materials, and methods used. The Lab provided a unique platform for interdisciplinary collaboration, allowing professionals from different sectors to exchange ideas and conservation techniques during their visits. Many commented on the value of the Open Lab as a space for professional development, noting that it facilitated knowledge exchange and helped them stay up-to-date with evolving practices in the field. Additionally, the opportunity to observe live conservation work was viewed as beneficial for those seeking to enhance their practical expertise **[14]**.

General public: Though typically less familiar with the intricacies of conservation, members of the general public were highly curious and showed great interest in the conservation processes on display. Many visitors were surprised by the meticulous nature of fabric conservation, particularly the precision required in handling and restoring delicate textiles. Guided tours were instrumental in making these complex procedures accessible to non-experts, with visitors frequently commenting that the experience reshaped their understanding of museum exhibits and the behind-the-scenes work involved in preserving cultural heritage. The interactive format helped demystify conservation work, leading to a greater appreciation for the role of conservators in protecting museum collections **[15]**.

4.1 Quantitative data

Between September and December 2023, the Open Lab welcomed over 108 visitors, with 92% of respondents rating their experience as "very satisfactory." The survey results highlighted the educational impact of the program:

- 85% of visitors reported that they had learned something new about fabric conservation.
- 80% indicated that they would recommend the Open Lab to others.

Further breakdowns revealed that students and professionals were particularly satisfied with the technical demonstrations and hands-on approach, while members of the general public appreciated the opportunity to observe conservation work up close. The overwhelmingly positive feedback suggests that the Open Lab successfully engaged a broad range of audiences, fostering interest and understanding across both expert and non-expert groups.

5 Discussion

The Open Lab's participatory model has proven to be an innovative and highly effective strategy for engaging a wide range of audiences in the specialized field of textile conservation. By inviting visitors to not only observe but also, in certain cases, participate in the conservation process, the Open Lab fosters a much deeper appreciation for the meticulous work involved in preserving cultural heritage. This immersive approach aligns seamlessly with contemporary trends in museum practices, which increasingly prioritize transparency, education, and public engagement **[16]**. Such an approach also helps to demystify the behind-the-scenes efforts of conservation, making the intricate and often invisible work more accessible and understandable to the public.

For students, the Open Lab is an invaluable educational tool, offering a rare opportunity to witness conservation techniques firsthand in a real-world setting. The ability to see complex procedures in action, rather than merely reading about them or observing from a distance, greatly enhances their learning experience. Feedback from students has indicated that the Lab has been instrumental in sparking a genuine interest in conservation as a potential career path. The unique combination of hands-on learning, direct observation, and the opportunity to engage with seasoned conservators offers students both a tangible and inspiring glimpse into the field. Many students have reported that the interactive nature of the Lab has deepened their understanding and appreciation for the conservation profession, making it more than just a theoretical concept but a viable career option.

Professionals in the field also gain from the Open Lab, particularly in terms of knowledge exchange and interdisciplinary collaboration. The Lab provides a dynamic platform where conservators from various backgrounds can meet, share their expertise, discuss common challenges, and experiment with new and emerging techniques in textile conservation. This collaborative environment is not only crucial for the personal growth of those working in the field but also serves as a driving force behind innovation and the cross-pollination of ideas, advancing the entire discipline **[17]**. The Open Lab effectively becomes a hub for creativity and problem-solving, facilitating advancements that might not be possible within more isolated, traditional conservation settings.

However, while the Open Lab has achieved significant success, there remains room for growth and improvement. Visitor feedback suggests that incorporating additional interactive elements could further enhance the educational value of the program, particularly for younger audiences or those without a background in conservation (Author, Year). Currently, the opportunity for hands-on involvement is limited, but expanding these experiences to include more practical engagement—such as allowing visitors to assist with minor, supervised restoration tasks or to handle replica objects—could foster even greater interest and understanding. These enhancements could make the experience not only more engaging but also more memorable, ensuring that visitors leave with a lasting connection to both the field of conservation and the museum itself **[18]**.

Moreover, integrating more advanced digital tools, such as augmented reality (AR) or virtual reality (VR), could offer new ways to bring conservation processes to life (Author, Year). By allowing visitors to virtually explore textiles at a microscopic level or simulate conservation decisions, the program could reach wider audiences, including those who may not be physically able to participate in traditional hands-on activities. Expanding the Lab in these directions would reinforce its role as a pioneering educational and collaborative space, ensuring its continued relevance and appeal in the future.

6 Future Implications & Conclusion

Looking ahead, the Open Lab has the potential to expand its role as a leader in participatory conservation education. Several strategies could be implemented to further enhance its impact:

Digital integration: One of the most promising avenues for growth is the development of a virtual version of the Open Lab experience, which would enable the museum to engage a global audience. Utilizing augmented reality (AR) and virtual reality (VR) technologies could create immersive, interactive experiences for remote visitors. These technologies would allow users to virtually explore the conservation process, interact with digital recreations of artifacts, and learn about textile preservation techniques in an engaging and accessible way. This would not only democratize access to the Lab's educational content but also position the museum as a pioneer in the use of cutting-edge digital tools for heritage education.

Expanded educational programming: Another key strategy is expanding the educational offerings of the Open Lab, particularly for school groups. By developing age-specific workshops, the Lab could cater to the needs and learning levels of different student groups, offering a more tailored experience. Additionally, providing pre-visit and post-visit materials—such as activity sheets, lesson plans, and multimedia content—could help reinforce the lessons learned during the tours. For educators, the Lab could offer teacher training programs on conservation topics, equipping them with the tools and knowledge to extend these lessons into their classrooms. Such programs would enhance the educational reach of the Open Lab and help integrate conservation topics into broader curricula.

Increased professional development opportunities: The Open Lab could further establish itself as a hub for professional development within the field of textile conservation. By offering specialized workshops and training programs tailored to conservators and heritage professionals, the Lab could foster skill development and knowledge exchange. Partnering with universities and research institutions would allow for a collaborative approach to training the next generation of conservators while also advancing the field of textile conservation through research initiatives. By providing continuous learning opportunities, the Open Lab could play a key role in elevating professional standards and best practices in the field.

Enhanced social media presence: Strengthening the Open Lab's presence on social media platforms could attract a broader audience and encourage greater public engagement. Regular updates on ongoing conservation projects, behind-the-scenes content, and interactive Q&A sessions with conservators would create opportunities for the public to connect with the Lab in new ways. By sharing time-lapse videos of conservation work, interviews with experts, and conservation tips, the Lab could build a larger online community interested in cultural heritage preservation. This strategy would not only raise awareness of the Lab's activities but also foster a sense of community among followers, promoting long-term engagement with the museum.

The Open Fabric Conservation Workshop (Open Lab) has successfully engaged a diverse audience in the conservation of fabric artifacts through its participatory model. By allowing visitors to witness—and, in some cases, participate in—conservation work, the Lab offers a forward-thinking approach to museum education. This immersive experience fosters a deeper understanding of the conservation process and helps bridge the gap between conservators and the public, creating a shared sense of responsibility for preserving cultural heritage.

Looking to the future, the Open Lab has immense potential to expand its educational and outreach efforts. By incorporating digital tools, offering professional development programs, and fostering increased community engagement, the Lab can continue to set a precedent for how conservation work can be made accessible, interactive, and educational. As museums increasingly evolve into spaces of learning and interaction, the Open Lab provides a valuable model for how conservation efforts can be made visible and engaging for all, ensuring that the public plays an active role in safeguarding cultural heritage for future generations.

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Conservation of cultural heritage from the perspective of sustainability

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Abstract. In recent decades, in a scenario of instability given by resource constraints, environmental crises and climate change, there has been a paradigm shift requiring new, more sustainable models, also involving the field of cultural heritage conservation. A new approach, based on an overall and more comprehensive view of conservation processes, is required, which calls for a re-evaluation of intervention strategies taking into account the different conservation operations and their implications. To this end, many directions are being taken to apply sustainability principles to the environmental, economic and social aspects of cultural heritage conservation.
However, the absence of a recognised definition of sustainability in restoration interventions and the lack of systemic principles to refer to still leaves many questions open in the field of conservation. Considering the aspect related to restoration products, the absence of parameters often leads to the diffusion and misuse of the term 'sustainable' in an indistinct semantic boundary where terms referring to 'green' and 'sustainable' practices alternate, mainly involving the environmental dimension of sustainability in conservation practices.
Starting from a semantic review of sustainability, the study aims to provide an integrated analysis of possible sustainability parameters to be integrated into assessment tools for restoration interventions, with reference to environmental, economic and social aspects, and in consideration of the compatibility, durability and effectiveness aspects of conservation interventions.

Keywords: Conservation, Sustainability, Cultural Heritage.

1 introduction

The decades following the mid-twentieth century were crucial for the emergence of new issues in the international debate, progressively involving cultural heritage and its protection.

This was the period in which, due to the effects of industrial growth, urban expansion, and the worsening environmental conditions with the consequent alarms generated by pollution and climatic conditions, the debate around development and its limits made it possible for the concept of sustainability to be incorporated into the various environmental, economic and social spheres to assume a decisive position.

It is important to underline that in recent years, the reflections on the need for new paradigms and the commitment to respond to new demands in global terms were already addressed and made known on the occasion of some international meetings such as the *United Nations Conference on the Human Environment* in Stockholm (1972) [1], or even for the drafting of the *World Conservation Strategy* by the International Union for Conservation of Nature (IUCN) in cooperation with the World Wildlife Fund for Nature and the United Nations Environment Programme [2]. This second document is particularly interesting if we consider the attention paid for the first time to the relationship between conservation (of resources) and sustainable development – the latter expression already present in the title of the document – and observe the similarities in the comparison between the definition of "conservation" given in the *World Conservation Strategy* – "Conservation is defined here as the management of human use of the biosphere so that it may yield the greatest sustainable benefit to present generations while maintaining its potential to meet the needs and aspirations of future generations. Thus, conservation is positive, embracing preservation, maintenance, sustainable utilization, restoration, and enhancement of the natural environment. Living resource conservation is specifically concerned with plants, animals and microorganisms, and with those non-living elements of the environment on which they depend. Living

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resources have two important properties, the combination of which distinguishes them from non-living resources: they are renewable if conserved; and they are destructible if not" [3] – with the better-known concept of sustainable development, provided a few years later by the Brundtland Commission [4].

However, it should be noted that in the 1980 document [5], in order to ensure sustainable development, the pre-eminent attention was paid to ecological and environmental aspects, and only later the vision was extended to the economic and social dimensions [6, 7].

With the United Nations Conference on Environment and Development held in Rio de Janeiro in 1992, the debate on sustainability and development was brought to the forefront of global politics and UNCED's Agenda 21 formalized the principles of sustainable development based on the need to renew resources faster than they are depleted [8], in fact taking up a concept already tackled in German sylviculture centuries earlier [9].

2 The value of sustainability in heritage conservation

In this context, sustainability has also become a fundamental requirement for architecture due to the high environmental impact and exploitation of natural resources attributed to the construction sector. Sustainability in the architectural field has therefore become synonymous with "green architecture" as an approach to architectural design based on the conscious use of resources, the use of non-polluting construction technologies and materials that are not dangerous for human health, on the prediction of the effects induced on the environment by the building throughout its life cycle, also in terms of origin, dismissibility and recycling of the materials used [10].

Only more recently, attention has been turned to cultural heritage, at first limited to improving the energy conditions of historic buildings, highlighting the advantages of preserving the existing heritage not only from the point of view of the intangible values linked to it, but also in environmental and economic terms [11].

Sustainability in the field of conservation has therefore required a new approach to restoration projects, understood as a complex process in which heritage care has been linked to environmental and social protection in the different spatial-temporal developments, underlining the need for a long-term vision [12].

This has led to the need for a re-evaluation of intervention strategies starting from decision-making, conservation management and planning processes up to individual conservation actions.

Only by considering individual conservation interventions can sustainability be pursued in different directions, including the definition of methodological approaches to reduce the risk of incompatibility of materials and treatments [13] and the use of procedures that are respectful of the environment and operators [14], through the selection and choice of materials for restoration [15] that respond to strategies aimed at ensuring adequate durability of conservation solutions and able to take into account a changing scenario such as climate change [16, 17].

3 A semantic revision. From sustainability to "green" language

In this context, the sequence of conservation operations usually carried out for the care of architectural artefacts increases its complexity. In addition to meeting the requirements of compatibility, efficacy and durability, the restoration materials and products used in the traditional sequence of cleaning, consolidation and protection operations [18] must meet new demands.

But, the absence of a recognized definition of sustainability in restoration interventions and the lack of systemic principles to refer to in order for an intervention to be considered sustainable leaves many questions open, starting with semantics. Examining the aspect related to restoration products, the absence of parameters often leads to the diffusion and improper use of the concept both in the scientific and commercial fields, in an indistinct semantic boundary that sees terms such as "bio", "bio-based" [19, 20], "green", "eco-compatible", "eco-friendly" [21, 22] or "sustainable", referring mainly to the environmental dimension of sustainability in conservation practices.

In fact, the value of sustainability in conservation operations is increasingly associated with practices or products linked to the term "green", as demonstrated by the expressions "green conservation", "green product" for the protection of cultural heritage.

But, as Yanarella, Levine and Lancaster [23] point out, the terms “green” and “sustainable”, although they are increasingly used interchangeably, do not have the same meaning and indeed have quite distinct references.

If the adjective “sustainable” is nowadays associated with all three pillars of sustainability, and therefore with the various environmental, economic and social aspects, the terms referring to “green” practices instead only cover the first dimension, which tends towards environmental and health improvement. And it was to this dimension that the expression “green chemistry” was born in the 1980s in response to environmental demonstrations and demands for environmental protection and safer living conditions [24, 25].

Sustainability requires an interaction of the components of the whole system, otherwise, “green” practices represent a single component that does not necessarily refer to a larger system [26].

The strategy involving sustainability therefore concerns a hierarchy of actions capable of maintaining a balance of the entire structure, which is not provided for in green terminology.

However, it should be noted that if the adjective “sustainable” runs the risk of a utopian dimension inherent in its definition and, at the same time, may result in a top-down request, the dissemination of the terms “green” may hide a misleading communication strategy that aims to declare itself committed to the low life-cycle environmental impact products and practices offered [27].

Friedman himself demonstrates in his book *Hot, flat, and crowded* that the use of terms belonging to the sphere of “green” is well accepted and practicable as it suggests quicker and easier to obtain solutions than the consideration of environmental, economic, social and cultural systems together to offer less unsustainable solutions [28].

