The Environmental Monitoring Campaign of the Museum of the Faculty of Archaeology of the Sohag University (Egypt)

(Article begins on next page)

Title: The Environmental Monitoring Campaign of the Museum of the Faculty of Archaeology of the Sohag University (Egypt)

Authors:

Ahmed Elsayed
Department of Applied Science and Technology, Politecnico di Torino, Torino, Italy

Luca Lombardo
Dept. of Electronics and Telecommunications, Politecnico di Torino, Torino, Italy

Marco Parvis
Dept. of Electronics and Telecommunications, Politecnico di Torino, Torino, Italy

Emma Angelini
Department of Applied Science and Technology, Politecnico di Torino, Torino, Italy

Sabrina Grassini
Department of Applied Science and Technology, Politecnico di Torino, Torino, Italy

DOI:

The Environmental Monitoring Campaign of the Museum of the Faculty of Archaeology of the Sohag University (Egypt)

Ahmed Elsayed
Department of Applied Science and Technology
Politecnico di Torino
Torino, Italy
Department of Conservation, Faculty of Archaeology
Sohag University
Sohag, Egypt
ahmed.elsayed@polito.it

Luca Lombardo
Department of Electronics and Telecommunications
Politecnico di Torino
Torino, Italy
luca.lombardo@polito.it

Marco Parvis
Department of Electronics and Telecommunications
Politecnico di Torino
Torino, Italy
marco.parvis@polito.it

Emma Angelini
Department of Applied Science and Technology
Politecnico di Torino
Torino, Italy
emma.angelini@polito.it

Sabrina Grassini
Department of Applied Science and Technology
Politecnico di Torino
Torino, Italy
sabrina.grassini@polito.it

***Abstract*—This paper describes a complete solution to assess the environmental conditions and the atmosphere aggressiveness in a museum indoor environment. The monitoring system is based on a wireless network composed of small sensors, designed to satisfy the requirements for their employment in the Cultural Heritage field. The sensors are stand-alone devices able to measure temperature and relative humidity for long times, connected through a wireless link to a small receiver for routing data to a cloud system. Cloud data can be accessed from everywhere in real time through smart-phones and easily downloaded for further analyses. The proposed system also contains a set of reference specimens coated with a Cu nanostructured films deposited by plasma sputtering located close to the sensors to assess the atmosphere aggressiveness. The results of a monitoring campaign lasted for one year in the museum of the Faculty of Archaeology of the Sohag University in Egypt, are discussed.**

***Index Terms*—Environmental monitoring, smart sensors, thin films, atmospheric corrosion**

I. Introduction

This paper presents the results of the environmental monitoring campaign carried out in the Museum of the Faculty of Archaeology of the Sohag University in Egypt.

The Museum of the Faculty of Archaeology is the second museum in Sohag after the National Museum of Sohag Governorate. The museum displays a private collection donated in 1979 by Dr. Amin Awad, a dermatologist whose desire was to open an educational museum for the students. In 2005 the museum opened officially to the public. The collection is hosted in a single large room ($8.50\ \mathrm{m} \times 13.25\ \mathrm{m}$, fig. 1) and features 674 pieces of different materials including, for example, 55 pieces in organic materials such as textile, paper, leather, wood, bone and ivory (e.g. some paper fragments are shown in fig. 2A). However, most of the pieces are made with inorganic materials such as stone, pottery and metals (e.g. fig. 2B and 2D), including a large number of copper, silver and bronze coins (e.g. fig. 2C). Moreover, these artefacts are dated from different ages, as 15 pieces from the ancient Egyptian age, 90 from the Greek-Roman age, 30 from the Christian age and 539 from the Islamic age. The artefacts are displayed in 26 different showcases, made of wood and glass, located in different positions in the room. In particular, there are 9 wall showcases ($75\ \mathrm{cm} \times 75\ \mathrm{cm} \times 50\ \mathrm{cm}$) and 17 room showcases in four different sizes ($75\ \mathrm{cm} \times 75\ \mathrm{cm} \times 65\ \mathrm{cm}$, $80\ \mathrm{cm} \times 80\ \mathrm{cm} \times 80\ \mathrm{cm}$, $150\ \mathrm{cm} \times 80\ \mathrm{cm} \times 25\ \mathrm{cm}$ and $145\ \mathrm{cm} \times 80\ \mathrm{cm} \times 30\ \mathrm{cm}$). All of them were painted with varnish and they use velvety textiles inside the showcases for displaying. The museum has some problems due to the room location which is exposed to the sun all the time (being it arranged on the last floor of the faculty building). Moreover, there are two air conditioning systems inside the museum and they typically are active during emploees' work time, from

