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Protecting Archaeological Collection: The Importance of Microclimatic Monitoring and preliminary diagnostic investigations in the Preservation of the “Sala delle Madri”

Antonio Spagnuolo[1,2], Carmela Vetromile[1,2], Antonio Masiello[2], Maria Francesca Alberghina[3], Salvatore Schiavone[3], Noemi Mantile[1], Giovanni Solino[4], Carmine Lubritto[1]
[1] *Department of Environmental, Biological and Pharmaceutical Sciences and Technologies and MAReA Centre, University of Campania “Luigi Vanvitelli”, Via Vivaldi 43, 81100, Caserta.*
antonio.spagnuolo@unicampania.it, carmela.vetromile@unicampania.it, noemi.mantile@unicampania.it, carmine.lubritto@unicampania.it
[2] *Energreenup srl; info@energreenup.it*
[3] *S.T.Art- Test di S. Schiavone & C. sas; info@start-test.it*
[4] *Territorial planning, environment and ecology sector, local authority Province of Caserta; giovannisolino@provincia.caserta.it*

***Abstract* – This study examines the importance of microclimatic monitoring in cultural heritage sites for the identification of critical environmental conditions and the development of appropriate conservation measures. In particular, the research focuses on the microclimate analysis in the 'Sala delle Madri' of the Archaeological Museum of Capua, Italy, which houses a collection of important Roman and Greek sculptures.**
The study reveals that the microclimatic conditions in the ‘Sala delle Madri’ are not constant throughout the monitored year and the environmental parameter are influenced by seasonal variations and natural phenomena. A preliminary diagnostic investigation has been performed on the sculptures located in the room to document the state of conservation of the sculptures and to plan a specific analytical protocol aimed to characterization of both original and restoration materials, verifying the influence of the microclimatic conditions, due to high temperatures and NO_2 levels.
The findings highlight the necessity for the implementation of conservation measures to mitigate the negative impact of environmental conditions and prevent further damage to the archaeological find displayed at Capua Museum. This study contributes to the wider awareness of the importance of preserving cultural heritage and the role of monitoring systems in achieving this goal.

Keywords - microclimatic monitoring, cultural heritage sites, environmental conditions, conservation, custom monitoring.

I. INTRODUCTION

In recent years, there has been an increasing focus on monitoring microclimatic conditions in cultural heritage sites due to their impact on preservation [1][2]. In this study, we present the results of a monitoring campaign of the microclimate in the 'Sala delle Madri' of the Archaeological Museum of Capua, Italy. The room houses a collection of important Roman and Greek sculptures and has been identified as having potentially critical environmental conditions, including high temperature levels [3][4][5][6].

These are the so-called "mothers" represented ex-voto for the granting of fertility to the goddess "Mater Matuta", an ancient Italic divinity of dawn and birth. A comprehensive microclimatic monitoring system was installed, consisting of multiparametric sensors, to assess the environmental conditions inside the room.

The data retrieved were correlated with the results of diagnostic investigations performed by non-invasive methodologies on the sculptures located in the room with the aim of documenting the state of conservation of original and restoration surface of the statues. The data have been collected over the period of one year in order to reveal that the microclimatic conditions in the ‘Sala delle Madri’ their daily and seasonal variability throughout the year, and their inertia with respect to external climatic phenomena.

Preliminary diagnostic investigations have been carried

out to document the state of conservation of the sculptures in the room and to understanding the influence of microclimatic conditions, in particular any effect due to hygrothermal and chemical factors. Two votive statues that already showed conditions of advanced degradation have been selected.

The monitoring campaign conducted in the 'Sala delle Madri' of the Archaeological Museum of Capua highlights the importance of microclimatic monitoring in cultural heritage sites for the identification of critical environmental conditions and the development of appropriate conservation measures [7][8][9][10].

This study contributes to the wider awareness of the importance of preserving cultural heritage and the role of monitoring systems in achieving this goal.

