UNDERSTANDING AND CONTROLLING THE ENVIRONMENTAL QUALITY IN MUSEUMS THROUGH IoT: AN INTERNATIONAL RESEARCH AND PRACTICE COLLABORATION TO SUPPORT MUSEUMS IN THE IMPLEMENTATION OF CLIMATE ACTION

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MUSEION project aims at developing an integrated IoT based platform for the sustainable management of environmental control and adaptation to climate change of museum collections. The MUSEION solution will thus provide the optimization of resources such costs, energy, staff workload, while contributing to carbon footprint reduction. This solution is a replicable IoT-based system, which will solve the problems of real objects in real conditions (sustainable environmental control and adaptation to climate change). It will consider the main components of the museum system that influence its optimal climate (i.e, museum itself, artworks and visitors) and will continuously monitor and allow visualization of environmental and air quality markers. The monitoring reports will be elaborated by a software designed to real-time calculate the overall Indoor Air Quality (IAQ) Index. The main advantage provided by the MUSEION system consist in the simultaneous monitoring and evaluation of the environment quality and its impact on various artefacts in various conservation condition.

Keywords: IoT, environmental control, museum collections.

MONITORING INDOOR ENVIRONMENTAL QUALITY IN MUSEUMS

According to UNESCO, the current estimated total number of museums worldwide is around 104,000, with more than 60% in Europe and North America. More than 11,000 museums are located in Eastern Europe. For example, by 2019 there was a total of 791 museums and public collections in Romania, while 662 museums operated in Hungary in 2020, according to Statista (https://www.statista.com/). The survey made within the European project Memori (https://memori.nilu.no/) on indoor air quality management in European museums found that the majority of the institutions have not measured airborne pollutants and do not know the damages related to poor environmental quality conditions. Moreover, there are a number of other factors that need to be monitored indoor in public buildings such as museums and libraries. In addition to the effects on health and well-being of the staff and visitors, there is the costly and considerable damage on cultural objects that museum and library own and have to keep in functional conditions as long as possible.

Outdoor pollution and indoor pollution combined with climate change effects create an environment increasingly harmful for museum and library collections. Climate change affects global temperature and precipitation patterns, thus influencing the intensity and, in some cases, the frequency of extreme environmental events, such as forest fires, hurricanes, heat waves, floods, droughts, and storms. The expected impact

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of climate change on built heritage is well-documented but one should also consider the changing indoor conditions (Leissner *et al*., 2015). Additionally, each material, depending on its preservation conditions, reacts differently to environmental parameters. Hence, due to the number of parameters and variables, and the synergy of their action, the control of indoor environment is a more complex problem than ever considered and needs a complex approach. It is therefore of vital importance to understand which pollutants and in what conditions cause negative effects to design effective monitoring systems enabling for preservation management supported and informed by knowledge resources.

To date, continuous measurement of climate and air quality parameters is not listed among those technologies conventionally used for preventive conservation in museums. Climate change and growing (mass) tourism are expected to strongly impact the preservation conditions of cultural heritage in the next decades, while a decrease in economic resources for heritage conservation is expected (Colette, 2007). To protect our heritage from these new conditions, adequate mitigation actions are required.

MUSEION Solution for Continuous Measurement and Understanding Climate and Air Quality Impact on Museum Objects

In this context, MUSEION aims at developing a digital platform for continuous environmental and AQ control as a smart decision support tool (Figure 1). The MUSEION platform will collect data from indoor sensors and transfer them for storage in the cloud through an IoT gateway. The real-time data will be further processed and visualized. An in-house developed software will calculate the index of air quality (IAQ) for all types of materials/artefacts enabling the conversion of environmental measurements into valuable judgements that support the analysis of the preservation conditions and identify the hazards that are endangering an artefact / a collection. IAQ index will assist museum professionals to implement suitable mitigation actions.

A pilot study for designing and optimizing the platform was selected, namely the Memorial houses "Fanny & Liviu Rebreanu" and "Ion Minulescu & Claudia Millian" owned by the National Museum of Romanian Literature. The collections in the two apartments, which occupy the entire second floor of a building from the interwar period, include literary documents, letters, manuscripts, unpublished photographs and an impressive collection of paintings and sculptures. The building is located in a central area of Bucharest, very trafficked.

MUSEION Architecture

Due to the extensive use of wireless sensor networks in all aspects of daily life, the project team tested different configurations for these networks' types in scenarios that include a sensor-based system used for monitoring air quality, weather conditions and environmental factors. The system is powered by solar panels and it can operate independently. The system architecture (Figure 2) is composed of two monitoring stations (Figure 3): the one placed outdoor monitors temperature, relative humidity, pressure, carbon dioxide, nitrogen dioxide, sulphur dioxide, while the indoor station monitors brightness, temperature, relative humidity, volatile organic compounds, ozone, ammonia, hydrogen sulfide, vibrations and dust particles. The information is gathered wirelessly in a Gateway and sent via MQTT to a Broker. Once the data is received by the Broker, it is stored in the InfluxDB a database created to store information for continuous parameter analysis.