The difference between the two fields emerges, in addition to a semantic divergence, also in the field of application, as William McDonough and Michael Braungart have demonstrated in *Cradle to Cradle: Remaking the Way We Make Things*. In fact, the concept of sustainability includes sustainable construction and production processes, which may contain green practices but not vice versa. The text shows that only in a broad system of production processes that require transformative approaches, in which not only the limits in terms of recycling are exceeded, but each product component is converted again safely, and without waste for the production of other components or products, sustainability is fully accomplished [29].

4 Tools for assessing the sustainability of restoration products

Behind one of the semantic innovations of universal scope, a series of contradictions emerges both in recent literature and in the operational field, bringing with them ambiguities and possible flexibilities of the term up to the absence of an unequivocal definition of the term “sustainable” in conservative practices.

In order to overcome this gap, the work carried out by international standardization bodies to develop standards is fundamental.

Among them, the European Committee for Standardization (CEN), which works for the standardization of bio-based products, points out, for example, how the prefix "bio" often appears in common language in terms such as "bioproduct", but without reference to clear definitions, some expressions can be misleading. The standard specifically indicates that «the term “biomass-based” or “bio-based” refers to the origin of the raw material. The prefix “bio” can refer to different functionalities (biodegradable, biocompatible, etc.) or processing (biological or biotechnological processes). In order to ensure transparent and non-misleading information [...], the prefix “bio” should be replaced by more accurate and informative equivalents and should refer to a European or international standard» [30].

But in particular, as the standard on sustainability criteria for bio-based products points out, «the bio-based content of a product does not provide information on its environmental impact or sustainability, which can be assessed through LCA and sustainability criteria» [31], the latter including environmental, social and economic aspects.

In Life Cycle Assessment (LCA) analysis [32, 33, 34], which allows to assess the environmental impacts of a product during the entire life cycle, there is certainly a valid approach for the study of all phases in an interdependent way. LCA is a fundamental tool for analysing the environmental impact of architectural artefacts and the materials used, and it is, in fact, the basis of certification schemes and environmental labels such as the Environmental Product Declaration (EPD), even if some limitations in the calculation method still emerge [35].

CEN itself has also established some sustainability parameters for the biological part of products, referable to

1. Environmental criteria (climate and air protection, conservation and protection of water resources, protection of soil quality and productivity, promotion of biodiversity, efficient use of energy and resources, waste management)
2. Social criteria (respect labour rights, land use and land use change, water use rights, promotion of local development)
3. Economic criteria (control of economic and financial aspects, including fraudulent, misleading or dishonest commercial practices) [36].

In this context, other organisations should also be mentioned, such as the European Chemicals Agency (ECHA) and the European Environment Agency (EEA), which are concerned with steering economic decisions towards improving environmental conditions by promoting standards for assessing the impact of chemicals and achieving the objectives of the European Green Deal.

In the European context, the two agencies have developed a specific framework of indicators to monitor the impacts of chemical pollution and steer production towards safe and sustainable chemicals [37].

Taking into consideration the various legislative and scientific references analyzed so far, the evaluation of a "sustainable" restoration product can therefore be said to be currently linked to various indicators relating, on the one hand certainly to safety for humans and the environment, i.e. the absence of toxicity of the products both for operators and for the environment, with a minimum environmental impact, of renewable origin and able to guarantee recyclability.

The assessment should also take into account social and socio-economic impacts, including local development, during the entire life cycle of the products.

It should also take into account production processes that are cost-effective and related to a circular economy, i.e. a regenerative production and consumption system where resources are preserved, and the production of waste is limited through different strategies. By involving the entire life cycle of products, a goal is reflected in the reduction of total materials consumption in order to keep them as far as possible in the cycles of use and to minimize, right from the design stage, the production of waste and pollutants [38].

However, the "sustainability" of a restoration product, in addition to the correspondence of the criteria referring to the production system and the life cycle, must be closely linked to the requirements of conservation, stability over time, compatibility, effectiveness and durability [39, 40].

In the comparative analysis between the restoration products, a quantitative evaluation should therefore be taken into consideration with regard to the time needed to obtain equal effectiveness of the treatment and also with respect to the extension of the surface itself to be treated and the operational choices of the restoration site, with consequent economic consequences [41].

Finally, with reference to the durability of a conservation intervention in the choice of a restoration product, considerations today cannot fail to take into account the data on the observed and expected impacts of climate change on cultural heritage, not only for the mitigation of impacts but also for the assessment of risks due to variations in climatic parameters and air pollution in relation to a specific conservation treatment, which must necessarily be monitored in the medium and long term [42].

5 Conclusions

Today, in order to establish the parameters through which a conservation intervention, and in particular a restoration product, can be said to be sustainable, it is first of all essential to revise the semantics of the terms in use in order to distinguish the different approaches and orientations, such as "green conservation" from "sustainable" practices in the field of conservation of existing heritage. Sustainability in restoration becomes a complex process that brings interdisciplinary and intersectoral assessments into the circuit, as well as spatiotemporal developments related to heritage care. If the evaluation of a product is expressed in the concrete interdependence of the actions of conservation, environmental protection, cost-effectiveness and social protection, the sustainability of a conservation intervention is inevitably linked to the specific and peculiar instances of conservation, and it is, therefore expressed in a solution of coexistence between the needs of today and those of the future, between the use of cultural heritage and its conservation.

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Protection coatings for stone monuments and artefacts of cultural heritage made of calcitic materials

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Abstract. The degradation of marble monuments and statues is an ever-growing concern due to increased industrialization, extensive urban development, and persisting environmental quality problems. Preservation of the built cultural heritage and artefacts necessitates the development of novel materials and methods in order to increase their resistivity against the detrimental impacts of atmospheric water and pollutants. Over the past few decades, numerous protective coatings have been introduced to ensure the integrity of cultural heritage and prevent their degradation by reducing the rates of building materials deterioration. Protective coatings designed for cultural items are generally expected to adhere to established restoration standards, including transparency, reversibility, compatibility with the surface, long-term durability, straightforward synthesis, cost-efficient maintenance, and non-toxicity. Among coatings most often used for the protection of calcareous stone, poly acrylates and nanoparticles of metal oxides play significant roles in conservation and restoration activities. Graphene derivatives, including graphene oxide (GO), have garnered significant attention as protective coatings. In this study, we have studied graphene oxide-based structures as potential coatings for historical monument protection. Specifically, the resistance to dissolution of Dionysos marble (DM) specimens (1.5 x 1.5 cm x cm) were treated with Polyacrylic acid, MW 2000 (PAA2000), Hydroxy ethylidene, -1-1 phosphonic acid, sodium salt (HEDP) solutions and with GO suspension. DM, consists mainly of calcite (>98% w/w). All compounds tested for the treatment of DM, possessed functional groups capable of interactions with calcitic marble surfaces. The specimens were equilibrated with the solutions and suspension as follows: 2-5×10^{-5} mol/L for PAA and HEDP 2×10^{-5}-5×10^{-4} % w/v GO suspensions in water. Equilibration was done by immersing DM test slabs in the solutions and the suspension in 50 mL vials, capped and rotated end over end to ensure homogeneity for 24 hours at 25^{0}C. Past equilibration, the specimens were rinsed with triply distilled demineralized water and air dried. The samples were mounted into special holders in special reactors, allowing the flow of calcium carbonate unsaturated solutions (σ=0.89, pH 6.50) with a flow rate of 4.5 $mL \cdot h^{-1}$ in contact with both specimen surfaces. From measurements of pH and calcium concentration at the outlet of the reactors, the rates of dissolution of the specimens for each treatment tested were calculated. It was found that the equilibration of the marble specimens with GO suspensions was the most efficient, yielding a dissolution rate of 70% lower in comparison with the respective of the untreated marble. PAA-treated specimens did also retard the rate of dissolution of marble but to a less extent (ca. 30%). HEDP treatment was ineffective in retarding the dissolution rate of the DM specimens, possibly because of the enhancement of the calcitic material solubility in the presence of HEDP or because of structural rearrangement of the adsorbed phosphonate species on DM calcitic grains.

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1 Introduction

The deterioration of the built heritage associated with the historical and cultural heritage threatens the loss of social identity and its legacy to future generations. Pieces of artwork kept indoors are exposed to controlled conditions in which environmental parameters like relative humidity, temperature, and light are monitored and/or controlled. Monuments of the built heritage and artefacts, mostly made from limestone and dolomitic or calcitic marbles [1] and exposed to atmospheric conditions, are threatened by weathering damages because of direct contact with wet precipitation. The problem is intensified in the presence of acidic pollutants and/or bacterial activity, which results in locally acidic conditions. [1]. Relatively easy quarrying, cutting, and carving make marble and limestone ideal for the construction of buildings and artifacts. However, these materials are prone to physical and chemical damage upon long-term exposure to environmental conditions.

Over the recent decades, a variety of protective coatings have been developed for the preservation of the integrity of the monuments, including the built heritage, aiming at reducing their rate of deterioration because of dissolution, which eventually leads to their complete destruction. Coatings for use in the conservation processes of monuments and artefacts should conform to certain criteria. They should ensure Transparency, reversibility, compatibility with the surface, long life, easy composition, low cost, and lack of toxicity [2]. In addition to the aesthetic aspect, the original appearance of archaeological or artistic objects should remain unaltered, and in case of corrosion (photooxidation - yellowing), the corrosion products should be removed without affecting the surface itself [3].

Significant advances have been achieved in coating science and technology over the past 30 years. Limestone and marble are sedimentary and metamorphic minerals respectively, the main component of which is calcite ($CaCO_3$). Contact of calcitic building materials with water can be dangerous because chemical dissolution leads to mechanical problems and the growth of microorganisms, such as mold, into the stone [5]. Biodegradation, based on activities of living organisms (fungi, bacteria, and algae), is an additional problem often associated with chemical deterioration and causes changes on the surface of the monument [6].

A wide range of acrylic polymer coatings have been used for limestone preservation against chemical and biological degradation for the last 50 years [7], mostly ethyl methacrylate (EMA) and poly (methyl methacrylate) (PMMA). For the same purpose, nanocomposites of TiO_2 with silane coatings [8], rendering resistance in water accumulation and photodegradation on stone building materials, have been applied. It should be noted that, in some cases, the formation of biofilms may act protectively for monument stones [9].

The majority of coatings applied to limestone monuments are considered as a short-term solution that needs regular inspection and re-application. The development of novel, effectively protective, and long-lasting, low-cost treatments, which can easily be applied both in portable and built heritage monuments, is needed. Graphene derivatives emerge as a possible solution [10]. From the graphene compounds family, relatively hydrophilic and chemically adaptable graphene oxide (GO) dispersions in water may be applied in the form of coatings for the protection of limestone and marble [11]. GO coatings were found to be effective in considerably limiting the deterioration of carbonated stones and degradation upon contact with water [12].

In this study, the effectiveness of the GO coatings, formed by deposition from aqueous colloidal suspensions on Dionysus marble (DM), a calcitic building material, can provide protection from dissolution upon contact with aqueous solutions undersaturated with respect to calcite. This is often the situation when monuments constructed from marble and/or calcitic limestone are exposed to wet precipitation. The study was done simulating the dissolution process at different conditions: stirred undersaturated solutions at constant pH, in small reactors in which DM slabs were exposed to calcium carbonate solutions undersaturated with respect to calcite, flowing at various flow rates, and in microchannels in which changes of a linear dimension of the DM calcitic crystals were monitored directly in a microchannel using snapshots from a video-camera. The effect of the GO coatings was compared with other coatings developed on DM treatment with poly acrylic acid (PAA) and 1-Hydroxyethylidene-1,1-diphosphonic acid (HEDP). The present work may be considered preliminary, proof-of-concept work for the evaluation of the functionality of novel coatings.

2 Experimental Section

The resistance to dissolution of DM specimens (1.5 x 1.5 cm x cm slabs) and powdered material was studied following treatment of the solids with polyacrylic acid, MW 2000 (PAA2000), Hydroxy ethylideno-1-1diphosphonic acid, sodium salt (HEDP) solutions and with graphene oxide (GO) suspensions ($5x10^{-4}$ w/v). The pH of the PAA and HEDP stock solutions and of the GO suspensions was adjusted to 6.8-7.0 with the addition of standard NaOH or HCl solutions, as needed. The DM samples (powder or slabs) were in contact with stirred calcium carbonate solutions saturated with respect to calcite at a constant temperature, 25 C in batch reactors. The desired concentrations of the test compounds in the saturated solutions were adjusted with the appropriate volume of the respective stock solutions and the suspension. The suspensions of DM in the presence of the test compounds were allowed to equilibrate for 5 days. Next, the solids were separated from the aqueous phase; they were washed with water and air-dried for 24h. The dried solids were used for the measurement of the rates of dissolution in calcium carbonate solutions undersaturated with respect to calcite (Fig.1). Table 1 summarizes the names of the substrates based on different treatments.

Table 1. Substrates treatment before dissolution study.

Substrate		Treatment solution
Powder	**DM1**	*Without treatment*
	DM2	*PAA2000* 2×10^{-5} *M*
	DM3	*HEDP* 2×10^{-5} *M*
	DM4	*GO* 5×10^{-4} *% w/v*
Specimens	**DMB**	*Without treatment*
	DMP	*PAA2000* 2×10^{-5} *M*
	DMH	*HEDP* 2×10^{-5} *M*
	DMGO	*GO* 5×10^{-4} *% w/v*

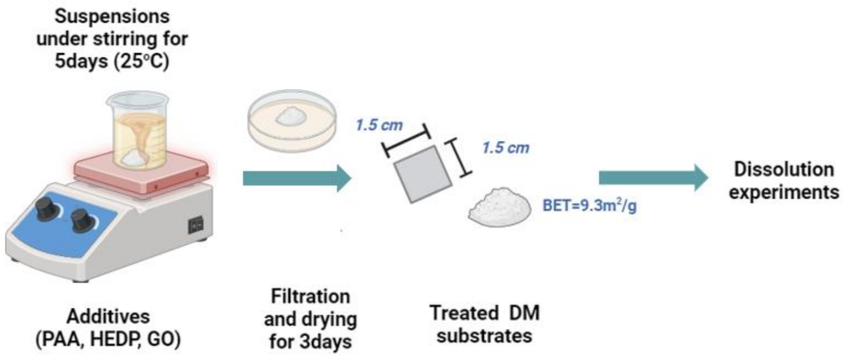

Fig. 1. Treatment process of marble substrates (powder or slabs) before dissolution kinetics measurements.