II. MATERIALS AND METHODS

For the project, a smart object has designed and assembled for the non-invasive control of indoor environmental parameters of the site. Station is equipped with a microcontroller with custom firmware equipped with Bluetooth-Wi-Fi dual telecommunication channel and operating in Start-Go-Stop mode. The collected data are sent to a remote cloud and visualized through an application with a low-level analytics module. The monitoring station, shown in Figure 1, is equipped with a microcontroller, a multi-in-one air quality module integrating several sensors, including a laser dust sensor, an infrared carbon dioxide sensor, electrochemical sensors for formaldehyde, ozone, carbon monoxide, TVOC grade, and nitrogen dioxide, as well as temperature and humidity sensors. Additionally, electrochemical modules for hydrogen sulfide and sulphur dioxide monitoring are installed. A micro-fan inside the station is switched on for a pre-set time and frequency to have a balance with the environment to be monitored. Holes were made in the container to facilitate air exchange between the inside and outside of the station. During each sampling, the station acquired approximately 115 data points and provided four different types of values for each measuring point, including minimum, average, maximum, and the last acquisition. The monitoring station has several strengths. Firstly, it has small dimensions, which make it possible to install in areas where space is limited (Figure 1).

Fig. 1. Multiparametric station.

Secondly, it is highly customizable, allowing the addition or removal of sensors depending on the type of monitoring to be carried out. This makes the station versatile since it can be adapted to different contexts and environmental conditions. By customizing the sensors, it is also possible to detect pollutants that might otherwise go unnoticed, providing even more accurate and comprehensive measurements. The ability to change the configuration of the station also makes it an efficient and economical option, as it can be adapted to different sites and purposes.

Non-invasive diagnostic investigations were performed on two votive statues in tuff selected for complexity of their surface due to the presence of restorations areas. Indeed, extended portions appear affected by a plaster that re-proposes the features of the faces and other details by altering the reading of the original surfaces. These restorations, considered historicized, have not been removed in order to document the conservation events of the collection over time. In the first step of ongoing study Visible fluorescence induced by Ultraviolet source (UVF) imaging was carried out on the votive statues depicting the "Madri" has been carried out to map the different materials constituting the surface of the sculptures. In particular, the two statues exhibited in room VIII, which were affected by incorrect past restorations (Figure 2).

Fig. 2. Two tuff statues involved in the preliminary diagnostic investigation.

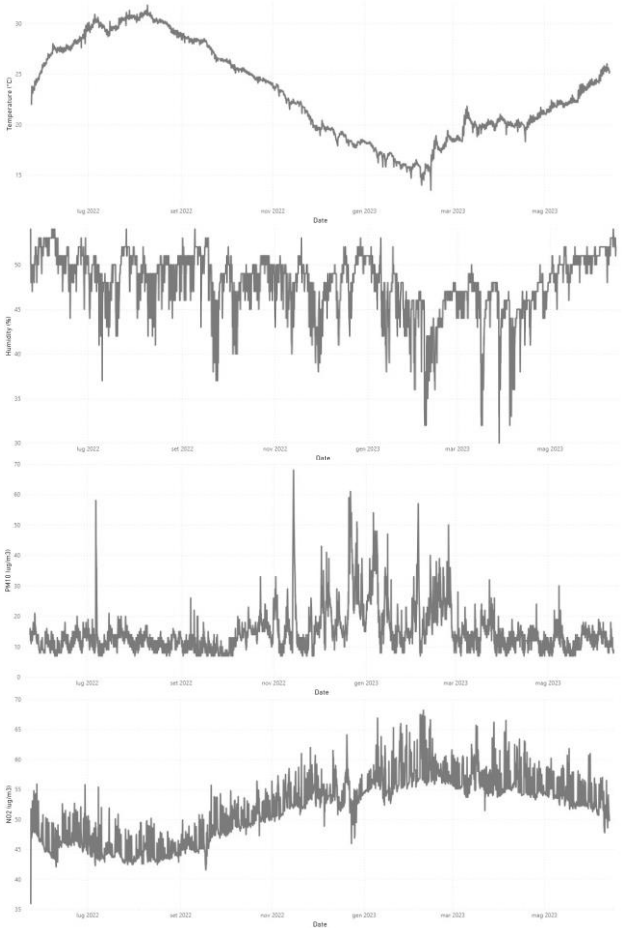
The observations and documentation were conducted to precisely locate the areas of restoration and document the state of conservation, as well as to identify the presence

of residues of organic and/or inorganic materials due to previous restoration work and/or foreign materials applied to the original layers. Moreover, digital optical microscopy has been used to observe and document the presence of restoration materials applied to the original surfaces, identifying the morphology and uniformity/homogeneity (presence of inclusions on apparently homogeneous surfaces) not visible to the naked eye.