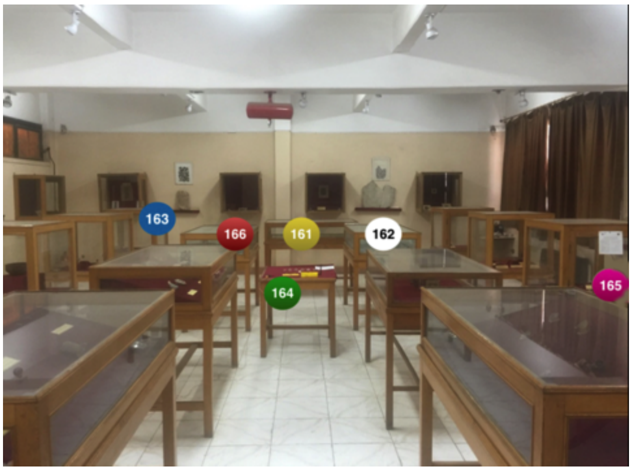

Fig. 1. The exhibition room of the Museum of the Faculty of Archaeology of the Sohag University (Egypt). The numbers indicate the position of the sensors during the environmental monitoring campaign.

Fig. 2. Some of the artefacts displayed in the museum featuring different materials: (A) paper fragments, (B) metallic pieces together the reference specimens coated with nanostructured Cu, (C) metallic coins and (D) pottery fragments.

8.30 until 14.00. For this reasons, the microclimate of the museum is quite unstable and sometimes the environmental conditions can be dangerous for the artefacts, especially the organic ones.

Furthermore, Sohag is a city located in the desert of Egypt ($26°33'N31°42'E$) and is affected by seasonal temperature changes. The weather in Sohag is very hot in summer with average temperatures in the range of 40-43 $°C$, and cold in winter with temperatures in the range of 12-15 $°C$, with non-frequent peaks of few degrees above zero.

These extreme changes coupled with the circadian cycles, require a continuous monitoring of the environmental parameters close to the artefacts as a safeguard strategy for ensuring long-lasting conservation of the collections displayed in the Sohag Museum [1], [2]. Moreover, particular attention

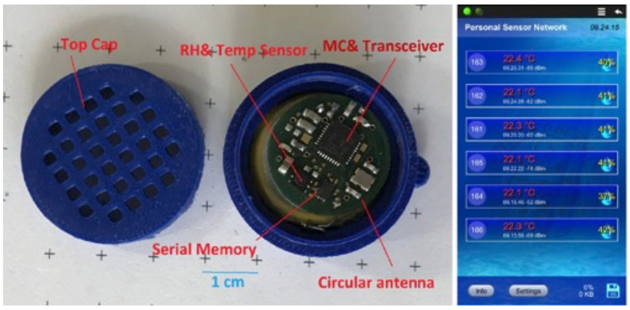

Fig. 3. The sensor for T and RH measurements employed in the Sohag Museum monitoring campaign (left) and an example of data shown in real-time on the smart phone of a museum curator (right).

has to be paid to the organic materials and the metallic artefacts whose degradation is significantly affected by the environmental conditions. According to the ISO 11844-3:2006 the indoor corrosivity toward metals and alloys can be assessed by measuring from one side, temperature (T) and relative humidity (RH), and from the other, airborne contaminants, such as gases and particles [3].

The environmental monitoring approach designed and deployed in the Sohag Museum campaign is therefore based on two actions:

- the deployment of a cloud-based sensors network capable of recording T and RH close to the artefacts, as shown in fig. 1;
- the deployment of some reference specimens coated with Cu nanostructured thin films for assessing the atmosphere aggressiveness, as shown in fig. 2B.

The campaign started in August 2016 and lasted for about one year allowing the museum curators to obtain information on the night/day and seasonal fluctuations of the microclimate parameters and on the aggressiveness of the atmosphere inside the display showcases.

