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Theocharis Katrakazis, Vicki Kontogianni, Eirini Tziviloglou, Vassilis Kilikoglou, Ioannis Karatasios, Athanasios Sfetsos, Diamando Vlachogiannis, Iason Markantonis, Maria Mertzani, Petros Prokos, Ekaterini Ftikou

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Monitoring the Effects of Climate Change on Microclimate and Building Materials of Monuments – the approach of "Herisktage" Research Project

Theocharis Katrakazis, *Institute of Nanoscience and Nanotechnology (INN)*, National Centre for Scientific Research "Demokritos" 15310 Athens, Greece

Vicki Kontogianni, *Institute of Nanoscience and Nanotechnology (INN)*, National Centre for Scientific Research "Demokritos" 15310 Athens, Greece

Eirini Tziviloglou, *Institute of Nanoscience and Nanotechnology (INN)*, National Centre for Scientific Research "Demokritos" 15310 Athens, Greece

Vassilis Kilikoglou, *Institute of Nanoscience and Nanotechnology (INN)*, National Centre for Scientific Research "Demokritos" 15310 Athens, Greece

Ioannis Karatasios, *Institute of Nanoscience and Nanotechnology (INN)*, National Centre for Scientific Research "Demokritos" 15310 Athens, Greece
i.karatasios@inn.demokritos.gr

Athanasios Sfetsos, *Institute of Nuclear & Radiological Sciences & Technology, Energy & Safety (INRASTES)*, National Centre for Scientific Research "Demokritos", 15310 Athens, Greece

Diamando Vlachogiannis, *Institute of Nuclear & Radiological Sciences & Technology, Energy & Safety (INRASTES)*, National Centre for Scientific Research "Demokritos", 15310 Athens, Greece

Iason Markantonis, *Institute of Nuclear & Radiological Sciences & Technology, Energy & Safety (INRASTES)*, National Centre for Scientific Research "Demokritos", 15310 Athens, Greece

Maria Mertzani, *Directorate of Conservation of Ancient and Modern Monuments (DCAMM)*, Hellenic Ministry of Culture 10553, Athens, Greece

Petros Prokos, *Directorate of Conservation of Ancient and Modern Monuments (DCAMM)*, Hellenic Ministry of Culture 10553, Athens, Greece

Ekaterini Ftikou, *Directorate of Conservation of Ancient and Modern Monuments (DCAMM)*, Hellenic Ministry of Culture 10553, Athens, Greece

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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