2.1 Dissolution experiments

Powdered DM with BET-specific surface area, measured with nitrogen, equal to 9.3 m^2 $g^{-1,}$ was used as reference material for the measurement of the rates of dissolution in calcium carbonate solutions undersaturated with respect to calcite. The rates of dissolution of DM treated with the test materials were measured as well (Table 1). The undersaturated solutions were prepared directly in a double wall batch reactor (V_R=200 mL) made of borosilicate glass (PYREX®) kept at 25.0 ± 0.1 °C with water from a thermostat, circulating between the walls of the reactor. The solutions were prepared by mixing accurately measured volumes of standard stock solutions of calcium chloride and sodium bicarbonate. Calcium chloride stock solutions were prepared from crystalline $CaCl_2 \cdot 2H_2O$ and standardized with atomic absorption spectrometry (AAS, Perkin Elmer AAnalyst 300) and by titrations with standard EDTA solutions with murexide indicator. Sodium bicarbonate stock solutions were prepared fresh before each experiment from the respective solid and dried overnight at 65°C. The final concentrations of calcium chloride and sodium bicarbonate in the undersaturated solutions was 1.25 mM, and the ionic strength was adjusted to 0.15 M with the addition of standard NaCl solution as needed. 1M standard stock solutions were prepared from accurately weighed solid and dried overnight at 65°C, without any further standardization. The pH of the undersaturated solutions was adjusted to 6.50 with a standard 0.1 N HCl solution. Following pH adjustment, an accurately weighed powdered solid (10 mg) was introduced into the undersaturated solutions. As a result of the dissolution of calcium carbonate, the pH of the solution increased. The dissolution of calcium carbonate is described by the reaction:

$$CaCO_3 + H_2O \leftrightarrow Ca^{2+} + HCO_3^- + OH^- \tag{1}$$

Changes in the solution pH as small as 0.005 pH units triggered the addition of standard HCl solution (0.1 M) from the precision syringe of a computer-controlled pH stat system. The dissolution process was monitored at constant pH. Samples were withdrawn and filtered through membrane filters (Sartorius, 0.2 μm), and the filtrates were analyzed for total calcium, by AAS. The experimental set-up for the dissolution experiments is shown in Fig.2.

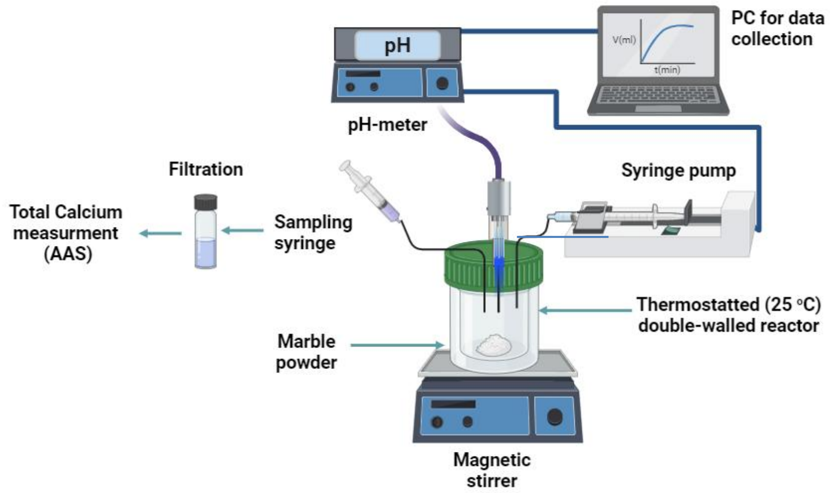

Fig. 2. Experimental setup for dissolution experiments at constant pH (pH- stat method).

2.2 Dissolution of marble slabs in thermostated small volume reactors

The dissolution of marble slabs was investigated in small double-walled reactors made of polyamide volume totaling ca. 10 mL, in which the marble slabs with dimensions ca. 1.5 cm x 1.5 cm were immobilized in special holders. The temperature in the small-volume reactors was kept at 25.0 ± 1.0 °C by water circulating from a thermostat. The flow rate of the undersaturated solution was adjusted to 4.5 $mL{\cdot}h^{-1}$ by using a syringe pump, and the duration of each experiment was 3 days. Samples were withdrawn at different times, with higher frequency at the initial steps, slowing down as the dissolution proceeded to equilibrium, filtered, and the filtrates were analyzed for total calcium concentration with AAS. Moreover, the pH of the solution was measured at the outlet of the reactor as a function of time. The pH-time profiles were used to monitor the dissolution process. The morphology of the marble slabs at the end of each dissolution experiment was investigated with scanning electron microscopy (SEM, Zeiss, Leo Supra 35). A schematic layout of the experimental setup and procedure is given in Fig. 3.

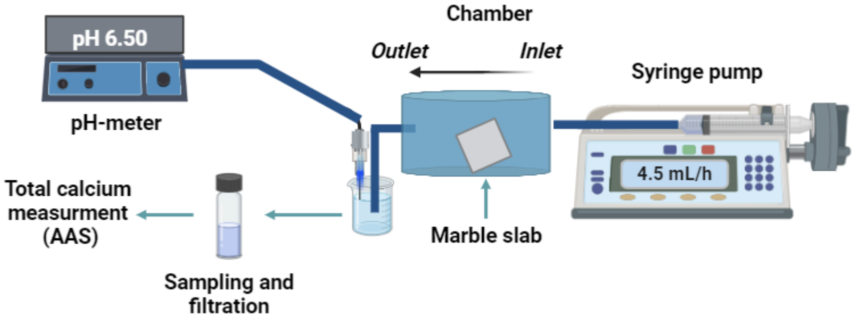

Fig. 3. Experimental setup for dissolution experiments of marble slabs with flowing undersaturated solutions.

Additional dissolution tests were done in porous media simulators made of Plexiglas®. The linear channel used had dimensions of 6 cm length, 1 mm width, and 0.3 mm depth. Grains of the marble specimens investigated were introduced in the microchannel. The undersaturated solutions were introduced in the channel with a syringe pump, which ensured a constant flow rate (0.2-0.5- 1 $mL \cdot h^{-1}$). The solution flow rate was low inside the channel, and the Reynolds number values calculated were 0.095, 0.238, and 0.477 for flow rates 0.2, 0.5, and 1 $mL \cdot h^{-1,}$ respectively. At these values, the flow was laminar and was sufficient to ensure the stability of the position of the introduced calcite crystallites (with and without treatment).

Optical monitoring of the marble substrates was done using an optical microscope (Zeiss, microscope with camera), which was connected to a digital camera (AXIS 223M Network Camera). Thus, it was possible to record and store photograph snapshots at regular intervals (every 30 min) on a computer through special data recording software (AXIS Camera Station). Past the end of each experiment, the photograph snapshots were processed with image processing software (ImageJ®). From the processing of the snapshots, data concerning size changes of the marble grains as a function of time were obtained. The experimental setup described is schematically presented in Fig.4.

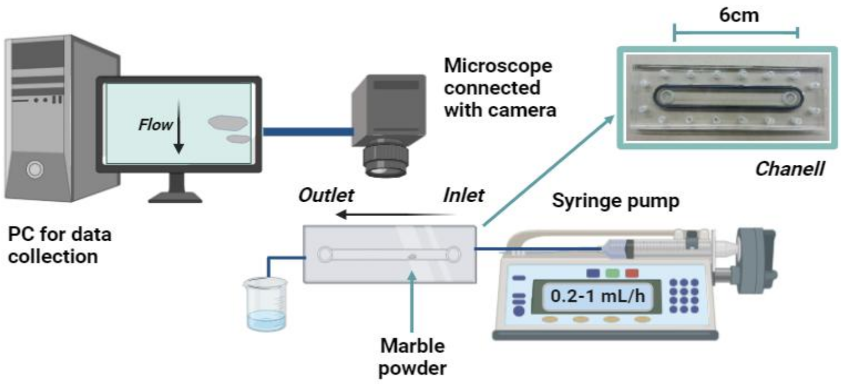

Fig. 4. Experimental setup for dissolution experiments of DM powders at different flow rates of the calcium carbonate solutions undersaturated with respect to calcite.

3 Results and Discussion

3.1 Dissolution experiments

The dissolution rates of DM were measured in solutions undersaturated with respect to calcite (which is the main chemical component of DM). The driving force for dissolution at constant temperature depends on the solution saturation ratio, SR, defined as:

$$SR = \frac{(Ca^{2+})(CO_3^{2-})}{K_S^o} \tag{2}$$

Where parentheses correspond to the activities of the ions enclosed and K_S^o is the thermodynamic solubility product of calcite. In the case of undersaturated solutions SR<1. For solutions saturated with respect to calcite SR=1. The activities of the free ions were calculated from the total concentrations of the main components of the solutions using PHREEQC® equilibrium calculations software, v. 3.3.12.12704 [21]. The relative undersaturation, σ, of the solutions, is defined by equation (4):

$$\sigma = 1 - SR^{1/2} \tag{3}$$

The relative undersaturation of the working solutions with respect to calcite was 0.99. The dissolution process was monitored as a function of time at a constant temperature of 25.0 ± 0.5 °C in a batch, magnetically stirred reactor. pH was kept constant at 6.50 at ionic strength 0.15 M NaCl.

In Fig.5, typical plots of the volume of standard solution of 0.1N HCl solution added to maintain the solution pH during solution, are shown. The solution undersaturation decreased as a function of time, which explains the trend shown on the pH-time profiles. The rates of dissolution were proportional to the respective rate of additions of acid solution.

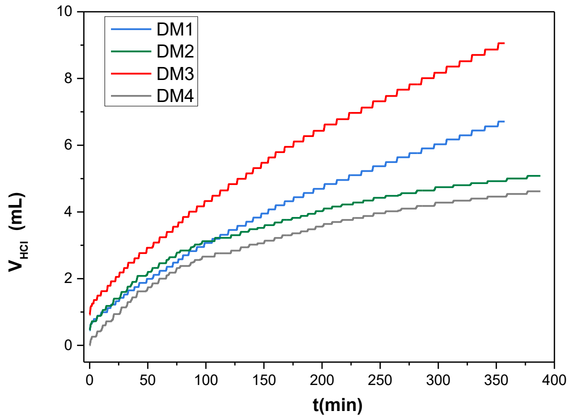

Fig. 5. Dissolution of DM in undersaturated calcium carbonate solutions (σ= 0.99, SR= 1x10^{-3}), 25 °C, pH 6.50, 0.15 M NaCl; (-) Without treatment -Blank (DM4); (-) PAA treatment (DM1); (-) HEDP treatment (DM2); (-) GO treatment (DM3).

The total calcium concentration as a function of time profiles corresponding to the volume additions as a function of time (Fig. 5) are shown in Fig. 6.

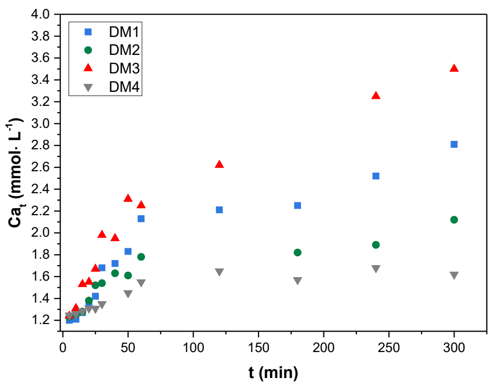

Fig. 6. Calcium concentrations (Ca_t) from dissolution of DM in undersaturated calcium carbonate solutions (σ= 0.99), 25 °C, pH 6.50, 0.15 M NaCl; (■) Without treatment -Blank (DM4); (●) PAA treatment(DM1); (▲) HEDP treatment (DM2); (▼) GO treatment (DM3).

The rates of dissolution of the respective DM specimens were calculated from the total calcium- time profiles according to equation (4) using data from the first 60 min following the contact of the solids tested, with the undersaturated solutions:

$$Rate\ of\ Dissolution, R_D = \left|\frac{d[Ca_t]}{dt}\right|_{t=0} \quad (4)$$

The calculated initial rates, are summarized in Table 2 and in the form of a plot in Fig. 7.

Table 2. Dissolution rates of DM powdered samples at constant pH; σ= 0.99, 25 °C, pH 6.50, 0.15 M NaCl

Substrate	**Dissolution Rate*** **(/×10^{-5} mol·m^{-2}·min^{-1})**
DM1	3.58
DM2	2.15
DM3	4.95
DM4	1.14

**The dissolution rate was calculated per BET specific surface area.*

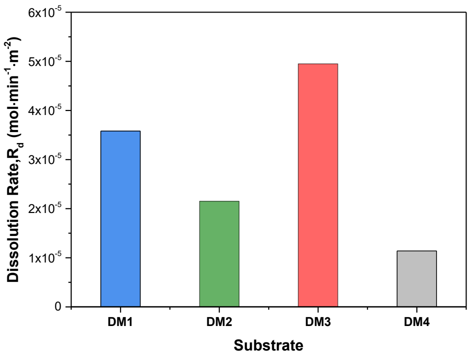

Fig. 7. Dissolution rates of DM with different treatments in calcium carbonate solutions undersaturated with respect to calcite (σ= 0.99); DM1: untreated; DM2: PAA treated; DM3: HEDP treated; DM4: GO treated; 25 °C, pH 6.50, 0.15 M NaCl

The dissolution rate of the DM with GO deposits (DM4) was the lowest in comparison with all other treatments. The rate was almost 70% lower than the rate of the untreated (blank) material. It is possible that the GO coating slows down the dissolution of marble because of the formation of protective film, which blocked effectively the active sites of dissolution on the surface of the DM material. The high concentration of oxygen-containing functional groups of GO (-COOH, -OH, -O-) possibly interact electrostatically with Ca^{2+} and Mg^{2+} cations of the DM, forming surface complexes with GO. PAA treatment reduced the rate of dissolution by 30% in comparison with the untreated DM. HEDP treatment accelerated significantly (ca. 20%) the dissolution in comparison with the respective for the untreated specimens.

The surface coverage by graphene oxide, the morphology of marble powder treated with different concentrations of GO suspensions was investigated by SEM. As shown in Fig.8(a), the grains of powdered DM treated with the GO suspension ($5x10^{-4}$ %w/v) were partly coated. The presence of grains completely covered with GO layers (Fig.8(b)), was confirmed by EDX line scan analysis (Fig.8(c)).

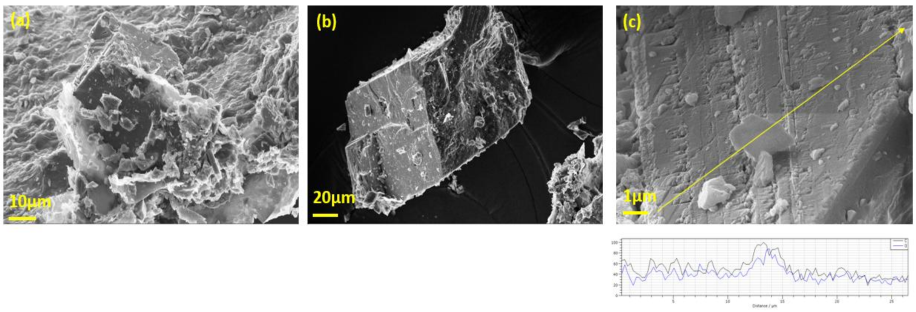

Fig. 8. SEM photos of marble grains following equilibration with GO suspensions ($5x10^{-4}$ %w/v) for five days.