II. Materials and Methods

Several devices are nowadays available on the market to monitor the environmental parameters and to detect the presence of gases and pollutants in indoor environments. However, most of these devices do not satisfy the requirements for their employment in the Cultural Heritage field, and often do not have the required sensitivity for detecting very low concentrations of gaseous pollutants in the air, as requested by the museum curators [4]–[7]. Among these requirements there are: minimal invasiveness (no cabling, small dimensions etc.) in order to avoid impairing the visitor fruition, long operative life, easiness of deployment and maintenance, reliability in different scenarios and low cost.

Moreover, the use of T and RH sensors positioned close to a set of reference metallic specimens allows to monitor the environmental parameters, and to assess, in a short time, the effect of aggressive atmospheric pollutants on the degradation of metallic artefacts [8].

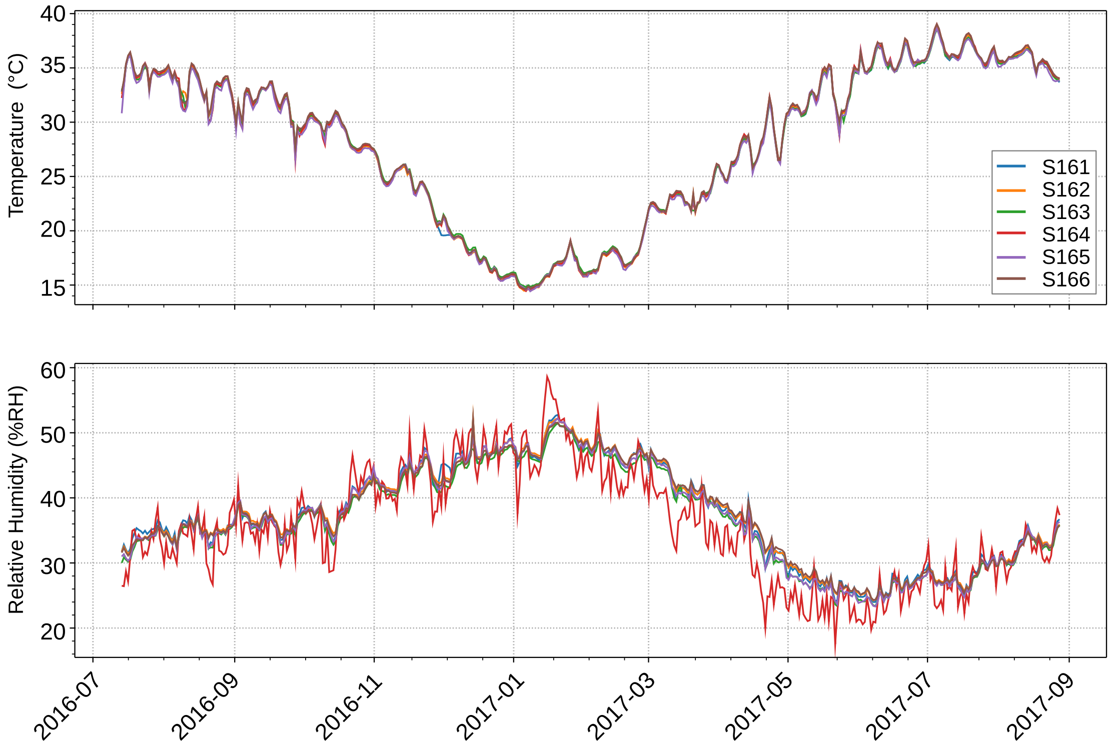

Fig. 4. T and RH measurements collected for one year during the Sohag Museum monitoring campaign from the smart sensors inside (S161, S162, S163, S165, S166) and outside (S164) the showcases.

A. *T and RH smart sensors*

A multi-point monitoring system, based on a network of small autonomous sensors, was employed. The cloud-based system was designed and developed by the researchers of the Department of Electronics and Telecommunications of Politecnico di Torino [9], [10] to satisfy the requirements of the museum curators.

The system is based on a network of small sensors ($\varnothing 35$ mm $\times$ 15 mm) connected through a wireless link to a small receiver. The sensors, shown in fig. 3 (left) are designed to measure T and RH every 15 minutes and to send the measurements to a receiver for routing the data to a cloud system. Once the measured data are stored in the cloud, they can be accessed in real time from everywhere through smartphones (fig. 3 right), and they can be easily downloaded for further analyses and remain available after their capture for backtracking of any abnormal condition.

