HERitage MONitoring (HER-MON) FOS INCREASING RESILIENCE IN THE CLIMATE CHANGE ERA

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Abstract
As an implementation study funded by "The Greek Green Fund," the project "HERitage MONitoring" aims to investigate whether it is possible to monitor and predict the alteration and collapse of historic buildings due to the changing environmental conditions caused by climate change. With the medium- and long-term study of the data in combination with the prevailing climatic conditions, conclusions will be drawn about the relations between them, and a system of early intervention will be proposed to deal with possible collapses and losses of essential elements of the monuments.The pilot application is in the city of Ermoupolis (Syros, Greece), where ten historic buildings from the digital database "HERMES" were selected in the first phase for monitoring. These buildings have an adequate geographical dispersion within the city and belong to different typologies and pathology phases.Buildings owned by the Municipality (or legal entities that the Municipality also participates in), the wider public sector, unknown owners, and well-known owners who gave their consent were selected.Along with the selection of buildings, the choice of parameters monitored in real-time was made. To record the values of the parameters, the basic infrastructure for the collection, transmission, storage, and visualization of data (databases, application server) was developed with the supply, installation, and trial operation of the equipment to evaluate and implement its final installation in the selected buildings.The data are collected in real-time and digital form using special sensors connected and powered by a small unit with a battery installed in the buildings. The collection of these data,and their study will allow the categorization of problems in buildings according to their criticality risk. This enables targeted priority conservation and better use of human, technical and financial resources and sets the foundation for the design of an alert system.The visualization of data in a web application allows remote access to them and thus both their study by external researchers and the information and awareness of citizens and the planning of interventions by the

competent services.Finally, innovative data collection and transmission technologies should allow the system to be further exploited for use in other areas of interest (environment, health, urban mobility).

Keywords: *Monitoring, Architecture, Heritage, Risk, Climate Change, Prevention, Sensors, LoRaWAN*

1 Introduction

Monumental structures are reflections of civilization and the builders who constructed them. They serve as a record of societal and cultural development. The way and timing of a building's conception, construction, use, abandonment, and eventual destruction reveal a society's growth and collapse. According to this perspective, preserving monuments as a part of a location's cultural history is especially significant because it can reveal a lot about the development of our culture and can also attract visitors, producing basic income from tourism. [1] On a grand scale, all cities can be considered "pieces of art." Except that this form of art is transient and cannot be controlled or altered as quickly as other forms of art, like music. Diverse people will eventually have different experiences in the city [2]. "Building is a process that goes on forever, as long as people inhabit an environment. It does not start here with a preconceived design and end there with a finished object. The 'final form' is nothing but fleeting..." writes Ingold, Professor of Anthropology at the University of Aberdeen, in his book 'The Perception of the Environment: Essays in livelihood, dwelling, and skill' [3]. However, humans inhabit a city in a short amount of time compared to the life of the city itself and should not impose predetermined patterns on it and its environment. Humans should adapt to the city, develop it according to the demands of the environment, and bequeath it to the next inhabitants.

An architectural monument has an essential role: to promote human memory and serve as a connecting link between the present and the past. The role is twofold, as the monument answers the problems of the present and preserves the memories of the past. When the monument is placed in the urban environment, it charges memories, ignites the imagination, and creates specific psychology in humans [4], [5]. The monument as a work of art is perceived only in a specific cultural environment, not everywhere, and certainly not always and not by everyone. Heidegger uses the word "Bewahrung," which means "preservation," but it has the same root as the word "Wahrheit," which means "truth," giving preservation the direction of preserving the "truth" of the monument [6]. But the monument, like any building, has a life cycle: It is born, it lives, and it dies, having its own life expectancy that differs significantly from building to building. Engineers are usually trained in the construction of buildings and complete their work when their creation is finished. Then the building begins to play its role, i.e., to accept all stresses and remain stable in its position [7]. The need to safeguard the unique characteristics of historic locations and their monuments is therefore indisputable. Monuments play a crucial role in tourists' aesthetic evaluation in historical and traditional towns where authenticity, originality, time, and scale are fundamental components of their image. The following logical question is, "How can one monitor the monuments of a historical site to safeguard them?"