DM powders, equilibrated with GO suspensions with lower GO content ($5x10^{-5}$ %w/v), resulted in the formation of uniform coating on marble calcitic grains (Fig.9).

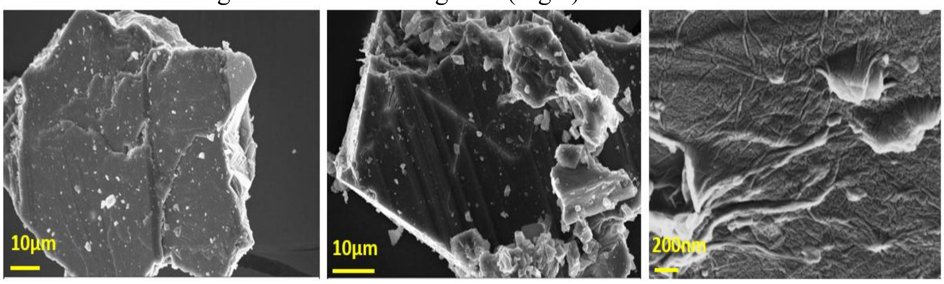

Fig. 9. SEM photos of marble grains past equilibration with GO suspensions ($5x10^{-5}$ %w/v) for five days.

The highest dissolution rates were obtained for the HEDP-treated powdered DM (DM3) (Fig.7). In most publications, referred that HEDP form complexes with calcium cations in different proportions of Ca^{2+} and phosphonate ions (1:1 or 1:2) in p H 8-8.5 [13]-[15]. This leads to the formation of a protective film, which tends to reduce dissolution rates. However, in the present work at the acid pH 6.5, rates of dissolution were higher in comparison with the respective DM without any treatment. This acceleration may be explained based on the calcium phosphonate adsorbed layer re-structuring on the surface over a period of time, resulting in the exposure of active dissolution sites of the mineral substrate [16].

The measured rate of dissolution for marbled treated with PAA (DM2), was lower in comparison with the corresponding to the untreated DM. PAA polymers have already been used in the past for marble and limestone protection due to their good adhesion performance [3],[17].

3.2 Dissolution of marble slabs

DM slabs, both untreated and treated (Table 1), were exposed to the flow of calcium carbonate solutions undersaturated with respect to calcite (σ=0.99) at a flow rate of 4.5 ml/h. The increase of pH measured at the outlet of the microchannel confirmed their dissolution. pH change over a period of 5 hours is shown in Fig.10. In the case of G- coated DM slabs (DMGO), pH increased at a slower rate during dissolution in comparison with the respective in the untreated DM (DMB). The highest increase and rate of increase was observed in the case of HEDP treatment (DMH).

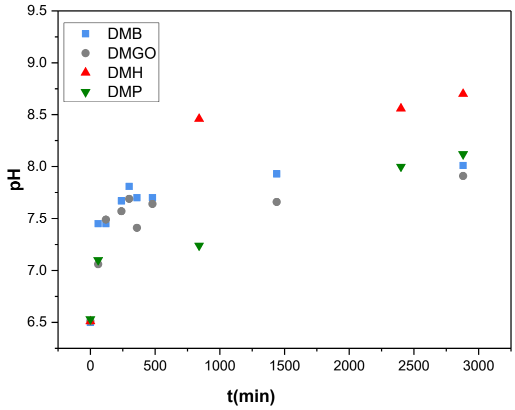

Fig. 10. pH changes as a function of time, of the calcium carbonate solutions undersaturated with respect to calcite during the dissolution of DM slabs; flow rate of the undersaturated solutions 4.5 mL·h^{-1}; ($\sigma_{initial}$= 0.99), 25 °C, 0.15 M NaCl; (■) Without treatment -Blank; (▼) PAA treatment; (▲) HEDP treatment; (●) GO treatment.

In addition to pH measurements in the undersaturated solutions, the calcium concentration was measured as well in the outlet from the reactor. As shown in Fig.11, calcium concentration also increased in all cases. The highest increase of calcium concentration in the solutions was observed for HEDP and the lowest for GO-treated DM slabs. The initial rates of the dissolution of the DM slabs were assessed from the variation of total calcium during the first 60 min of the dissolution process presented in (Fig.12), which was rather fast. From the calcium concentration measurements, the rate of dissolution was calculated for the first hour. The dissolution rates of the DM slabs calculated for both untreated and treated are shown in Fig.13. The main difference between these experiments and the pH-stat experiments (DM powders) was that the rate in this case was calculated per geometrical unit surface area of the slabs.

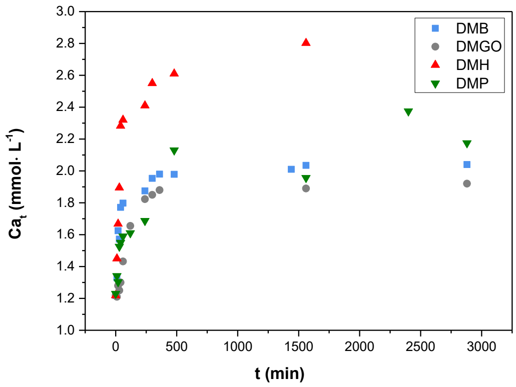

Fig. 11. Dissolution of DM slabs in calcium carbonate solutions undersaturated with respect to calcite ($\sigma_{initial}$= 0.99); Total calcium concentration in the solutions during dissolution as a function of time. 25 °C, 0.15 M NaCl; Flow rate=4.5 mL·h^{-1}; (■) Without treatment -Blank; (▼) PAA treatment; (▲) HEDP treatment; (●) GO treatment.

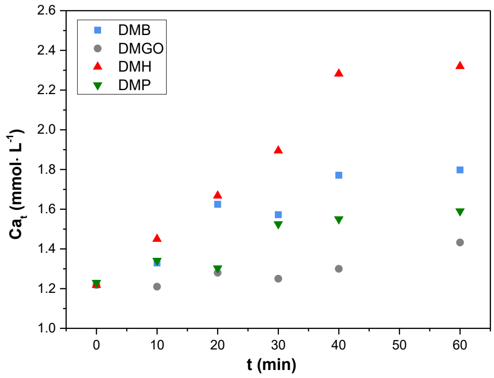

Fig. 12. Calcium concentrations (Ca_t) from Dissolution of DM slabs underflow of the calcium carbonate solutions undersaturated with respect to calcite ($\sigma_{initial}$= 0.99). Plot of the total calcium (Ca_t) concentrations in the undersaturated solutions as a function of time for the first 60 min of the dissolution process; 25 °C, 0.15 M NaCl; Flow rate=4.5 mL·h^{-1}; (■) Without treatment -Blank; (▼) PAA treatment; (▲) HEDP treatment; (●) GO treatment.

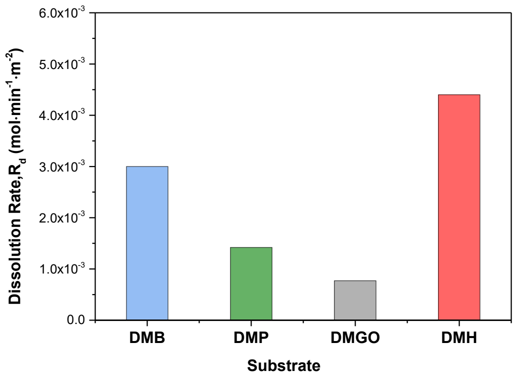

Fig. 13. Dissolution rates of DM slabs without and past treatments with solutions of PAA, HEDP, and GO suspensions in solutions undersaturated with respect to calcite ($\sigma_{initial}$= 0.99), underflow; 25 °C, 0.15 M NaCl; Flow rate=4.5 mL·h^{-1}. DMB: blank; DMP: PAA treated; DMGO: GO treated; DMH: HEDP treated.

The rates of dissolution of DM slabs showed the same trend as the measurements of dissolution of powdered DM at the pH-stat experiments, suggesting that both experimental models are reliable for conducting rapid tests for materials candidates for the protection of building materials of the cultural heritage. More specifically, the highest rates of dissolution were found for the treatment of DM with HEDP and the least for GO-treated specimens. The dissolution rates of the DM slabs coated with GO (DMGO) yielded the lowest rates of dissolution, being almost 74% lower than the respective for the untreated specimens. The efficiency of GO coatings may be explained by the fact that at pH ca.7.0, at which treatment is done, GO has a high negative charge because of the almost complete ionization of the -COOH groups and the positive surface charge of calcite [18]. Electrostatic interactions contribute to the formation of a coating that effectively blocks the active sites for dissolution. The results obtained are encouraging for the use of GO as a protective coating for marble, in agreement with similar studies [19], [20].

The effect of dissolution on the morphology of marble slabs was examined by SEM. The morphology of the DM slabs before and after dissolution is shown in Fig.14(a) and (b). Surface deterioration (compared with flat parts of the surface of the marble before dissolution) was observed with the formation of pits on the specimen surface, with sizes between 50 to 100 nm or even > 200 nm. For the specimen treated with PAA (DMP) (Fig.14(c)), as may be seen, PAA provides a more uniform coating, which, however, does not seal the pores on the specimen surface. In the HEDP-treated specimen (DMH), the development of pits was apparent past dissolution. The appearance of some needle-like and plate-like "transparent" crystallites (Fig.14(d)) suggested the formation of Ca-HEDP or Mg-HEDP. This was supported by the results of the EDX analysis. Finally, for the treatment of DM with GO (DMGO), the surface coverage of the slab seemed to be low, with dark flakes of GO spreading all over the surface. Past dissolution of the GO treated specimens surface damages and pit formation was drastically reduced.

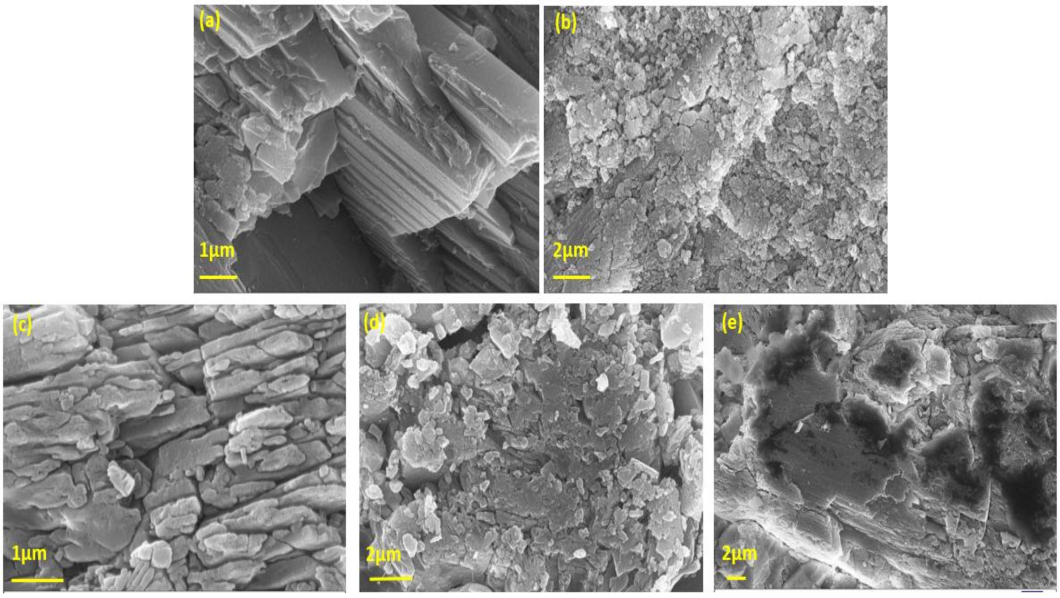

Fig. 14. Dissolution of DM in calcium carbonate solutions undersaturated with respect to calcite $\sigma_{initial}$= 0.99). SEM pictures of the morphology of the surface of DM slabs (**a**) Untreated marble, DMB (**b**) DMB, (**c**) DM treated with PAA, DMP, (**d**) DM treated with HEDP, DMPH and (**e**) DM treated with GO suspension, DMGO; 25 °C, 0.15 M NaCl; Flow rate=4.5 mL·h^{-1}.

3.3 Dissolution of DM grains in microchannel reactors

Powdered DM coated with GO (DM4) was brought in contact with the undersaturated solution, flowing at rates in the range of 0.2-1.0 mL·h^{-1}. The dissolution process was followed by monitoring changes in a linear dimension, x, of the DM grains. The (linear) dissolution rates, $\bar{R}_{diss}$ were calculated from equation (5):

$$\bar{R}_{diss}[m \cdot min^{-1}] = \frac{dx}{dt} \quad (5)$$

At flow rates of the undersaturated solutions in the microchannel 0.2 and 1 mL·h^{-1}, no change in grain size was observed, even after 5 days. It is possible that the GO film covering the DM grains observed completely inhibited the dissolution process. Considering that a limited number of DM grains were monitored (<10) in an equal number of experimental runs, it is clear that a significantly larger number of observations is needed. Typical pictures of DM grains inside the microchannel in contact with the undersaturated solutions are shown in Fig.15

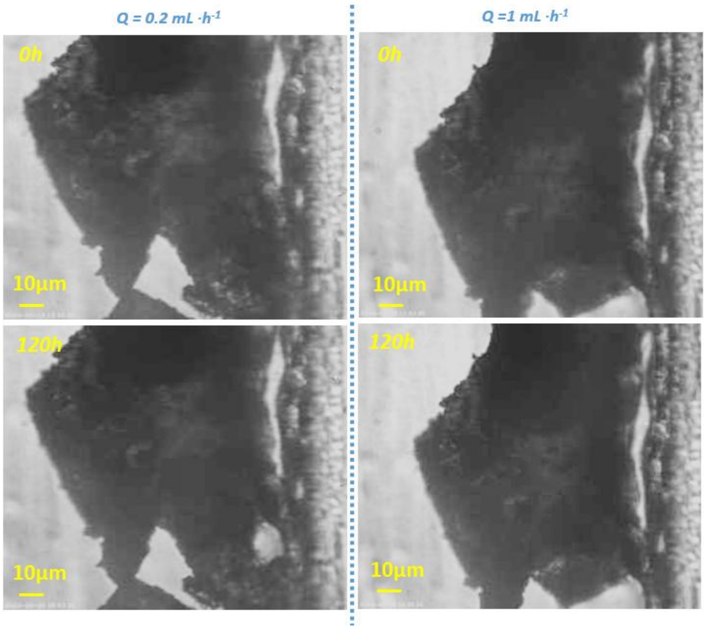

Fig. 15. Sequence of images captured during dissolution of GO coated DM grain (DM4) underflow of undersaturated solution; $\sigma_{initial}$= 0.99, 25 °C, 0.15 M NaCl; Flow rate=0.2 and 1 mL·h^{-1}.