The sensor sensing element is a Sensirion $SHT21$ device, that measures temperature with a typical uncertainty of ± 0.3 $°C$ and relative humidity with a typical uncertainty of $\pm 2\%$ RH. A total of five sensors were positioned in five showcases (codes S161, S162, S163, S165, S166) where organic materials and metallic artefacts are displayed, as shown in fig. 1. One sensor (code S164) was positioned in the exhibition room, outside the showcases for comparison.

B. *Cu reference specimens*

Cu nanostructured thin films are characterized by a quite high susceptibility to atmospheric corrosion so they can be used for assessing the aggressiveness of indoor atmospheres in short times.

The film nanostructure leads to an high reactive surface area and allows detecting the presence of atmospheric corrosion products at nanoscale level.

The reference specimens are pure copper sheets (99.96% purity) in size of 30 mm $\times 30$ mm $\times 0.45$ mm. The specimens were polished with abrasive paper (from $320 - 1000$ grit), cleaned with ethyl alcohol in an ultrasonic bath for 5 minutes and dried with acetone.

The reference specimens were coated with Cu nanostructured thin films (about 200 nm thick) deposited by plasma sputtering. Deposition processes were performed in a lab-scale parallel plate reactor, using a Cu target (99.99% purity) and Ar ($99,99\%$ purity) as discharge gas. The Cu target was positioned on the cathode electrode connected to a RF power supply (13.56 MHz) through an impedance matching unit. Before any deposition the chamber was evacuated at a pressure of 1.5×10^{-7} mbar to avoid any surface contamination, and the Cu target was cleaned by pre-sputtering for approximately 15 min at 50 W. The depositions were performed at room temperature ($T_f < 70$ $°C$), with an Ar pressure of 1.3×10^{-2} mbar and an input power of 300 W.

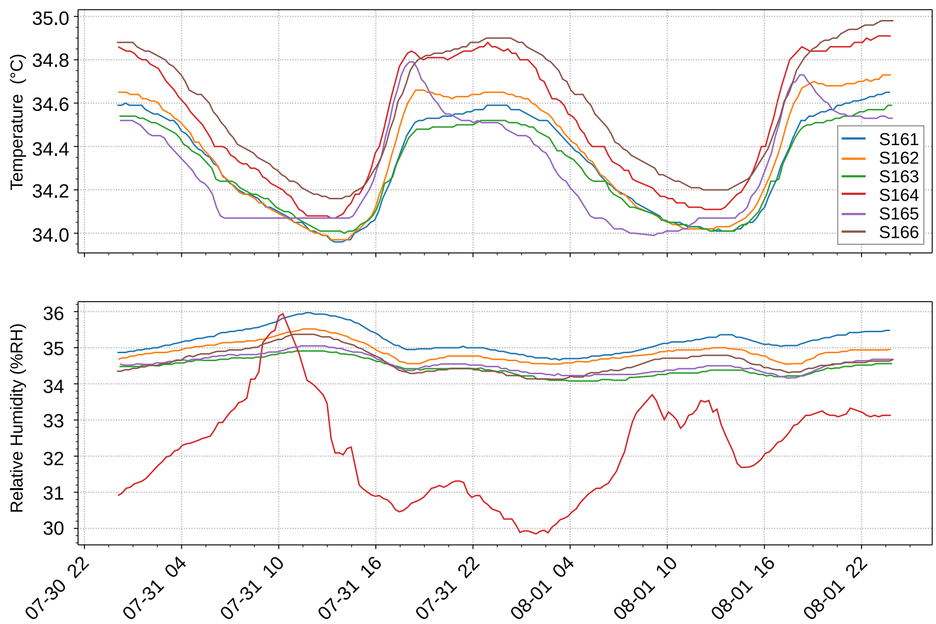

Fig. 5. T and RH measurements collected for about two days in summer from the smart sensors inside (S161, S162, S163, S165, S166) and outside (S164) the showcases.

Chemical and morphological characterization of the Cu reference specimens were performed by means of a Field Emission Scanning Electron Microscope (FESEM) (Merlin Zeiss) equipped with a quantitative SSD probe (Oxford x-act), as a function of the exposure time to the museum indoor atmosphere.