III. DISCUSSION

The microclimate monitoring data were collected over a one-year period, from May 2022 to June 2023. It should be noted that before June 2023, the room did not have any mechanism for air conditioning the indoor air.

The data showed that the temperature inside the room ranged from 13.4°C in February 2023 to 31.8°C in August 2022 showing that the environmental conditions inside the room prove to be particularly critical during the summer and winter months. The relative humidity (RH) ranged from 30% in March 2023 to 54% in June 2023. The concentration levels of various atmospheric pollutants, including CO_2, NO_2, CH_2O and O_3, were recorded at different levels throughout the year (Figure 3).



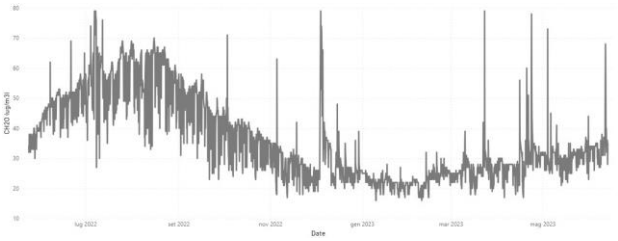


Fig. 3. Temperature (3a), Relative Humidity (3b), PM10 (3c), NO_2 (3d) CH_2O (3e) trends

An accurate statistical analysis of the collected data was carried out following UNI standards [11] [12] [13]. The results were compared with the normative standards related to museum environmental parameters.

The statistical analysis showed that the hygrothermal values recorded are not always within the limits suggested by the standard (especially in the summer and winter months); nitrogen dioxide values were also outside the optimal ranges recommended for museum environments.

The first non-invasive diagnostic investigations clearly distinguish the mortar integrations and original tuff surface was influenced by environmental conditions, showing diffuse alteration and detachments phenomena due to differentiate behaviour of original and integration materials at daily or seasonal thermo- hygrometric changes. In particular, the visible fluorescence images induced by ultraviolet sources document the extensive integrations that covers the original stone surfaces by altering the faces and other details of the Mothers. The restoration part appears under UV characterized by a bluish-white fluorescence clearly distinguishable from the original surfaces which do not show characteristic fluorescence, readable as dark areas or areas of different colour compared to the original contiguous areas of the same colour when observed in the visible. Moreover, UVF imaging revealed the presence of residues due to previous treatments, making the surface susceptible to environmental aggressions such as deposition of atmospheric particulates, microorganisms, and salts, which leads to further deterioration (Figure 4).

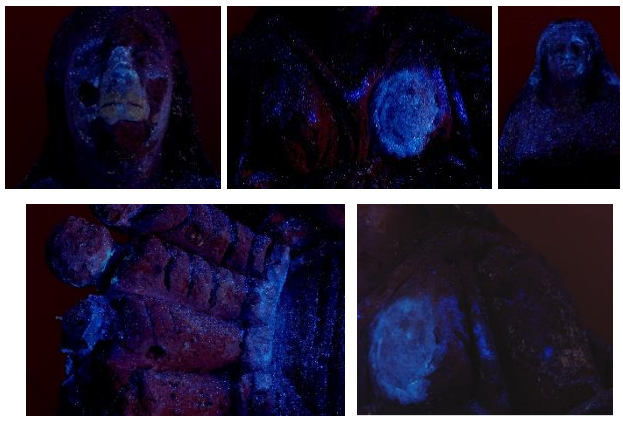


Fig. 4. UV Fluorescence images: bluish-white areas documented the remake part e provide a mapping of votive statues surfaces for the evaluation of the state of conservation

Digital optical microscopy allowed the observation and documentation of the restoration integrated surfaces and original tuff, identifying morphology and uniformity/homogeneity not visible to the naked eye (Figure 5a-b). Moreover, optical microscope documentation revealed trace of a possible preparation layer related to an original polychrome feature on original surface not involved in past restoration works (Figure 5c).