At a higher flow rate (0.5 mL·h^{-1}), as may be seen in the optical microscope pictures shown in Fig.16, changes of one dimension of a typical DM grain as a function of time could be clearly seen and measured. Specifically, the initial and final DM grain sizes measured were 98.65 μm and 64.17 μm (Fig.16), respectively. This decrease in the magnitude of the characteristic dimension was gradual, and its variation as a function of time reached a plateau value corresponding to the final size of the characteristic linear dimension selected, as may be seen in Fig.16. Reaching the plateau needed 69h.

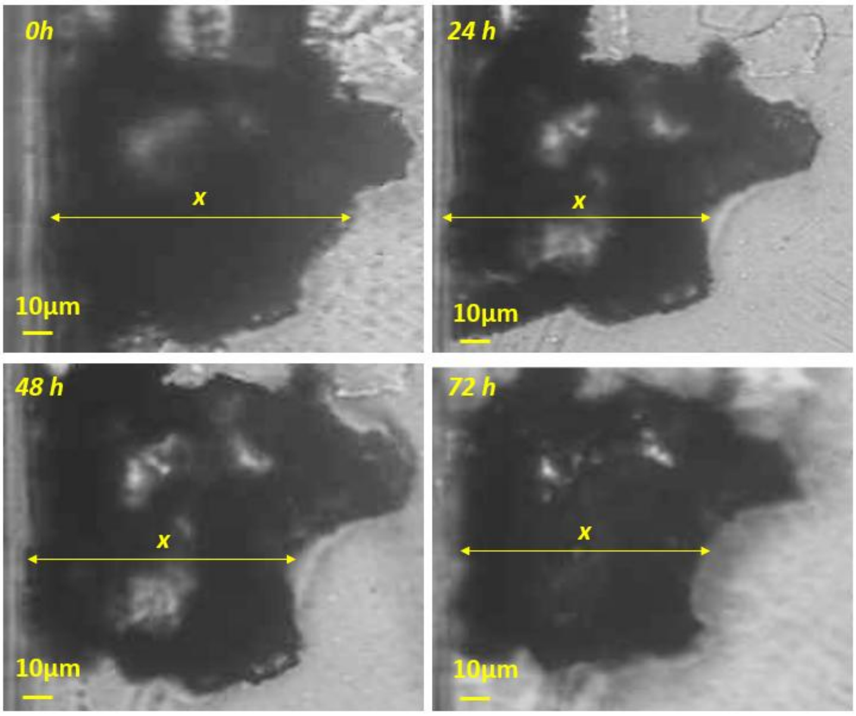

Fig. 16. Sequence of images captured during dissolution of GO coated DM grain (DM4) under flow of calcium carbonate solution undersaturated with respect to calcite; $\sigma_{initial}$= 0.99, 25 °C, 0.15 M NaCl; Flow rate=0.5 mL·h^{-1}.

The initial rate of dissolution calculated from the grain size change, was equal to 0.46 μm·h^{-1} (or 7.7×10^{-9} m·min^{-1}). The relationship between the linear rate of dissolution, $\overline{R}_{diss}$ with the respective mass loss rate, R_{diss}, expression is related with Eq. (6) [21]:

$$R_{diss}\ [Kg \cdot m^{-2} \cdot min^{-1}] = SF \cdot \rho_{calcite} \cdot \overline{R}_{diss} \quad (6)$$

In Eq. (6)*, SF is a shape factor, which for spheres and cubes is 1, and c is* the density of calcite (the main chemical component of DM = 2711 Kg·m^{-3}). From Eq. (6) the mass loss rate of dissolution is equal to 2.1x10^{-4} mol·m^{-2}·min^{-1}. The calculated value is one order of magnitude higher thnt the rate of dissolution obtained from the pH-stat experiments at pH 6.50, where the initial rates of dissolution of powdered DM were measured. The reason for this discrepancy may be the difference in particle size. The smaller the particle size, the faster it is expected to dissolve. However, a significantly larger number of crystallites should be measured to establish a relationship between the two methods of measurement of the rate of dissolution.

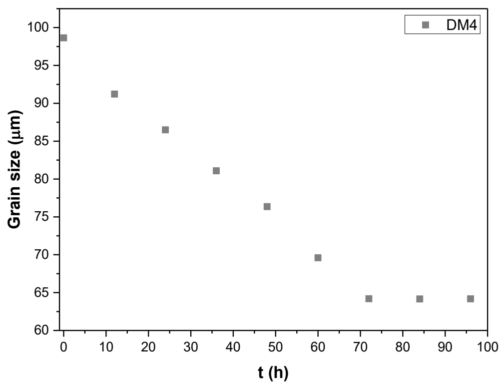

Fig. 17. Dissolution of selected GO-coated DM grain (DM4). Grain linear dimension size change as a function of time; $\sigma_{initial}$= 0.99, 25 °C, 0.15 M NaCl; Flow rate=0.5 mL·h^{-1}.

As may be seen in Fig. 17, the rate of dissolution is constant for a time period of ca. 65 hours. Past this time, the dissolution process ceased apparently reaching near saturation solubility. The constancy of the rate of dissolution is possible that is due to the fact that changes in the solution saturation with respect to calcite were minimal (at the slowest flow rate tested, 0.5ml/h, the change in calcium concentration was ca. 2.5%, which is within experimental error). The higher the flow rate, the smaller the changes are expected, provided that the mechanism of dissolution remains the same. It may, therefore, be suggested that the number of active sites remains constant, leading to a constant rate of dissolution, which may be monitored for long time periods. Earlier work has shown that the dependence of the rate of dissolution of DM, R_{diss}, in calcium carbonate solutions undersaturated with respect to calcite, was first order with respect to the relative supersaturation with respect to calcite, $\sigma_{calcite}$, suggesting surface diffusion-controlled kinetics [13]:

$$R_{diss} = k_{diss}\sigma_{calcite} \quad (7)$$

In the present case of DM slabs, should the mechanism be mass transport controlled, it should be:

$$k_{diss} = \frac{D}{\delta} \quad (8)$$

In Equation (8), D is the diffusion constant of the diffusing growth units (of the order of magnitude of inorganic ions, Ca^{2+}, or CO_3^{2-}, i.e., simple multiples of 10^{-10} m^2·s^{-1}) and δ the thickness of the boundary layer around the DM grains [22]:

$$\delta = (5.74\mu m) * r^{0.145} * (\Delta\rho)^{-0.285} \quad (9)$$

In Eq. 9, r is the radius of dissolving DM grains (98.7 μm) and $\Delta\rho$, the density difference between DM grain and water (1.71 $g \cdot cm^{-3}$). Substituting in Eq. 9, we obtained the value δ=9.6 μm. The dissolution constant calculated from the respective rate value measured was 7.8×10^{-9} $m \cdot min^{-1}$. The value of D according to the measurements should, therefore, be 1.24×10^{-15} $m^2 \cdot s^{-1}$. The value is unrealistically low for mass transport. It may, therefore, be suggested that in the microchannel as well, the mechanism of dissolution of the DM grains was again controlled by surface diffusion. This implies that reduction of active sites for dissolution of DM grains results in the reduction of rates of dissolution, concomitant with the application of coatings, provided that their conformation allows blocking and thus reducing active sites for dissolution on the calcitic crystals of DM grains.

Clearly more work should be done in the investigation of the effect of flowrate on the kinetics of dissolution of DM over a rather wide range of undersaturation with respect to calcite.

4 Conclusions

DM powders and slabs were treated with two solutions of compounds possessing functional groups that may interact strongly, forming chemical bonds with calcitic materials and with a suspension of GO particles, which are deposited on DM by electrostatic interactions. The dissolution of DM was studied in calcium carbonate solutions undersaturated with respect to calcite at constant and/or variable pH in stirred batch reactors and in a microchannel and small flow-through reactor, respectively. The common conclusion from all measurements was that GO-coated DM yielded the lowest rates of dissolution, the reduction reaching as much as 60% in comparison with the untreated material. The microchannel reactor in which dissolution rates are monitored by video recording and/or by successive pictures taken as a function of time is a useful tool for screening the effect of various treatment agents for stone protection. HEDP and PAA low MW polymers were less efficient in reducing rates of dissolution in acid pH, although alkaline pH values have been reported as very efficient. Apparently, the extent of molecular ionization and of the conformation of these compounds on the surface of calcitic materials like DM is very important with respect to the protection of calcitic materials.

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Resilient and adaptive renovation of 20th century buildings towards net-zero carbon built heritage – The approach of the SINCERE research project

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Abstract. In contemporary European urban landscapes, the presence of 19th and 20th-century modern period architecture stands as a defining characteristic, contributing significantly to EU Built Heritage. These structures serve as substantial reflections of local and national identity. However, despite their historical significance, many of these buildings present considerable challenges in terms of energy efficiency, particularly in heating and cooling systems. Addressing this issue is crucial for preserving their cultural value while aligning with contemporary sustainability goals. The SINCERE project endeavors to explore the intrinsic worth of Built Heritage while offering practical solutions to improve energy performance and reduce the carbon footprint of historic buildings. Through the integration of innovative restoration materials, energy-efficient technologies, ICT tools, and socially innovative approaches, SINCERE aims to facilitate the transition of these structures towards net-zero carbon emissions. Adopting a holistic approach, the project encompasses various scales, from individual building components to entire cityscapes, considering factors such as structural integrity, architectural uniqueness, and local environmental conditions. Additionally, SINCERE aims to empower stakeholders with innovative solutions covering the entire lifecycle of buildings, from restoration to maintenance. By providing sustainable restoration options and raising awareness through outreach, the project fosters a culture of preservation within European communities, securing the legacy of Cultural Heritage for future generations.

Keywords: Built heritage, Structural and thermal retrofitting, Extended reality, Digital twins

1 Introduction

Built Heritage holds unique cultural, social, environmental, and economic value, playing a vital role in preserving history and culture while offering opportunities for climate action and resilience, as highlighted by initiatives like the EU's "Green Deal." Climate Change (CC) poses significant challenges globally, impacting environments, societies, and economies. To ensure the transmission of Cultural Heritage (CH) to future generations, it is crucial to develop tools and technologies to protect Built Heritage from

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CC risks and align its preservation with the Sustainable Development Goals (SDGs) outlined in the UN's "2030 Agenda for Sustainable Development." Renovating 19th and 20th-century buildings using resilient and adaptive technologies contributes to reducing greenhouse gas (GHG) emissions, conserving EU heritage, and promoting economic growth, social well-being, and environmental preservation in cities, in line with circular economy principles.

SINCERE is European collaborative research project which aims to explore the significance of built CH values while offering strategies to reduce the carbon footprint and enhance energy efficiency in historic structures, aligning with the goals of achieving net-zero carbon buildings. This is achieved through the adoption of innovative, sustainable, and economically viable restoration materials and methods alongside energy harvesting technologies, ICT tools, and socially innovative approaches.

Employing a multi-scale approach (Fig. 1), SINCERE addresses various levels, from material to city-scale, focusing on the structural elements, external envelope, and transparent components of buildings. These interventions are staggered over different timeframes to furnish decision-making support to stakeholders involved in the process. Consideration is given to the entire lifecycle of buildings, encompassing restoration, operation, monitoring, and maintenance phases.

Energy performance enhancements, tailored to the unique characteristics of each building, including its structural, architectural, functional, and material attributes, are optimized with respect to local environmental conditions and anticipated future climate changes. SINCERE offers a range of sustainable restoration options, evaluated using Building Information Modeling (BIM) and Digital Twin (DT) tools tailored for historical buildings, facilitating the selection of optimal solutions and the planning of necessary adaptation measures.

Lastly, SINCERE prioritizes public awareness and engagement, aiming to empower Europeans to advocate for the preservation of Cultural Heritage buildings. This is accomplished through the dissemination of scientific findings via cultural activities at both national and international levels.

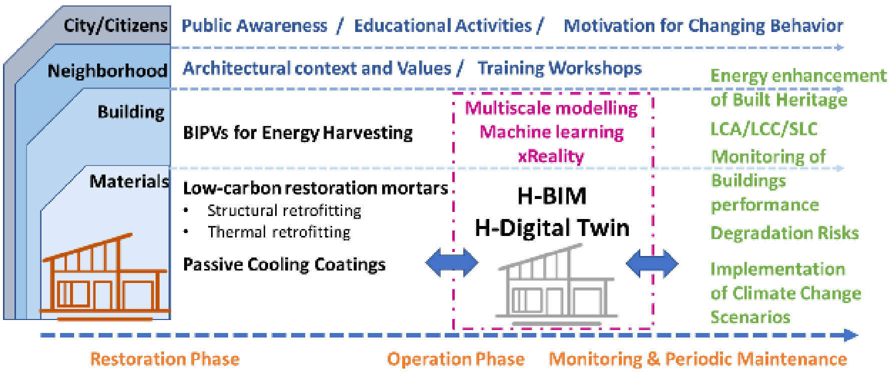

Fig. 1. Different scales and actions towards net-zero energy buildings.

2 Project objectives

The SINCERE project aims to achieve seven distinct research, technological, and societal objectives (OBJ) as presented below, each of which corresponds to key outcomes within the project framework. In line with these objectives, the project encapsulates its core strategies and methodologies that are applied in four pilot cases across Europe (Madrid-ES, Rhodes-GR, Ostrava-CZ, Holon-IL)

OBJ-01: Transform CH buildings to a key actor and main stage for raising stakeholders' and citizens' awareness on renovation/reuse concept, as a circular economy element to tackle climate change.

OBJ-02: Development of a smart interoperable platform integrating Historic BIM (H-BIM) / Historic DT (H-DT) and immersive XR technologies to provide digital tools for sustainable renovation and retrofitting of CH buildings.

OBJ-03: Reduction of environmental impact during restoration and maintenance by developing low-energy and low-carbon restoration mortars with enhanced compatibility and service life.

OBJ-04: Reduction of energy demands during operation of the restored CH buildings due to enhancement of building thermal performance and enhancement of the service life of repair mortars and of heritage buildings.

OBJ-05: Enabling solar energy harvesting during building operation with green, low-cost, large area fully sustainable building integrated photovoltaics (BIPVs).

OBJ-06: Understanding the multi-scale and multi-physics behavior of high-performance repair mortars and developing fast-running numerical design tools to achieve whole-life carbon savings.