III. Result and Discussion

Temperature and relative humidity are strictly related for an indoor space such as a building or a museum showcase: an increase in temperature leads to a decrease in relative humidity, and viceversa. The generally accepted T and RH values required for preserving collections in museum indoor environments are for temperature, $20 \pm 2\ ^{\circ}C$ and for relative humidity $50{\pm}3\%$ RH, on a daily basis. Moreover, the climatic conditions of the museum's country have to be considered, as wells as the sudden T and RH fluctuations which may increase the degradation rate of artefacts.

The microclimatic measurements collected during the one-year monitoring campaign, by the six sensors positioned inside and outside the showcases of the Sohag Museum, are shown in Fig. 4.

Changes in the microclimatic conditions between summer and winter may be observed. As expected high RH fluctuations are detected in the exhibition room (S164), where peaks of 60% of relative humidity are reached during winter, while more stable microclimatic conditions are present inside the museum showcases. Inside the showcases, T decreases from an average value of $35\ ^{\circ}C$ in summer, to a minimum average value of $15\ ^{\circ}C$ during the winter season. Meanwhile, RH increases from 35% RH to about 50% RH. Recently, the Australian Heritage Collections Council developed the guidelines for the environmental controls in cultural heritage institutions. They emphasize the need of the evaluation of the local climate conditions and of the adoption of showcases, which might minimize the reliance on full air-conditioning, in order to develop appropriate conservation strategies. According to these guidelines [11], the requested climatic conditions are divided in three categories as a function of T and RH values on daily basis:

- hot humid climates: 22-28 $^{\circ}C$, 55-70% RH
- hot dry climates: 22-28 $^{\circ}C$, 40-60% RH
- temperate climates: 18-24 $^{\circ}C$, 45-65% RH.

Following this classification, Egypt can be considered an hot dry climate country, consequently the environmental conditions inside the Sohag Museum are in ther proper range, with lower relative humidity values. The microclimate inside the showcases can be considered quite safe for the long-time preservation of the museum collections. Fig. 5 and 6 show the typical night/day T and RH fluctuations detected in summer and winter, respectively. The plotted data can be

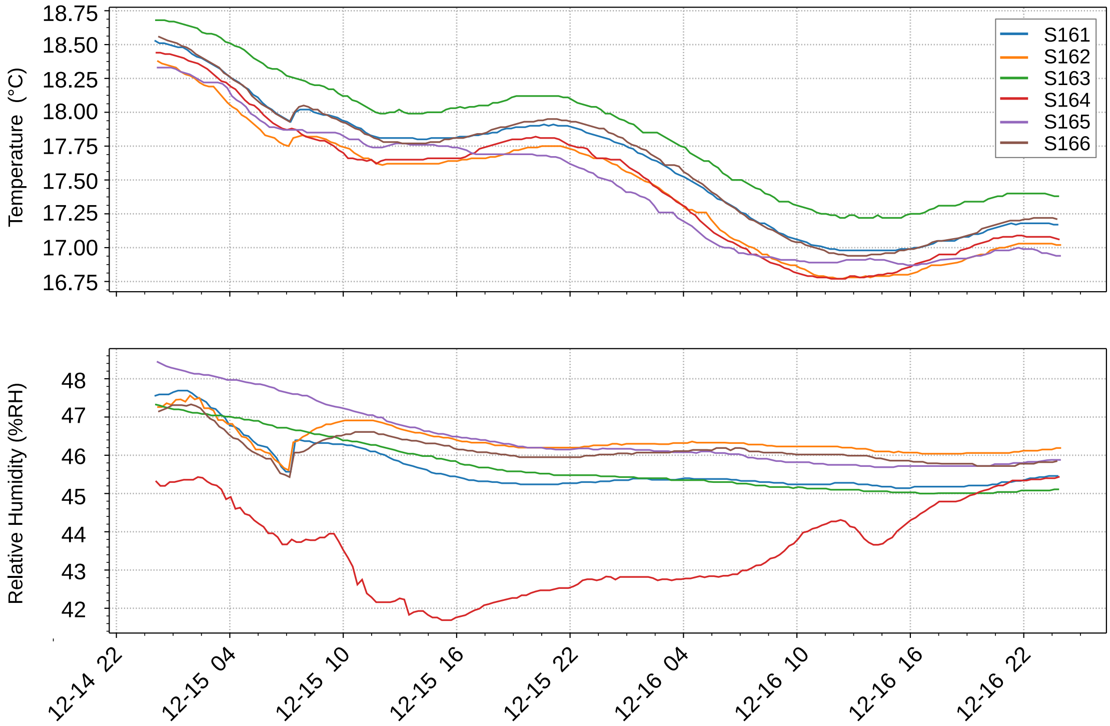

Fig. 6. T and RH measurements collected for about two days in winter from the smart sensors inside (S161, S162, S163, S165, S166) and outside (S164) the showcases.

considered representative of the T and RH behavior during the two seasons.