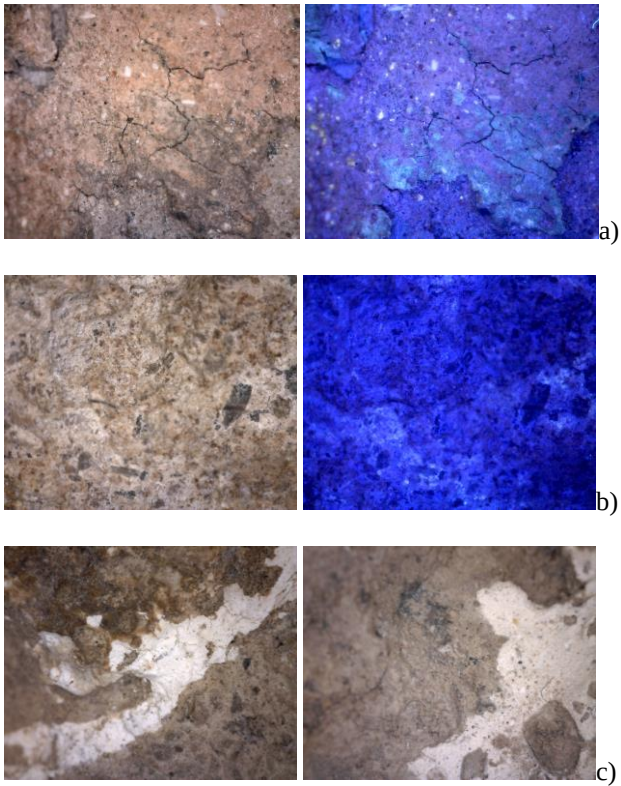


Fig. 5. Digital optical microscope Vis and UV images (50 ×) on: a) mortar constituting the sculptured surfaces integration due to past restoration work; b) original tuff surfaces; c) supposed traces of a preparation layer of a original pictorial layer.

The information provided by the preliminary UVF and MO mapping will make it possible to identify the correct and significant sampling areas for subsequent analytical studies on the various materials identified through infrared spectroscopy investigations, ion chromatography and XRD analyses.

This second step of ongoing studies will allow to characterize the degradation products formed as a result of the interaction with the conservation environment and to evaluate the influence of the degradation of the historicized integrations on the preservation of the original tuff surfaces.

IV. CONCLUSION

The study highlights the importance of microclimate monitoring in cultural heritage sites to identify critical environmental conditions and develop appropriate conservation measures. The monitoring system installed in the ‘Sala delle Madri’ revealed that the microclimatic conditions in the room were not constant throughout the year, and the environmental conditions were particularly critical during the summer and winter months.

The preliminary non-invasive investigations performed on the sculptures located in the ‘Sala delle Madri’ also revealed that the state of conservation of the sculptures was strongly influenced by microclimatic conditions, as observable by encrustation, incoherent deposits, detachments and alterations affecting the interface between the original surface and the historicized mortar integration that will be characterized in the second step of studies. The identification of the newly formed products will allow the evaluation and planning of the necessary interventions to avoid the degradation of the original materials which could be accelerated by the chemical or physical interaction with the altered restoration materials, extensively present on the two statues analysed.

The data collected were accurately analysed and compared with UNI standards related to the museum's environmental parameters, indicating that some values recorded were outside the optimal ranges, requiring intervention to improve the environmental conditions in the ‘Sala delle Madri’ and preserve the sculptures adequately.

The study underscores the necessity of implementing continuous on artworks and on environments monitoring initiatives to ensure the optimal preservation of museum collection. An innovative breakthrough in research is certainly the implementation of the microclimatic monitoring system described in this study, that offers a highly customizable and versatile option for monitoring environmental conditions in cultural heritage sites. The system's small size and adaptability make it ideal for use in areas with limited space and allows it to be customized to meet the different monitoring needs of specific contexts. The system's ability to detect pollutants that might otherwise go unnoticed and provide accurate and comprehensive measurements is particularly innovative. By using this monitoring system, it is possible to identify critical environmental conditions that may negatively impact the preservation of cultural heritage sites and to implement appropriate conservation measures to mitigate any potential damage. The customizable and versatile features of the system make it an efficient and economical option for monitoring microclimatic conditions in cultural heritage sites.

The findings of this study may contribute to the development of future conservation strategies aimed at

mitigating the negative impact of environmental conditions on cultural heritage, ensuring their conservation for future generations.

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