OBJ-07: Validation of SINCERE technologies at 4 demonstration sites – Pilots in Spain, Greece, Israel, and the Czech Republic, and assessment of societal, economic, and scientific impact.

3 Methodology

In framing the methodology for the research and development of innovative technologies, inspiration is drawn from the Getty Conservation Principles for Concrete of Cultural Significance and the Cádiz Document InnovaConcrete Guidelines for the Conservation of Concrete Heritage. Emphasizing holistic approaches, this methodology aims at modernizing upgrades to CH concrete buildings while preserving their historical significance, enhancing performance, and ensuring sustained durability.

3.1 Incorporation of advanced functionalities in low-carbon structural retrofitting cementitious composites

Novel low-carbon and low-embodied energy binders that have been produced at lower temperatures than OPC and incorporate high amounts of Supplementary Cementitious Materials (SCMs) are studied for use in structural retrofitting cementitious composites, ensuring compatibility with historic concrete. The feasibility and effectiveness of incorporating functionalities such as self-healing [1] and reinforcement protection into structural retrofitting materials (Fig. 2) are evaluated. Advanced cementitious composites for structural retrofitting, including Textile Reinforced Mortars (TRM) [2] and fiber-reinforced high-performance concrete (UHPFRC) [3], are produced on different scales. The performance of these mixes is evaluated according to EN standards, with a particular focus on tensile and bending behavior, crack development, and monitoring using digital imaging and non-destructive tests. Long-term durability is assessed through experimental and numerical modeling approaches, feeding into life cycle assessments and H-DT models.

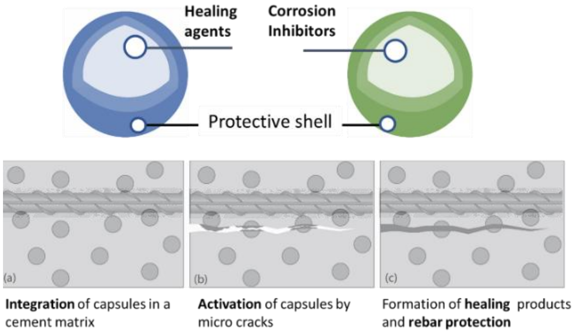

Fig. 2. Encapsulated healing agents and corrosion inhibitors for elongating the lifespan of repair interventions.

3.2 Development of low-carbon thermal retrofitting mortars

SINCERE focuses on the production, characterization, and assessment of low-carbon mortars with enhanced thermal properties. Two types of repair mortars are developed: one incorporating microencapsulated Phase Change Materials (PCMs) [4], and the other integrating sustainable insulating materials. PCMs with inorganic shells compatible with restoration mortars and those made from natural and sustainable materials are considered. The phase change temperatures are chosen according to different climates and regions in which the mortars obtained are applied. The phase change temperature, heat enthalpy, particle size distribution, and compatibility with the mortar matrix are evaluated. Optimal shell composition for microcapsules will be determined, along with the incorporation rate of PCMs and their performance in terms of fresh state, compatibility, and durability. Additionally, the chemical and phase compositions of hemp-based mortars [5] are characterized, along with mechanical properties, thermal conductivity, water resistance, and durability performance. Thermal properties of hardened mortars are assessed through differential scanning calorimetry, thermal conductivity measurements, and infrared thermography under various conditions. Real application simulations with hot-box models that allow the dynamic study of heat transfer are also used in their characterization [6].

3.3 Development and upscaling of radiative cooling paints and membranes

A rational design approach guides the integration of various physical mechanisms in SINCERE systems. Porosity and nano-/micro-particles, including phase change materials (PCMs), are utilized to enhance solar reflectance, adjust surface wettability, optimize heat emission, and reinforce mechanical robustness and UV resistance. Controlled porosity plays a crucial role, enabling efficient light scattering for solar reflectance and enhancing heat emission through multiple scattering of Mid-Infrared (MIR) radiation. Additionally, pores can facilitate the creation of super-hydrophobic or self-cleaning surfaces like slippery liquid-infused surfaces (SLIPS).

Nano-/micro-particles augment the properties of the polymer host, offering hardness modification, UV resistance, light scattering for reflectance, and enhancement of heat emission in the MIR window. PCMs, when incorporated, enable the creation of novel radiative cooling composites [6].

3.4 Development of solar energy harvesting BIPVs

In SINCERE, halide perovskite solar cells [7] are integrated into building surfaces (windows and facades) for efficient, low-cost energy harvesting with zero carbon emissions. The flexible and color-tunable properties of halide perovskites make them ideal for BIPVs, particularly on vertical facades. Perovskite cell color can be adjusted by varying thickness and composition, while transparency is controlled by the perovskite layer's thickness during fabrication. To ensure high efficiency and stability, focus will be on 3D formamidinium-rich absorbers and lead-free perovskites. Energy alignment between perovskites and charge transport layers are optimized for efficient charge extraction, with attention to device physics to minimize voltage and current losses.

3.5 Computational multiphysics-multiscale material modelling in CH and integration in LCA/LCC/SLCA

SINCERE's development of materials and technologies is complemented by the formulation, implementation, and validation of multiscale modeling and design techniques. Computational tools will accurately quantify the carbon footprint of these materials, facilitating comparison with conventional counterparts and informing a Durability-Based Design approach. This approach integrates data on material composition, embodied energy, waste, and durability improvement over the entire life cycle. Economic impacts are evaluated, comparing total costs incurred across the life cycle of materials and components with those of conventional products [8]. Environmental and social impacts are also assessed through life cycle approaches, considering factors such as environmental life cycle costing and social life cycle assessment according to UNEP/SETAC guidelines. The ultimate goal is to implement strategies for sustainable improvement, using numerical simulations and laboratory tests to train AI algorithms and support materials design processes. These results will also inform evolutionary damage risk assessment through H-BIM and H-DT, validated against monitoring data from pilot demonstrators.

3.6 Immersive technologies and digital twinning in heritage buildings' lifecycle management

Immersive technologies, and in particular mixed reality (MR) and virtual reality, are gradually changing the way people interact with machines and digital information, and SINCERE brings these technologies to the lifecycle management of built heritage. In SINCERE, a location-based indoor MR application is developed for mobile phones (Fig. 3), as well as a virtual reality application. The MR application takes advantage of recent advances in computer vision AI to automatically understand the scene around a user in a building by means of automatic object detection, classification, segmentation, and 3D reconstruction to facilitate operation and maintenance field tasks. The mixed reality and virtual reality applications are the advanced interface of the historical digital twin platform that forms the basis of all static and real-time information and content organization and the predictive models for material degradation, energy consumption, and climate changes bridging the physical and digital building. SINCERE proposes a DT framework to optimise the energy performance of heritage buildings and assess and improve buildings' lifecycle management by providing predictive analytics and insights for energy consumption, structural durability patterns, and materials service life. The H-DT developed in SINCERE exploit a historical BIM (of suitable level of development – LOD) as a spatial reference and backbone of the visual DT. The BIM model is made and regularly updated by multi-sensor reality capturing. DT leverages advanced analytics and simulation techniques to evaluate the effectiveness of different restoration options; by simulating various scenarios, one can identify the most cost-effective and durable solutions for energy optimization and structural longevity, thus providing decision-making tools involved in the restoration process. Various key parameters are considered, such as energy consumption patterns, building structural characteristics, environmental conditions, occupancy and usage patterns, technological solutions, cost considerations, and predictive modeling [9-11].

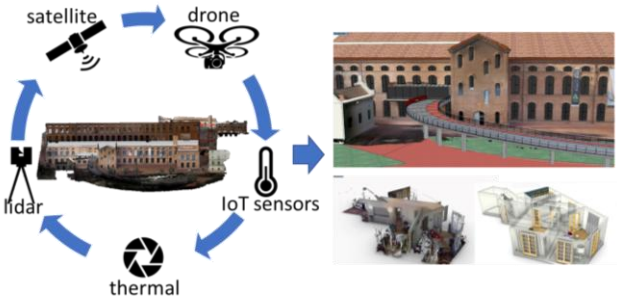

Fig. 3. Multimodal recording of built heritage.

3.7 Climatic models/scenarios, Risk assessment, and future projections validated by historical data

In SINCERE, advanced climate modeling techniques generate high-resolution projections for CH sites using CMIP6 SSP scenarios [12]. Employing statistical downscaling and ML/AI, uncertainties are minimized, and extreme event scenarios are predicted accurately. A unique aspect is the focus on compound climate events, enhancing understanding of complex factors impacting site degradation. Stakeholders participate in selecting CH degradation modes. Impact models, validated with historical data and IoT sensors, inform customized risk assessments [13]. SINCERE integrates climate projections with impact models, providing early warnings via the project's H-DT.

4 Project outcomes and impact

SINCERE materials and technologies are tailored to address the specific needs outlined below, aligning closely with the project outcomes for Built Heritage as identified by relevant authorities and industry professionals in the CH sector.

Enhanced availability and performance of solutions for reliable and respectful historical renovation of heritage buildings, preserving architectural and cultural identity. SINCERE addresses this need by providing several innovative and sustainable materials and digital tools for respectful retrofitting of Built CH, from material to city levels.

Sustainable, energy and resource-efficient historical renovation of heritage buildings by:
- implementing novel types of low-carbon cement, including encapsulated admixtures for self-healing and protection of rebar reinforcement in historic concrete,
- developing low-carbon restoration mortars for latent heat storage and insulation,
- reducing the embodied carbon in the finished products and extending the service life of green repair mortars, following the LCA/SLCA-centered building approach, and
- developing an IoT platform for multiple data collection and interpretation and one H-BIM/ H-DT tool for automated analysis and simulation processes.

Protection of the value and long-term inclusiveness, accessibility, and usability of cultural heritage sites by:
- supporting the concept of adaptive reuse and rehabilitation of existing CH buildings,
- promoting the Preservation of Built Heritage via novel ICT and green materials, SINCERE contributes to the inclusive and sustainable ways of living described in the New European Bauhaus.
- proposing multi-functional materials that could provide new criteria for modifying the legal or regulatory constraints for conserving and managing 20th century listed buildings and thus maximizing the economic and societal benefits for EU citizens.

Cost-effective and less disruptive modernisation and preservation of the Built Heritage environment by:

- using low-carbon retrofitting materials compatible with the historic substrate,
- enabling energy savings during production of restoration materials,
- using transparent BIPVs, supporting at the same time the efficient energy production for adaptive modernization,
- by applying radiative cooling coatings that can save over 65% of buildings' energy consumption, which is consumed by HVAC systems,
- by using XR and building performance simulation tools that offer the ability to visualize the aesthetic impact at the early design stage, thus analyzing and evaluating any conflicts or alterations in advance.

Enhanced prevention and monitoring of the Built Heritage environment by:

- enhancing the sustainability of repair mortars, implementing low carbon yet durable cement,
- developing an interoperable platform integrating H-BIM/H-DT technologies for providing tools not only for real-time monitoring,
- Provide several tools for visualising in several modes (XR) the results, thus facilitating communication, education, storytelling, and citizen engagement actions,
- Provide DT and machine learning algorithms for optimizing both materials and Built Heritage performance, also predicting critical structural and degradation risks.

Acknowledgements

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Restoration of rising damp in the Sassi of Matera through the use of innovative technologies

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Abstract. The millennial bond between the city of Matera and its calcarenite rock is of fundamental importance to understanding the history of the city's architectural heritage.
Calcarenite, a sedimentary limestone rock of biochemical origin, is easily workable but is characterized by low mechanical resistance and significant vulnerability to biological and physico-chemical degradation processes, especially those related to the presence of water.
Starting from the eighties of the last century, when a strategic plan for the recovery of the Sassi was launched, numerous restoration projects have been carried out. Furthermore, improper repair and rebuilding of masonries have profoundly altered the aesthetic and formal value of the buildings. Despite these challenges, Matera's architectural heritage gained significant recognition in 2019 when the city was designated as the European Capital of Culture.
Configuring itself as a laboratory of experimental restoration practices, Matera is well suited for analysis aimed at identifying the best practices currently available in the field of architectural heritage conservation. Therefore the paper is focused on the critical analysis of interventions carried out on three emblematic cases of the city that have suffered significant surface deterioration due to environmental and construction factors, as well as the presence of rising damp in the walls: the Church of San Pietro Barisano, the Church of San Francesco D'Assisi and the Diocesan Museum.
From these studies it was possible to identify the general procedural aspects that lead towards the proposal of a protocol of best conservation practices, which pays attention to every phase of the design process.

Keywords: Sustainable conservation, Calcarenites, Degradation phenomena, Innovative technologies, Non-invasive diagnostic

1 Introduction

The connection between Matera and its calcarenite rock is crucial for understanding the city's architectural heritage. Calcarenite, a sedimentary limestone rock of biochemical origin, consists of limestone granules bound together by calcitic cement or a fine-grained calcareous matrix. It's the unique composition of limestone granules that delineates the properties and characteristics of this stone material. Despite its ease of workability, calcarenite exhibits low mechanical resistance and significant vulnerability to biological and physico-chemical deterioration processes, especially in water content. [1-2-3-4]

The original matrix of Matera consisted of open caves carved into the rock, designed to utilize solar radiation passively for year-round comfort. Over time, these caves evolved into buffered caves, featuring masonry facades with an opening for the entrance door and an overhead light to ventilate and illuminate the interior. Later, the buffered caves were extended outwards with the construction of barrel-vaulted masonry, called *lamioni*, enclosed by front façades with the characteristic scaled tympanum.

Calcarenite is a material in which "nothing is wasted" [2] and the processing waste is used to fill the walls, make mortar, and plaster. The use of a single material gives the Sassi of Matera heritage a uniform appearance and ensures material compatibility, creating a perfect synergy and compactness, even structurally, between the rock and the built environment.

Starting from the eighties of the last century, when a strategic plan for the recovery of the Sassi was launched, numerous restoration projects have been carried out. Various commercial products have been used to consolidate and protect the damaged surfaces of dug and built structures [3-5]. However, many surface treatments were neither effective nor durable, with issues such as yellowing and detachments due to the chemical, physical and mechanical incompatibility of acrylic and siloxane-based materials with the stone substrate. Furthermore, improper repair and rebuilding of masonries have profoundly altered the aesthetic and formal value of the building surfaces. Despite these challenges, Matera's architectural heritage gained significant recognition in 2019 when the city was designated as the European Capital of Culture.

Since any intervention on the built heritage requires a multidisciplinary approach that includes every aspect of the construction, it is interesting to understand how degradation has been treated by analyzing the preliminary diagnostic phases (prior to restoration interventions) and the subsequent monitoring and control of their effectiveness. This consideration takes into account the delicate ecosystem of the Sassi di Matera, which requires understanding the entire context in order to arrive at a restoration protocol that allows for the rehabilitation of this architectural heritage.