Fig. 5 shows an average temperature change, less than $1\ ^{\circ}C$, during the circadian cycle detected by the sensors with similar results recorded by the devices positioned both inside and outside the showcases. The temperature variation detected by sensor S164, however, proceeds faster due to the absence of the low-pass filter provided by the showcases. The relative humidity trend recorded in the same days shows a completely different behavior. Inside the showcases, the RH changes are negligible (from 34.5% to 36%), with respect to the RH variation of about $\pm 5\%$ in the exhibition room. This remarkable difference may be related to the air conditioning system, which however does not affect the environment inside the well-sealed showcases.

During winter, as shown in fig. 6, the temperature is lower, with an average value of 18-20 $^{\circ}C$ with negligible variations between night and day. The temperature is a little bit lower during the day because of the air conditioning system that does not work during the night, like in summer. The relative humidity, even if higher with average values of about 46-48% RH, is more stable inside the showcases than in the exhibition room. However, the RH values are still inside the range requested by the guidelines for the conservation of multi-materic artefacts in indoor environments. Moreover, the RH stability confirms that the showcases are well sealed and therefore the relative humidity inside may be attributed to the periodical opening performed by the museum curators (as confirmed by the peaks detected by sensors S163 and S166 which were opened at 15^{th} December 2016 for maintenance).

The surface characterization of the Cu reference specimens allows to confirm that the showcase microclimatic conditions are appropriate for the conservation of the museum collection. Slight corrosion attacks can be observed at microscopic level on the Cu nanostructured films exposed inside the showcase as shown in the FESEM images of fig. 7.

The degradation of the Cu films proceeds slowly in summer; as a matter of facts only few corrosion products are detected on the reference specimen surface after the two first months of the monitoring campaign (August-September 2016). During winter, the degradation proceeds quite slowly, no significant corrosion is detected after six months of exposure to the showcase atmosphere. Due to the higher variation of the climatic conditions and in particular to the faster RH fluctuation, the degradation proceeds faster for the Cu nanostructured reference specimens exposed in the exhibition room (fig. 7).

The chemical analysis performed by means of the quantitative SSD probe on the corrosion products on the surface of the reference specimens reveals that they are mainly composed of copper sulphides and copper oxide. (fig. 8). The presence of quite high amounts of sulfur in the corrosion products is due to the presence of sulfur-containing air pollutants in the museum atmosphere. Moreover, the sulfur content detected inside the showcases can be due to the use of velvet textiles for displaying the artefacts. The sulfur amount detected in the corrosion products increases four times after six months as a consequence of the long-term exposure and the changes of the museum climate from summer to winter, confirming that a slight degradation is still in progress.

IV. Conclusions

The environmental monitoring campaign carried out for one year in the Sohag Museum allowed both to assess the feasibility of the proposed approach as well as allowed the validation of the cloud-based sensor network developed at Politecnico di Torino.

The involvement of the museum curators was very important both in the design of the monitoring system as well as in the development of the future conservation strategies which will be designed to ensure the long-lasting preservation of the museum collections.

From the experimental findings it appears that the collections are displayed in quite safe conditions in properly sealed showcases and that the relative humidity is the factor that influences to the greatest extent the conservation state of the artefacts, so special precautions must be taken during the opening of the showcases. Furthermore, notwithstanding the slight corrosion of the reference specimens, the installment of an air filtering system for air pollutants and the use of more stable materials for displaying the artefacts will be considered to reduce the amount of sulfur-containing compounds in the indoor atmosphere.