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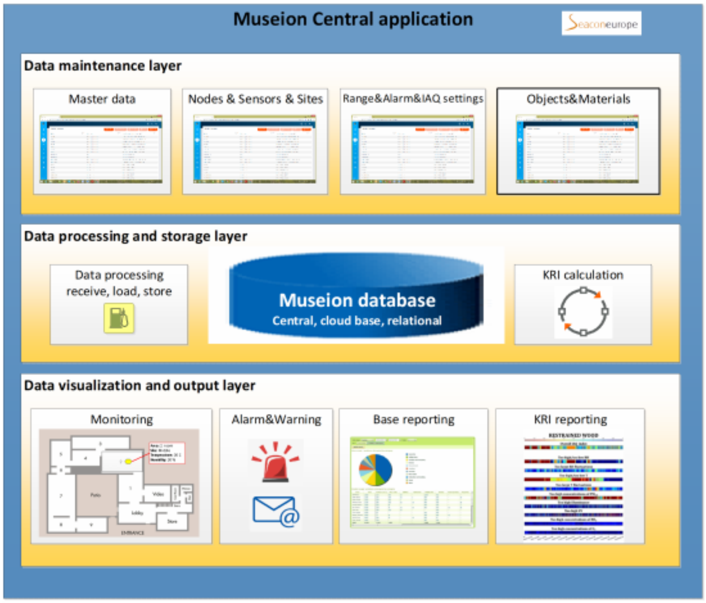

Figure 1. MUSEION system concept

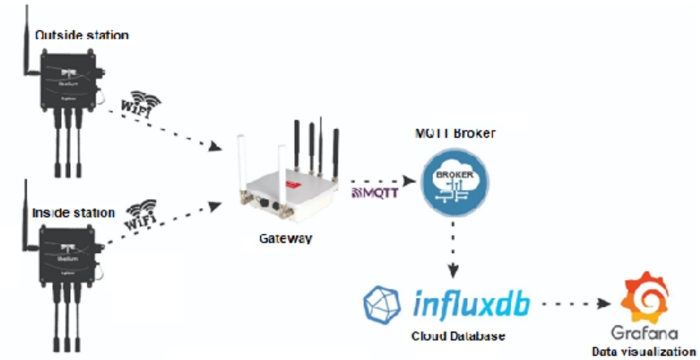

Figure 2. Architecture of the system

The monitored parameters saved in Grafana Cloud can be directly analysed with the use of charts, tables, and graphs using Grafana, an open-source web data visualization tool, which allows for the representation of the parameters. A dashboard especially designed for MUSEION project is illustrated in Figure 4. In this platform, thresholds for each parameter may also be established. In order to reduce the environmental risk to artefacts, museum caretakers are immediately informed when undesired situations occur, for example, when nominal values exceed the accepted values.

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Figure 3a. Outdoor station installed on the balcony

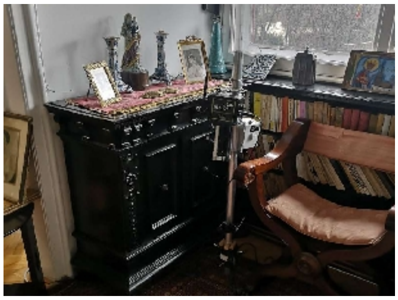

Figure 3b. Indoor station installed in one of the apartment's rooms

Figure 4. Example of Grafana dashboard

Data Analysis and Visualization

The software application that supports the analysis and visualization of IAQ index (Anaf *et al*., 2018) using real measurement data is currently under development. It consists of database, web client user interface and communication, and data processing subsystem with complex functionality:

- Gather, store and process data; area description (facility and premises, measurement points also on the blueprint);
- Object and material description (including location and sensitivity against environmental parameters (from very low to very high-sensitivity) including photo; sensor network description (with measured characteristics) (Figure 5);
- Calculation parameter data storage (categories, intervals, risk levels); sensor network data reception and storage (near real time approx. 20 minutes);
- Key Risk Indicator (KRI) (Anaf *et al*., 2018) calculation which is multi-step algorithm giving a number between 0 and 1 (0 = no damage, 0.05 = negligible damage, 0.25 = low damage, 0.5 = moderate damage, 0.75 = high damage, 1 = extremely high damage) that indicate the risk level each monitored material/object based on its material and conservation condition.

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The calculation level is KRI factors, area / material / object/ sensitivity/ hour, the lowest level could be aggregated on higher level (day, season, facility etc.)

Figure 5. Example of location, object and material description

Data visualization includes (reporting examples are illustrated in Figures 6, 7):

- Dashboard with facility blueprint and last measures. By clicking on the measurement point, users can view the last received measurements and then backward values for certain intervals.
- Sensor measurement reports, which show the incoming measured data in different groupings, filters and display methods.
- KRI result reports showing the incoming measured data in different groupings, filters with coloring using different display methods.

FINAL REMARKS

For the MUSEION pilot study the continuous real-time indoor environmental quality monitoring is fundamental for an active management strategy. The collections are kept and exhibited in apartments in which the environmental quality conditions were mainly intended for human health and comfort. These conditions may be different from what is required to protect artefacts. Moreover, different artefacts (i.e., paper, textile, paintings and photographs) require different environmental conditions. Museion system is therefore essential to understand the dynamics of the different air quality factors and climate parameters and how to control them to achieve safe environment conditions while providing a healthy and safe facility for employees and visitors.