Ermoupolis is a unique neoclassical ensemble at the national and global level, as the NTUA research records more than 1,200 buildings that have survived to this day. At the same time, since 2013, the Syros Institute, in collaboration with the Municipality of Syros-Hermoupoli, has been digitally monitoring all the historic buildings through the digital database "HERitage Management e-System (HERMES)," which has been distinguished for its innovation by the European Union [8]. HERMeS proved that a large number of buildings (more than 137) currently have serious pathology problems, and some of them may collapse. In the last year, the collapses of historical buildings and monuments in Ermoupoli have increased, attracting the media's attention to the risk of losing National cultural heritage [9]. The purpose of the project “HERitage MONitor” (HER-MON) is the installation of a real-time pathology data collection network of the historic and preserved buildings of Ermoupolis, intending to immediately utilize this data for the early diagnosis of problems and the planning of the necessary intervention actions as a priority. Digital data are collected by autonomous measuring devices (sensors) installed in the selected buildings, transmitted at regular intervals, and stored in a database for further study and visualization. For the needs of the HER-MON, we used innovative technology that allows data transmission over long distances with extremely low energy consumption and without the obligation for user licenses. This reduces the maintenance cost of the equipment and increases its sustainability, expandability, and repeatability in other cities and regions.

2 Methodology

2.1 Preparation and Research

The first phase selected the historical buildings to be studied through the "HERMES" digital database. The selected buildings are geographically dispersed in Ermoupolis; they belong to different typologies and are in various states of pathology. The above data are in possession of the Syros Institute in a geodatabase [10]. The selected buildings are owned mainly by the Municipality (or by legacies in which the Municipality also participates) and by an unknown owner. In this way, the proposed activities in the buildings do not bind owners who would have to allow equipment to be installed in their buildings. To select the historical buildings, we followed a four-step inquiry: (i) Researching in HERMES database (1.200 buildings), (ii) Filtering buildings with different typology, style, year of construction, and conservation state (32 buildings selected), (iii) Spreading the buildings to different geolocation (18 buildings selected), (iv) Visiting the final 18 buildings in-site to understand the challenges (10 buildings selected as shown in Figure 1

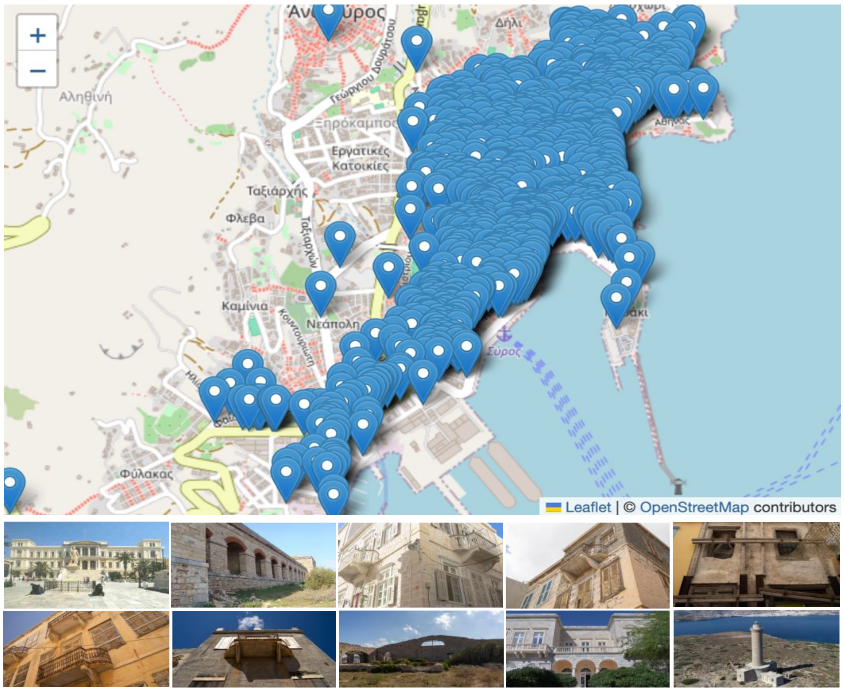

Figure 1. From 1.200 historical buildings (left), ten buildings were selected to host HER-MON sensor devices (right).