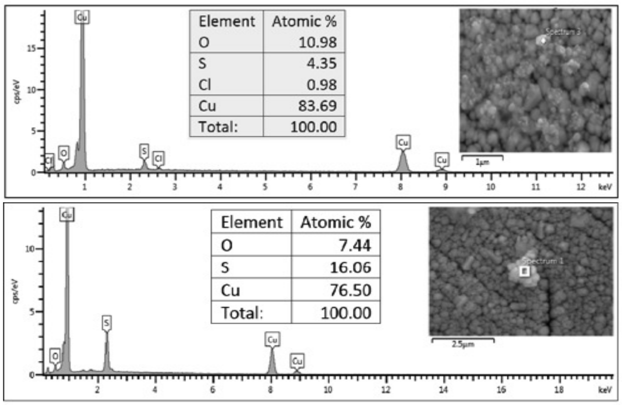

Fig. 8. Chemical composition of the corrosion products detected by the quantitative SSD probe on the Cu reference specimens positioned near sensor S162 after 2 months (top) and 6 months (bottom) of exposure to the showcase atmosphere, respectively (as an example).

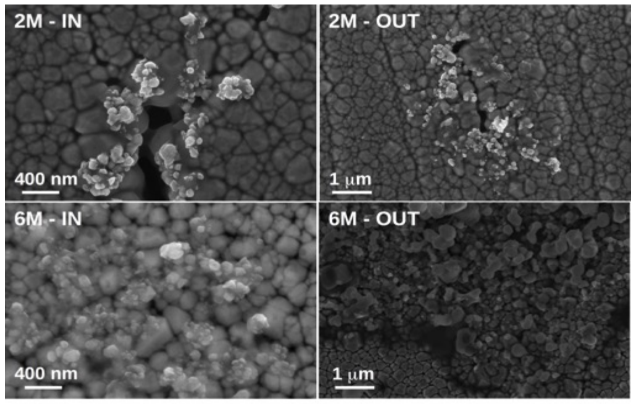

Fig. 7. FESEM images of the Cu nanostructured reference specimens exposed for 2 and 6 months inside (left) and outside (right) the showcase close to sensor S162 (as an example).

References

[1] C. M. Grzywacz, “Monitoring for gaseous pollutants in museum environments”, Getty Publications, 2006.

[2] Washington, DC: National Park Service “The Museum Handbook Part I: Museum Collections” available at https:// www.nps.gov/ museum/ publications/ MHI/CHAPTER4.pdf, last checked on 04-06-2018.

[3] ISO 11844-3 Corrosion of metals and alloys - Classification of low corrosivity of indoor atmospheres, Part 3: Measurement of environmental parameters affecting indoor corrosivity, 1st, 2006.

[4] Z. Guo, P. Chen, H. Zhang, M. Jiang, C. Li, “IMA: an integrated monitoring architecture with sensor networks”, IEEE Trans. Instrum. Meas., vol. 61(5), pp. 1287-1295, 2012.

[5] J. Schmalzel, F. Figueroa, J. Morris, S. Mandayam, R. Polikar, “An architecture for intelligent systems based on smart sensors”, IEEE Trans. Instrum. Meas., vol. 54 (4), pp. 1612âĂŞ1616, 2005.

[6] C. Grzywacz, “Monitoring for gaseous pollutants in museum environments”, Getty Publications, 2006.

[7] T. Prosek, M. Kouril, M. Dubus, M. Taube, V. Hubert, B. Scheffel, Y. Degres, M. Jouannic, D. Thierry, “Real-time monitoring of indoor air corrosivity in cultural heritage institutions with metallic electrical resistance sensors”, Studies in Conservation, vol. 58(2), pp. 117-128, 2013.

[8] E. Angelini, F. Civita, S. Corbellini, D. Fulginiti, A. Giovagnoli, S. Grassini, M. Parvis, “Innovative monitoring campaign of the environmental conditions of the Stibbert museum in Florence”, Applied Physics A, vol 122(2), pp. 1-12, 2016.

[9] S. Corbellini, E. Di Francia, S. Grassini, L. Iannucci, L. Lombardo, M. Parvis, “Cloud based sensor network for environmental monitoring”, Measurement, vol. 118, pp.354-361, 2018.

[10] L. Lombardo, S. Corbellini, M. Parvis, A. Elsayed, E. Angelini, S. Grassini, “Wireless Sensor Network for Distributed Environmental Monitoring”, IEEE Transactions on Instrumentation and Measurement, vol. 67(5), pp. 1214-1222, 2017.

[11] S. Brown, I. Cole, V. Daniel, S. King, C. Pearsonet, “Guidelines for environmental control in cultural institutions”, heritage Collection Council, 2002.