A workshop has been organized within the ICAMS 2022 Conference with various museum professionals and numerous stakeholders, potential users of Museion system, to get feedback and optimize the performance of the actual system.

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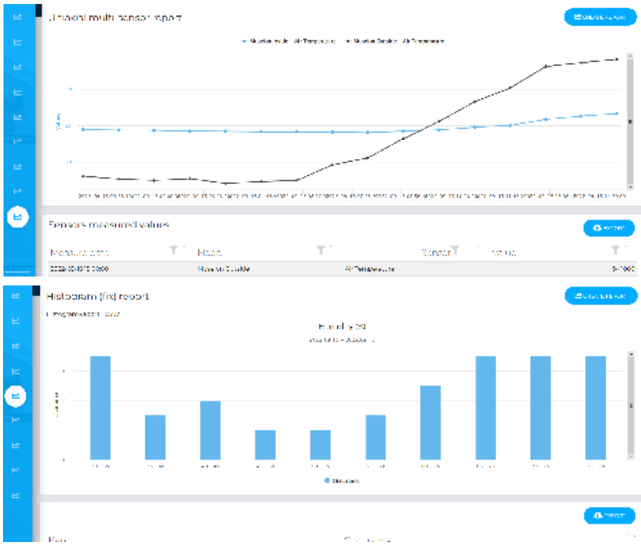
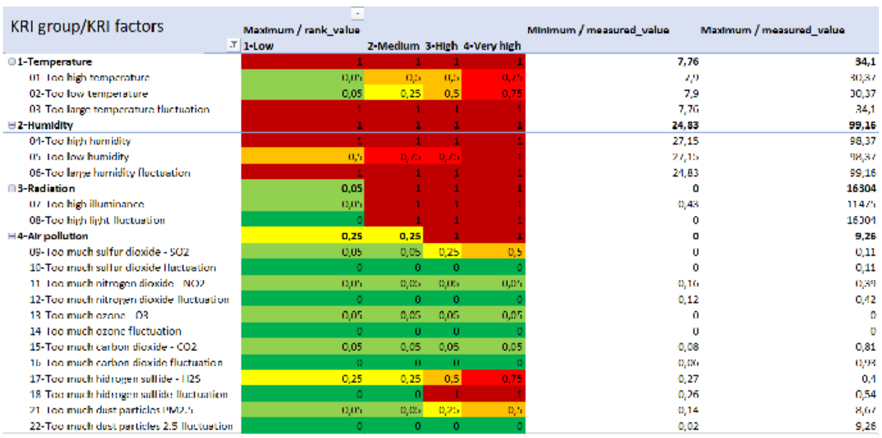


Figure 6. Monitoring reports



KRI group/KRI factors	Maximum / rank_value 1-Low	2-Medium	3-High	4-Very high	Minimum / measured_value	Maximum / measured_value
1-Temperature	**1**	**1**	**1**	**1**	**7,76**	**34,1**
01-Too high temperature	0,05	0,5	0,5	0,75	7,9	30,37
02-Too low temperature	0,05	0,25	0,5	0,75	7,9	30,37
03-Too large temperature fluctuation	1	1	1	1	7,76	34,1
2-Humidity	**1**	**1**	**1**	**1**	**24,83**	**99,16**
04-Too high humidity	1	1	1	1	27,15	98,37
05-Too low humidity	0,5	0,75	0,75	1	27,15	98,37
06-Too large humidity fluctuation	1	1	1	1	24,83	99,16
3-Radiation	**0,05**	**1**	**1**	**1**	**0**	**16304**
07-Too high illuminance	0,05	1	1	1	0,43	11475
08-Too high light fluctuation	0	1	1	1	0	16304
4-Air pollution	**0,25**	**0,25**	**1**	**1**	**0**	**9,26**
09-Too much sulfur dioxide - SO2	0,05	0,05	0,25	0,5	0	0,11
10-Too much sulfur dioxide fluctuation	0	0	0	0	0	0,11
11-Too much nitrogen dioxide - NO2	0,05	0,05	0,05	0,05	0,16	0,39
12-Too much nitrogen dioxide fluctuation	0	0	0	0	0,12	0,42
13-Too much ozone - O3	0,05	0,05	0,05	0,05	0	0
14-Too much ozone fluctuation	0	0	0	0	0	0
15-Too much carbon dioxide - CO2	0,05	0,05	0,05	0,05	0,08	0,81
16-Too much carbon dioxide fluctuation	0	0	0	0	0,06	0,93
17-Too much hidrogen sulfide - H2S	0,25	0,25	0,5	0,75	0,27	0,4
18-Too much hidrogen sulfide fluctuation	0	0	1	1	0,26	0,54
21-Too much dust particles PM2.5	0,05	0,05	0,25	0,5	0,14	8,67
22-Too much dust particles 2.5 fluctuation	0	0	0	0	0,02	9,26

Figure 7. KRI result report

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