Along with the selection of the buildings, the parameters that are monitored in real-time were also chosen. Indicatively, such parameters are temperature, relative humidity,and atmospheric pressure in closed buildings with the aim of early warning about the water inflow. Also, the inclination of the stone structures - especially the facades of the buildings or main structural components, such as the roof beams- the range of selected cracks and gaps, the vibrations in the building, and other elements of their pathology are recorded. It was important to install an essential infrastructure for the data study: visualization applications (databases, application server) were developed. We tested the operation of part of the equipment to evaluate and propose the technological solution that was developed.

2.2 Field Activities

The next step was the study and installation of the telecommunications infrastructure and the structure of the monitoring devices at the selected points. The proposed monitoring network is technologically innovative and does not require a connection to a power network or the Internet (WiFi). Therefore, the installation is direct, without special requirements. The placement was done with the help of specialized staff (from partner "Kudzu") and members/volunteers of the Syros Institute and HERMeS NGO. After the installation was complete, the entire system flow was tested, starting from the collection of the data, sending it in time, storing it, and ending with its presentation. The Kudzu IoT hardware platform measures and monitors the required parameters. It is a modular sensor data collection and transmission system that can operate autonomously in the field for a long time. It consists of three distinct parts that will be described in detail below, the power and communication accessories and the sensor elements, which may vary according to the needs of the installation. It provides excellent flexibility in collecting and transmitting data, significant energy autonomy, low construction cost for mass monitoring and easy installation. It allows the collection of data from different sources (sensors) and their parameterization in the field even after the end of the installation, thus providing the opportunity to enrich the prediction model with new data where this is deemed necessary [11]. Another feature of Kudzu IoT that makes it suitable for this project is the ability to feed from different sources. Thus, it can be modified according to the needs of each installation, allowing its uninterrupted operation for an extended period. It allows operation with battery power or direct power supply where possible. Conclusively, it allows the use of solar power to help supply energy to remote installations where it is impossible to change the energy source periodically. Lastly, Kudzu IoT allows data transmission using the most basic wireless transmission protocols without selecting a predefined mode. Thus, the collected data can be transmitted via WiFi technology where this is available (e.g., homes or public buildings in operation) or by making use of the mobile telephony data network or even using LoRaWAN technology that allows the transmission of data over long distances with minimal energy consumption [12] [13]. It is still possible to transmit data via satellite link, which is not considered necessary in this project but may be helpful in the future for monitoring buildings and monuments that are outside the coverage of traditional telecommunications infrastructure.