Configuring itself as a laboratory of experimental restoration practices, the city of Matera is well suited for an analysis aimed at identifying the best practices currently available in the field of architectural heritage conservation.

Considering the highly variable characteristics of calcarenite, alongside the different construction types incorporating hypogea, excavated and constructed elements, and the rich historical evolution of Matera, the paper is focused on the critical analysis of interventions carried out on three emblematic cases of the city that have suffered significant surface deterioration due to environmental and construction factors, as well as the presence of rising damp in the walls: the Church of San Pietro Barisano, the Church of San Francesco D'Assisi and the Diocesan Museum, which have become the laboratories of numerous restoration experiments. [1-5-6-7-8-9-10].

2 Characterization of materials and forms of degradation

A multi-analytical methodological approach has been adopted for the preliminary evaluation of the conservation status of the case studies, including the characterization of buildings materials. Light microscopy and optical microscopy analyses were carried out on six samples taken by the facade of San Pietro Barisano. These analyses have identified a biocrimite with secondary porosity not filled by cement or matrix and the X-ray diffractometry has also highlighteda significant presence of calcite, dolomite, gypsum, quartz, nitrates and akermanite. [1]

In each of the three case studies, site inspections conducted during previous restoration interventions uncovered a widespread presence of efflorescence, sub-efflorescence and biological patinas. This has been accompanied by detachments of plasters, exfoliation of paint films, alveolization, decohesion and crumbling of stone surfaces. [1-5-7-8-9-10-11-12]

The diagnostic campaign conducted on the buildings' microclimate utilized a thermo-hygrometer Hanna Instruments model HI 18564 to measure environmental thermo-hygrometric parameters; contact thermo-hygrometer Gann model Hydromette BL UNI 11 equipped with an active electrode B 55 Bl, to determine thermo-hygrometric parameters of surfaces. [11]

The results provided by these investigations (Table 1) have shown how the presence of rising damp in the buildings is to be considered a determining factor both for the worsening of the pathological conditions and indoor microclimate.

Table 1. Environmental parameters

Church of San Pietro Barisano		
	Indoor	Outdoor
UR	79,4 %	56,3%
T air	17,5 °C	23,4 °C
T dew	13,8 °C	14,2 °C
U sp	9,81 g/kg	10,01 g/kg
Church of San Francesco D'Assisi		

	Indoor	Outdoor
UR	54,4 %	51,6 %
T air	25,9 °C	25,9 °C
T dew	15,9 °C	15,1 °C
U sp	11,24 g/kg	10,66 g/kg
Diocesan Museum		
	Indoor	Outdoor
UR	50,4 %	34,8 %
T air	28,8 °C	27,4 °C
T dew	4,8 °C	7,9 °C
U sp	10,31 g/kg	7,80 g/kg

The presence of rising damp within the masonry of the three case studies was confirmed by thermographic surveys conducted with a “Testo” thermal camera model "890-2 Kit", which fully complies with the recommended values and ensures the reliability of the results obtained thanks to its characteristics: the geometric resolution of 640x480 pixels (with super resolution of 1280x960 pixels), and the thermal resolution of 0.04°C, and an IFOV of 0.71mrad.

Due to the widespread presence of capillary rising damp it was decided to intervene with the installation of some CNT® device to monitor the phenomenon. The innovative CNT® dehumidification system patented by Domodry® is a generator of weak impulsive electromagnetic waves, suitably modulated in a defined frequency range and totally harmless, that neutralize water molecules, rendering the polarity effect induced by the capillary's electric field null. [13-14-15-16]

As a result, the molecules can no longer be attracted by the difference in charge of the capillaries in the masonry: the rise of water is therefore interrupted at the cause, while the excess humidity already present inside is gradually expelled by spontaneous evaporation, quickly depending on the construction characteristics of the wall, the amount of water initially present in the masonry itself, and the climatic conditions of the location.

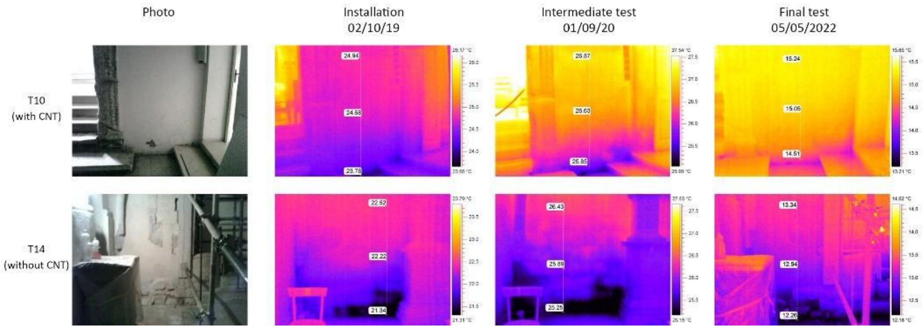

Fig. 1. Results of thermographic investigations in the Church of San Francesco D’Assisi - © 2022, photos of authors.

To monitor the effectiveness over time of this innovative technology, thermographic tests have been carried out after one year and after two or more years from the installation. These results have confirmed the effectiveness of CNT in the area covered by the device (T10), while in the area not covered by the action of the CNT device (T14), the presence of rising damp first detected persists (Fig. 1). However, once rising damp is eliminated, it is also necessary to take action to remove biological colonization and salt efflorescence that compromise the monument’s surfaces.

The buildings’ deterioration induced by the internal microclimate was exacerbated by significant external thermos-hygrometric fluctuations. Particularly with regards to soluble salts, these variations further facilitated cycles of crystallization and dissolution, hastening the disintegration of the stone substrate and the occurrence of surface alveolization.

3 Experimental interventions

In both the Church of San Pietro Barisano and the Church of San Francesco D’Assisi, all the tests carried out to remove biological patinas [8-10-11-12-17] followed the same general procedure: identification of bacterial and fungal species, selection and application of biological and/or fungicidal products, verification of the effectiveness of disinfecting treatments, surface cleaning, consolidation and protection of stone substrate.

In the case of the Church of San Francesco D'Assisi, the most striking degradation was the loss of material (alveolization, erosion), the changing in color of surface, and aesthetical decay for refacing/repair with mortar or protecting material [18].

The experimental phases involved different façade samples (Fig. 2). On the samples SFP1, SFP2, and SFP3 a commercial cleaner was sprayed. For the consolidation of the surface, two types of commercial consolidating agents based on acrylic resins were used: SFC1, SFC3, SFC4, SFC5, SFC7 samples – type 1 (one brush coat and one spray coat until saturation of the surfaces, diluted in water at a ratio of 1:5); SFC2, SFC6 sample – type 2 (one brush coat and one spray coat until saturation of the surfaces, diluted in water at a ratio of 1:10). Before proceeding with the subsequent phases, cleaning was conducted on samples as follows: employing a saggina brush on SFC2 and SFC3, and using a saggina brush followed by washing with demineralized water on surface SFC1.

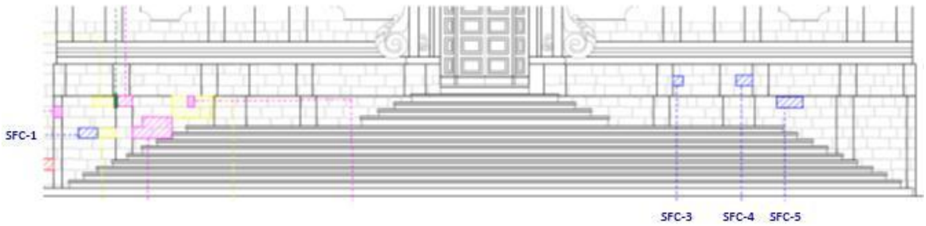

Fig. 2. Main façade of the Church of San Francesco D'Assisi with samples location - © 2022, photos of authors.

Subsequently, we proceeded with the preparation of a grouting mortar to fill a gap and create a joint, mixing tuff and lime in a 3:1 ratio on the sample previously treated with consolidant. On the surfaces of samples SFC10 and SFC12, a spray coat of consolidant with water repellent was applied, while on sample SFC11, a spray coat of consolidant without water repellent was applied.

To verify the effectiveness of the product, six months after application of the products, were carried out non-destructive in situ tests: Colorimetric Test (UNI EN 15886:2010) [19], conducted using a Konica Minolta CM-2600d spectrophotometer; Water Absorption Test (UNI 11432:2011) [20]; Scotch Tape Test (ASTM D3359-08, 2008) [21].

For the Colorimetric test, measurements were executed with an aperture diameter of 8 mm, specular component excluded (SCE), illuminant D65 and viewing angle of 10°. [1] In almost all treated areas, chromatic variations not visually appreciable ($\Delta E<5$) were recorded; the only exceptions are represented by zones SFC-1 and SFC4 treated with consolidant type 1, for which the ΔE values are 7.4 and 13, respectively.

Water Absorption Tests were conducted on both treated and untreated areas, with a water quantity of 5 ml and a contact time of 1 minute. In the samples SFC-1, SFC-6, and SFC-7, the treatments resulted in a decrease of approximately 50% in water absorption compared to the untreated stone; in zone SFC-4, this decrease was limited to 30%.

Scotch Tape Tests (STT), executed with a strip of adhesive paper (50 x 22 mm), are weighed using an analytical balance with a sensitivity of 0.1 mg. It is pressed onto the stone surface and allowed to adhere for 90 seconds. This test was repeated four times at each point [1] and showed that the lowest total weight (TRM) released at the end of the tests was measured in zones SFC-5 and SFC-7 treated with consolidant type 1, which therefore appears to be the most effective. No variation was recorded in zone SFC-6 compared to the untreated stone; also, in zone SFP-4, the application of the products does not seem to have yielded good results. Evaluating the material loss in each individual "tear" of each test, therefore, in terms of RM (released mass, mg/cm2), no significant differences are appreciable in zone SFC-1 compared to the untreated stone; it is also noted that in both cases (untreated stone and treated stone), the highest RM value is obtained with the last "tear," probably following the removal of the most superficial and coherent portion.

4 Discussion of results and conclusion

This study is part of a broader research project that aims to develop a digital protocol of good practices for architectural heritage conservation by promoting preventive and predictive maintenance. The results of the investigation underline the key-role of pre and post intervention diagnostics.

The critical analysis of interventions on building heritage reveals a lack of planned programs of interventions. The prevalent conservation practice envisages emergency actions on a single issue without a multidisciplinary approach focused on preventive and planned maintenance. For all these reasons, the research activities have been focused on procedural aspects for the proposal of a protocol of best conservation practices. This protocol emphasizes attention to every stage of the design process, from the preliminary understanding of the building to the monitoring and verification phases of the interventions.

The effectiveness of an intervention hinges on a thorough understanding of the building's historical context, material, and pathologies. The diagnostic plan should be founded on morphological identification of degradations, detection of thermo-hygrometric parameters and non-destructive analyses, such as IR thermography, colorimetric test, scotch tape test and water absorption test [11-12-22-23]. These analyses should serve as the foundation for any subsequent invasive tests (weight tests, optical microscopy, X-ray diffraction on powders, spectroscopy, X-ray microtomography...).

Furthermore, it is imperative that the conservation process of architectural heritage does not exclusively prioritize isolated, short-term interventions, but instead adopts a forward-looking approach towards long-term preservation. This approach ensures the continual maintenance of the heritage value and its transmission to future generations.

Achieving this goal requires complementary and synergistic interventions. Particularly in cases of rising damp, the initial priority should be the installation of an effective dehumidification system, such as the CNT device. However, it's essential to recognise that this step alone is necessary but not sufficient for fully restoring the conservation status of buildings [13-14].

5 Author contributions

Conceptualization, G.B. and A.G.; methodology, G.B.; resources, G.B. and A.G.; data curation, G.B.; writing and editing, C.R; review G.B. and C.R.; supervision, A.G. All authors have read and agreed to the published version of the manuscript.

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Optimizing the In Situ Deposition of Carbonate Hydroxyapatite for the Consolidation of Marble in Cultural Heritage Monuments

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I. Extended Abstract

Strengthening the structure of marble is key to restoring its mechanical properties and contributing to the stability of stone monuments. Marble consolidation as a conservation technique has been attempted since the 1950's, initially using organic consolidants, i.e., acrylics, vinyl and silicone polymers, as well as epoxies [1,2]. These strategies, however, suffered from incompatibility, reversibility and low durability problems and were gradually replaced by the use of inorganic salts or bases with low water solubility. In recent years, the use of calcium hydroxide [3], calcium oxalate [4,5], and hydroxyapatite [6–8] has gained attention for the strengthening and stabilization of deteriorated or fragile marble surfaces. This method generally requires optimized deposition of the above materials in sub-micron or nano-sized particulate form, thus enabling their incorporation into the porous structure of marble, allowing (permitting) an efficient consolidation [9,10]

Hydroxyapatite (HAP), a calcium phosphate with the formula $Ca_{10}(PO_4)_6(OH)_2$, is known for its extremely low solubility (K_{sp} ~10^{-98}); in particular, its carbonate form, carbonate hydroxyapatite (c-HAP), $Ca_{10}(PO_4)_{6-y}(CO_3)_y[(CO_3)_{x+(½)y}(OH)_{2-2x}]$ is commonly found in bones and teeth of vertebrates. The apatite family has been explored for various applications, including its potential for the conservation of marble and other calcareous materials. Marble, a calcareous metamorphic rock, is susceptible to deterioration over time due to environmental factors such as acid rain, pollutants, and biological activity.

The method entails depositing (involves the deposition of) the highly insoluble hydroxyapatite salt from aqueous solutions of diammonium phosphate (DAP). This is achieved by the interaction of diammonium phosphate (DAP) aqueous solutions on the surfaces of calcareous or marble objects of cultural heritage, providing a mechanism to reconnect and restore the cohesion lost in the porous marble substrate. Concurrently, the formation of a thin, sufficiently bonded layer on the surface acts protectively, retarding the decay process. This study evaluated the method's effectiveness combining infrared spectroscopy with SEM-EDX micro-analysis. The method was optimized by the addition of simulated body fluid (SBF), a cocktail of inorganic salts, showing particularly positive results in both immersion and surface application scenarios. Among the application methods tested, the dripping method presented satisfactory results on the monument, although immersion, if feasible, is considered ideal as the most efficient c-HAP formation was observed.