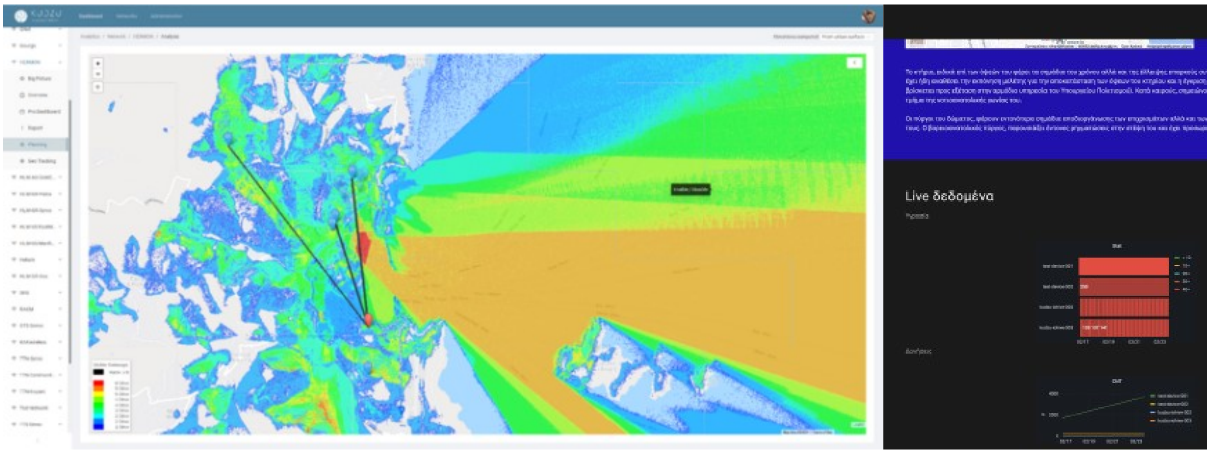

Figure 2. Left: An example of the coverage of the LoRaWAN network for one of the selected historical buildings that the HER-MON monitors. Right: Screenshot of live data from HERMON web portal (www.hermon.gr)

After that, a website was created to present the data in real-time, covering the need to disseminate the project results. It features access control to separate its use between system administrators and external visitors. After the pilot operation, the necessary corrections were made, and the network installation was finalized. The network was announced through the appropriate actions of the Syros Institute, including a Workshop on the topic of Cultural Heritage at Risk (Heritage at Risk) in collaboration with local, national, and European bodies (Municipality, Region, Ministries, Europa Nostra, etc.), an analytical training with the aim informing the local agencies of the island, and in particular the intervention agency (Directorate of Technical Services of the Municipality of Syros-Hermoupoli) regarding the operation and objectives of the monitoring network of historic buildings, and the issuance of a digital guide for the operation and installation of similar networks in other buildings or places.

2.3 Exploitation and Dissemination Activities

In a “Digital Tools in Cultural Heritage” workshop in Syros, Greece, we presented the project's ideas and outcomes to various national and international experts, professionals, architectural heritage activists, and students. We also cooperated with other projects that use IoT for monitoring with sensors similar variables for natural and cultural heritage [14][15], exchanging valuable knowledge.

Figure 3. Dissemination Workshop demonstrated the use of sensors in a variety of projects for cultural heritage

3 Results and Discussion

The project HER-MON successfully addressed several difficulties and challenges in using IoT for monitoring the conservation state of historic buildings at risk:

1. The buildings to be studied are usually off-the-grid (there is no power supply). Collecting data and monitoring their condition has always been exceptionally high in cost, material, services, and maintenance.
2. Many recording devices collect the data locally, so their physical collection is required for their utilization. When the study of the information is delayed, there is no possibility of early intervention.
3. While there is a wide range of accurate monitoring sensors that measure the pathology state of buildings, the industry doesn't offer options for low-cost monitoring systems that are easily accessible and installed in mass on a historical settlement consisting of many buildings.
4. The collected data are usually transmitted via mobile networks within the urban web. Data transmission is expensive (data usage private contracts) and requires high energy consumption, increasing maintenance costs (battery replacement, charging, etc.)
5. Also, the possibility of using mobile networks is limited to the areas where it is covered by cell phone companies, making it impossible to transmit data from remote locations. Especially in the South Aegean region, many important historical monuments are not covered due to insularity.

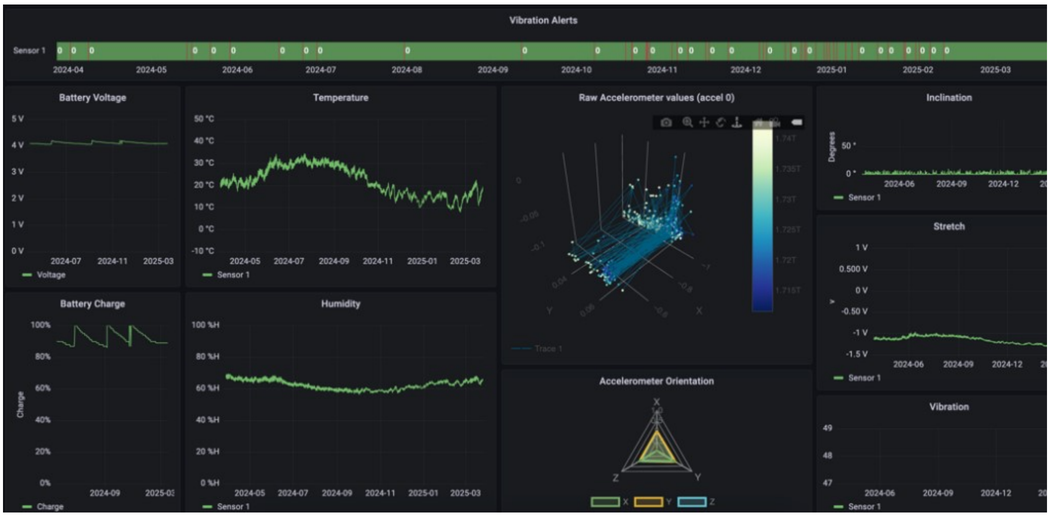

Figure 4. Visualization of selected data of Building n.05: Municipality of Ermoupolis, from March 2024 to March 2025 (1 year).

Until today (March 2025), the installed sensors are still successfully transmitting data. The installation has proven unexpectedly durable for over 2 years, considering some of the sensors are installed on the exterior façade of buildings, exposed to extreme wind and temperature. Collecting these data will help the stakeholders of HERMON to analyze and compare them over several years and calibrate a sensoring pattern that can create an alert system for possible collapse. This way, valuable results will be produced on climate change's effect on these historical buildings, a theory strongly supported by the scientific community [16] [17]. It is stated that the ageing of materials is caused by their inherent physical and chemical properties and environmental conditions [18]. Extreme fluctuations in temperature and heavy rainfall stress the materials systematically. With the climate change observed in the last decades, these phenomena seem to become more intense and frequent. Climate changes in the coming years are expected to bring about:

- ✓ Increase in the frequency of extreme temperatures (single days but also hot episodes lasting at least three days)

- ✓ Increase in the intensity of phenomena (absolute maximum temperatures, amount of rain per hour)
- ✓ Increase in the duration (persistence) of the phenomena
- ✓ Time shift of the appearance of the phenomena [19]

The already burdened buildings will have to deal with these new conditions, even in a state of reduced strength. HERMON could become a helpful technology tool that senses the changes, records the data, and informs the stakeholders to take immediate action if necessary.

4 Conclusions and future work

The project's general goal is to protect the man-made cultural environment of Ermoupolis through research and utilization of measurement data concerning the alteration of the city's historical buildings and monuments. To achieve the goal, the live monitoring of the pathology of ten (10) historic and preserved buildings of Ermoupolis is required, with the study and installation of an innovative network of sensors. Data collection in real-time and in digital form allows early prediction of problems. Analyzing these data will also enable categorizing issues according to their criticality. This way, priority-targeted rehabilitation, and the best utilization of human, technical and financial resources become possible. At the same time, the appropriate selection of buildings to be the most representative in terms of date of construction, problems and alterations, location in the city, and cultural value, allows the drawing of valuable conclusions for the whole of Ermoupolis. Based on these records, one can predict what to expect from all similar buildings. The visualization of the data in an online application allows remote access to them and thus both their study by external researchers as well as the information and awareness of citizens. An essential objective of the project is training the competent intervention service in dangerous buildings, namely the Technical Services Directorate, whose engineers will learn how to monitor the network and intervene when necessary. Finally, innovative data collection and transmission technologies allow the system to be further exploited for use in other areas of interest (environment, health, urban mobility).

Figure 5. Installation of a "HERMON" device in a 19th-century wooden beam on a roof

Future work includes research and analysis of the collected data to support the correlation between the increased rhythm of pathology problems in historical buildings and the intense environmental conditions because of climate change [20].

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