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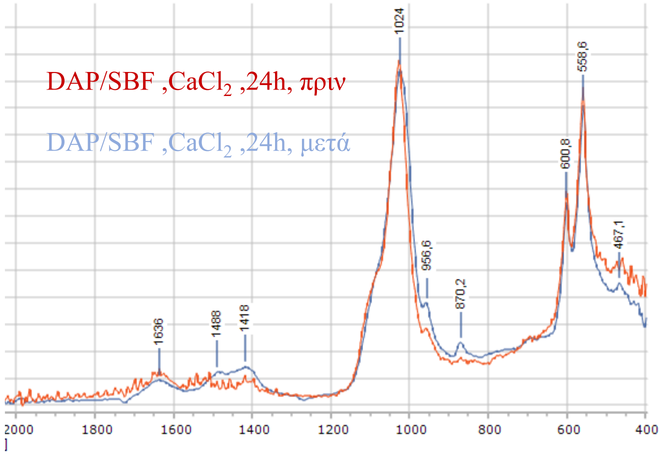

Figure 1. FTIR spectrum of the $CaCl_2$-enriched marble area after treatment with DAP, and SBF showing the formation of c-HAP

The HAP formation process requires the availability of calcium through the reaction of DAP with Ca ions, readily provided by the marble itself. This raises the concern of sacrificing some of the marble surface integrity for the consolidation process. At a first level, the formation of c-HAP, as shown by FTIR spectra (Figure 1), demonstrates that some of the calcium provided by the marble- still remains in the calcite form. An attempt was also made to further reduce this effect, by enriching the marble surface with $CaCl_2$ before applying the DAP solution.

The results of the method were highly encouraging, achieving significant hydroxyapatite formation and surface coverage along with satisfactory penetration and adhesion to the surface. Analysis of the FTIR spectra of the reaction products provided insights into the different phases of formation, shedding light on the chemical kinetics and the precise products being formed.

Although additional research is required, this method has shown great promise in terms of strengthening and stabilizing structures, offering compatibility due to its inorganic nature, and potentially providing long-term protection.

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Multifunctional composite coatings consisting of polymers and zinc oxide nanoparticles for the protection of stone heritage

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I. Extended Abstract

Protection of heritage buildings against the effects of rain and atmospheric humidity is extremely important, as water is a major source of natural stone degradation induced by the freezing-thawing cycles and salt deposition. Biomimetic superhydrophobic coatings can offer enhanced protection to stone, as they have the ability to repel water drops through the famous lotus effect [1]. The first superhydrophobic material designed specifically for the protection of stone heritage was produced by our group about two decades ago [2]. The idea was to tune the wetting properties of products, which were already used in conservation practice (e.g. silane/siloxanes [3]), by adding small amounts of engineered nanoparticles (NPs). The latter affect the morphology of the composite material, which is deposited onto stone, creating a lotus-like, two-length scale hierarchical surface structure. In the last two decades the method has been adopted by numerous scientists using different conservation materials and NPs (usually silicon oxide, SiO_2 NPs) for the protection of limestone, marble and other stones used in heritage buildings, as described in review articles e.g. [4-6]. The suggested composite materials consist mainly of products which are already tested and recommended for stone conservation and a small fraction of NPs. Selecting certified products, used in conservation practice, reduces the danger to induce any undesirable, hazardous side-effect which can be developed through time.

In the present study we produce two composite materials which are applied on marble. The study has two novelties. First, zinc oxide (ZnO) NPs are added to the polymer matrices, instead of the extensively studied SiO_2 NPs, to induce surface roughness which is necessary to achieve superhydrophobicity [7]. The goal is to produce a multi-functional material that can serve simultaneously three purposes: (i) water repulsion, (ii) chemical self-cleaning through photo-degradation and (iii) biocidal activity. It well known that ZnO has photocatalytic [8] and biocidal [9] properties. However, to the best of our knowledge the combined demonstration of the three aforementioned properties by a single composite material, designed for stone protection, has not been achieved yet. Second, to induce enhanced oleophobicity, combined with superhydrophobicity. Oleophobisation of natural stone surfaces is highly desirable to protect heritage buildings which are located in urban areas and are therefore threatened by oil-based urban pollutants [10].

ZnO NPs were added in an aqueous, non-toxic and eco-friendly, silane sol (Dynasylan SIVO 121), in various concentrations and sprayed onto marble specimens. The produced composites are named hereafter as DZn. To enhance the oleophobic character of the resulting composite coating, the above recipe was modified as follows. ZnO NPs were added in an aqueous, mixture consisting of Dynasylan and a water-based fluoropolymer (C6 fluorocarbon polymer, cationic). Dispersions of various NP concentrations were prepared and sprayed onto marble resulting in composites which are named hereafter as DFZn. Prior to deposition, the dispersions were stirred vigorously for 30 min. Spray deposition was carried out using an airbrush system (Paasche Airbrush) with a nozzle diameter of 733 μm. The spray method was employed for the deposition of sols, as it offers flexibility and can be easily used to treat large surfaces. The treated marble specimens were annealed at 60° for 1h to remove residual solvent and accelerate curing. Contact angles of water (WCA) and oil (OCA) drops (8 μL) were measured using the ImageJ software. At least three drops were placed on different areas of coated marble specimens and average values were calculated.

The results are shown in Figure 1. WCAs on coatings which were prepared without NPs (i.e. zero NP concentration in Figure 1) were 115.6±1.7° and 129.5±1.0° for the DZn and DFZn coatings, respectively. A rapid increase of WCAs is shown in Figure 1 when a small amount (1% w/v) of ZnO NPs was added in the coatings, exceeding the threshold of superhydrophobicity (>150°). Further increase of NP concentration in the DFZn coating does not have any effect on WCA

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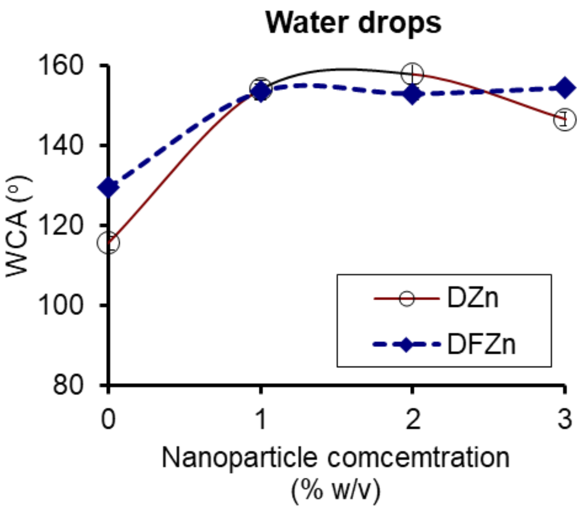
which is practically constant and large (>150°). However, WCA on the DZn coating decreased when the NP concentration increased from 2 to 3% w/v.

A similar trend is reported for the OCA results of Figure 1. OCA on the DFZn coatings initially increases with NP concentration and becomes large (roughly 140°) and practically stable for coatings which were prepared using elevated NP concentration (>1% w/v). OCA on the DZn coatings initially increases and then drops when the NP concentration increased from 2 to 3% w/v. The results of Figure 1 are in agreement with previously published data which investigated the effect of the concentration of SiO_2 NPs in composite coatings. The increase of WCA and OCA with NP concentration was attributed to the formation of a two-length scale hierarchical structure [1,6] whereas the drop of OCA at elevated NP concentration was attributed to the formation of anomalies (grooves) which are formed [10].

The ongoing research intends to study the surface morphologies of the coatings using Scanning Electron Microscopy (SEM) and, moreover, to subject the coated stone specimens to other important tests, including water absorption by capillarity, vapour permeability and colourimetry. Finally, the chemical self-cleaning through photo-degradation and the biocidal activity of the composite coatings will be accessed.



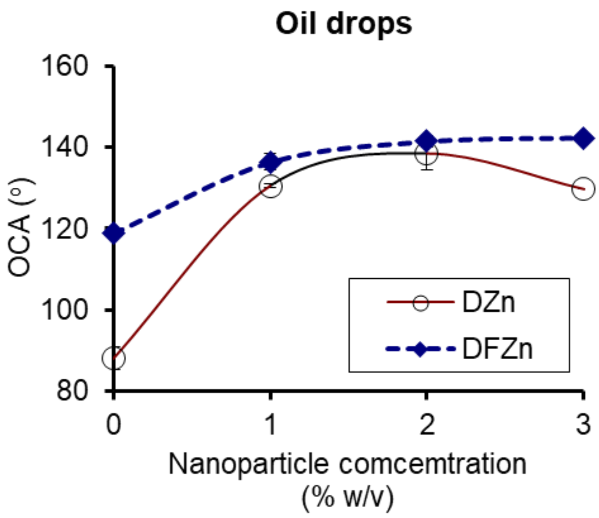


Figure 1. Contact angles of water (WCA) and oil drops on coated marble are shown in the left and right plots, respectively.

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Hydrophobization of limestone using fluorinated and TEOS-based polymers

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I. EXTENDED ABSTRACT

Natural stone and stone-built cultural heritage suffer weathering and decay by condensed water. Consecutive freezing and thawing cycles inside the pores of the stone cause the stone deterioration. In addition, air pollutants can also be transferred and cause stone decomposition [1,2]. Hydrophobization of natural stone surfaces is a practical method to impede water induced degradation of buildings of cultural heritage. Silane/siloxane-based products are commonly used for the conservation of natural stone since they possess three important properties: high depth of penetration, stability, and hydrophobicity [3,4]. The inherent hydrophobic character of the silane/ siloxane-based materials originates from the organic groups which are attached to the Si atoms of the backbone chain. Polysiloxane networks originate from small precursor molecules of silanes and siloxanes. These molecules can penetrate deep into the stone network before they become highly viscous gels (i.e., polysiloxanes) through the sol-gel process [5]. This results to higher depths of penetrations by the silane-based consolidants, compared with the high molecular weight organic polymers used in the past for stone consolidation [6,7]. Polysiloxane materials are often considered as hybrid materials because their backbone chains are formed by the siloxane (Si-O) bond which is of “inorganic” nature, while the substituents attached to the Si atom are generally “organic” radicals [7]. This dual nature of polysiloxane compounds offers both stability and hydrophobicity. Stability originates from the high strength of the Si-O bond compared with the C-C bond which forms the backbones of organic polymers. In particular, the strengths of the Si-O and C-C bonds correspond to 108 and 83 kcal/mol, respectively [4]. High Si-O bond strength offers siloxane-based materials with considerable thermal stability as well as good corrosion and UV resistance [4,8-10]. The introduction of fluorine molecules enhances water repellency and resistance by lowering the surface tension of the treated surfaces [11,12].

In the present work two materials were used to treat limestone specimens: Dynasylan F8261 (1H,1H,2H,2H- Perfluorooctyltriethoxysilane, PFOES), purchased from Evonik, and KSE 300 which according to the manufacturer (Remmers) is a stone strengthener on a silicic acid ester base and it is provided for the consolidation of natural stone. In the first set of experiments F8261 was directly sprayed onto the stone samples. Several deposition/spraying cycles were applied resulting in several layers of coating onto the treated stones. In the second set of experiments, stone samples were first immersed in KSE300 baths (dip coating) for 72 h and then F8261 was sprayed on top of treated stones. The latter were purchased from the local market. Static contact angle of water drops (CAs) and colour changes (ΔE*) were measured as a function of deposition cycles i.e. number of deposited layers. ΔE* was calculated using the following equation:

$$\Delta E^* = \sqrt{(L_t^* - L_u^*)^2 + (a_t^* - a_u^*)^2 + (b_t^* - b_u^*)^2}$$

where L*, a* and b* are the brightness, the red–green component, and the yellow–blue component of the CIE 1976 scale, respectively.

The “t” and “u” subscript characters indicate the treated and untreated samples, respectively.

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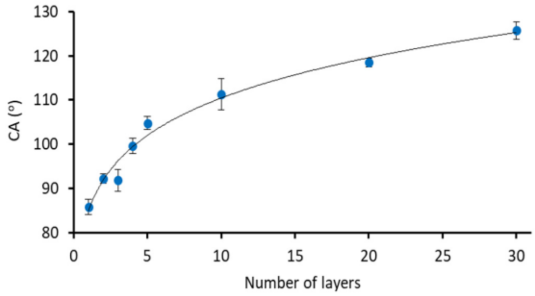

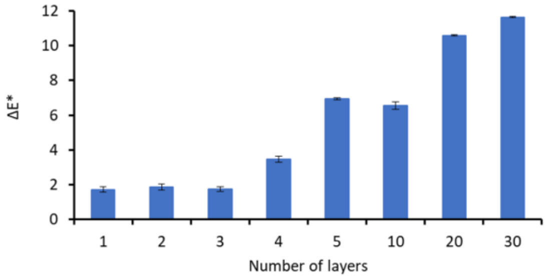

Figure 1. Results obtained after treating limestone samples with F8261. Contact angles of water (CA) drops (left) and colour change (ΔE*) vs the number of coating applications on limestone. A power law fitting is included in the left plot to guide the eye. The results for the limestone samples which were treated only with F8261 (first set of experiments) are included in the plot of Figure 1. Figure 1a shows that CA increases with the number of deposited layers from around 85° (limestone sample coated by 1 layer) to 125° (sample coated by 30 layers). Therefore, the results of Figure 1 suggest that hydrophobization of limestone is promoted with the deposition cycles of the fluorosilane material. According to the results of Figure 1b, the deposition of the first 4 layers of coatings induced an acceptable colour change i.e. ΔE*<5. However, the deposition of more layers (more than 4) resulted in augmented colour changes.

In the second set of experiments, limestone samples were first treated with KSE300, followed by the application of F8261. The CAs, measured after the deposition of one, two and three layers of F8261 were 115°, 121° and 122°, respectively. Notably, 30 layers of F8261 on bare limestone were necessary to achieve a CA of 125° whereas the same degree of hydrophobization was roughly reached with only 3 layers of fluorosilane when it was deposited on limestone which was pretreated with the TEOS-based material. As F8261 is a material of low viscosity, it can easily penetrate into the porous network of limestone. Hence, multiple depositions of F8261 are necessary to form a continuous coating on the surface of limestone and therefore to achieve surface hydrophobization. However, with the pretreatment step the pores of limestone are filled with KSE300 and therefore only few deposition cycles of fluorosilane are necessary to form a continuous coating. However, the second set of experiments resulted in augmented change of the original colour of limestone as ΔE*>10, regardless of the number of the deposited F8261 layers. It should be stressed, that the colour change was induced mainly by the pretreatment step and not by the deposition of the fluorosilane. The colour change induced, in the second step, by the deposition of F8261 was not noticeable. In particular, the total colour difference (ΔE*) between limestone samples treated with both materials (KSE and F8261) and limestone samples treated only with KSE was <3.

The present research is in progress. Scanning Electron Microscopy will be employed to study the surfaces of treated limestone samples and measurements on water absorption by capillarity will be carried out.

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