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EDITORIAL

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Preventive conservation, predictive analysis and environmental monitoring

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The aim of Preventive Conservation (PC) is to prevent or minimise the risk of irreversible damage to cultural artefacts as a result of the environmental factors to which they are exposed, such as relative humidity (RH), temperature, light, atmospheric and air pollutants, vibrations, etc. PC strategies for collections include the implementation of environmental recommendations to ensure the long-term stability of cultural objects and to establish adequate control procedures to monitor these conditions. Recording and analyizing environmental data allows the assessment of the risk(s) that certain conditions pose to cultural objects. However, this analysis is challenging due to the diversity and heterogeneity of the materials present in cultural objects. This suggests that environmental monitoring alone cannot be considered an effective PC strategy and needs to be linked to the use of degradation models for the different materials in relation to the environmental parameters mentioned above to allow damage prediction and the establishment of tolerance thresholds of the site or, in other words, the conditions beyond which risk (and often irreversible damage) may occur.

The development of technological solutions available nowadays to record the environmental condition of cultural assets is considerable. However, many of the existing systems lack a predictive function that estimates the potential future degradation of the object(s) caused by its exposure to that environment but that also provides recommendations for its proper conservation.

The collection 'Preventive Conservation, Predictive Analysis and Environmental Monitoring' brings together 15 papers from different research groups presenting the latest technological advances in the study of the behaviour and aging of cultural heritage materials, as well as in environmental monitoring and its contribution to the design of preventive conservation strategies. In this topical collection, papers can be grouped in two main areas. The first one includes the contributions dealing with different aspects of material degradation of cultural objects (including long-term prognosis of the degradation process of cultural objects and multi-scale degradation computational modelling). A second group of papers is dedicated to connectivity, sensing, and cloud computing technologies (including wireless and Radio Frequency Identification (RFID) technologies applied to cultural heritage, as well as Internet of Things (IoT) and big data analytics applied to preventive conservation).

Regarding the papers on material degradation, studies on paper, wood, canvas paintings and dyed textiles are presented. Maraghechi et al. [1] present an efficient method based on rotational rheometry experiments for measuring viscosity-average degree of polymerisation to determine the extent of degradation of cellulosic paper. The study presents rheometry as an accurate alternative method to the conventionally used glass capillary viscometry methodology. Moreover, rheometry requires less sampling than viscometry and may be thus particularly advantageous in paper degradation studies where sample availability is limited.

As for wood degradation, Cirule et al. [2] evaluate the effect of three types of artificial light sources (LED, incandescent, and fluorescent lamps) on the colour change

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(total discolouration as well changes in colour lightness, chroma -saturation-, and hue) of two hardwood species (birch, oak) and two softwood species (spruce, pine-sapwood and heartwood). The different wood samples tested showed a high sensitivity to radiation emitted by artificial light sources, and changes in colour were visually perceivable in all woods already at relatively low irradiation doses. Hardwoods proved to be more resistant to discolouration. The study carried out by Riparbelli et al. [3] in wooden panel paintings subjected to environmental hygrometric variations, revealed the complexity of these objects and the significant variability in terms of materials and deformation behaviours. In this paper, it is shown that wooden panel paintings are affected by a nonlinear state-dependent behaviour. This means that each of the parameters characterising these artworks (hygroscopicity, mechanical stiffness, fibre direction, and conservation environments, etc.) constitute a set of interconnected and interacting physical subsystems, whose temporal evolution is highly dependent on the knowledge of the initial conditions, boundary conditions and inner structural mechanics characterisation. The authors explain that the behaviour of wooden panel paintings can only be measured (not predicted), and only when all the material properties and boundary conditions are specifically determined through direct experimentation on real works of art, the results of the numerical simulations can be accurate and correspond to their actual behaviour.

In relation to canvas paintings, Lee et al. [4] explore three degradation phenomena in model canvas paintings under desiccation (bulging formation around the corners, crack formation in glue and ground layers, and, finally, plastic deformation in the ground and oil paint layers) through finite element method (FEM) and extended-FEM (XFEM) computer models. The results showed that the geometrical deformation of the stretcher was a result of the shrinkage of the glue, which reduced the tension stress in the centre of painting. On the other hand, the difficulty of creating cracks in the centre of the model painting suggested that there are other reasons for cracks in paintings than the desiccation simulated in this study. The cracks developed in the models with weak grounds is in line with what has been observed in real case studies. It was also shown that the specific range of RH that initiated the crack is highly dependent on the specific material characteristic used in this investigation, and the time of occurrence and size of the crack can vary according to the different material characteristics adopted for the models. The fact that the mechanical properties of the materials mentioned in this study are time and strain-rate dependent, evidences the need of further investigation with models representing different aged oil canvas paintings with various materials and layer compositions under different rate of environmental changes. In line with this study, Janas et al. presented two complementary papers. In the first one [5], the results show that glue-sized canvas behave as a composite support in canvas paintings, playing a significant role in its performance. This finding modifies and refines the current understanding of paintings behaviour at high RH and evidences the need of developing further models and experimental work to correlate deformation experienced by canvas paintings and risk of physical damage to paint layers. Following this approach, in their second contribution [6], Janas et al. show that oil paints continue to get stiffer and more brittle after 30 years of drying under laboratory conditions, which indicates that the paint molecular system is still evolving. Contrary to earlier predictions, the evolution of paint film properties did not slow down with the drying time, and dramatic increases in stiffness and decreases in the strain at break were observed for some paints during the late stage of drying. This study demonstrated that some oil paints could be more brittle than the ground layer and, in consequence, more vulnerable to cracking, which directly affects the understanding of paintings as physical systems and the implementation of appropriate environmental specifications for painting collections. The authors suggest different approaches to better document and understand the effects of environment on paintings such as the use of computer modelling to simulate 'real-time' moisture diffusion (and the resulting strain and stress fields) across paintings, as well as collection analysis to identify the impact of the existing climatic conditions and trace new damage accumulating in paintings to inform environment specifications.

Dyed textiles were finally the focus of the last of this group of papers on material degradation. In their paper, Hagan and Poulin [7] used a published dataset of colour measurements from more than 100 dyed textile samples containing early synthetic organic colourants from the period 1874–1905 to better understand the light sensitivity of heritage collections with prior light exposure. The results evidenced the shifting distribution of lightfastness for the sample set with light dose, toward higher Blue Wool (BW) ratings with increasing exposure. As the dose progressed, dyes that start at BW1 sensitivity progress to BW2, then BW3 and so on. The findings from this work may assist with boundary approximations of object sensitivity when prior light exposure is known, or when a reasonable estimate is available. The results were further interpreted to provide practical information for risk assessment in exhibit lighting applications. An analysis of experimental data is summarised as a tool for this type of decision-making process.

The second group of papers presents the latest technological advances in sensor electronics, wireless LPWAN

(Low Power Wide Area Networks) communications, cloud computing and big data, in connection to preventive conservation strategies. For example, Rioual et al. [8] discuss the main features of low cost air-quality sensors consisting of a reactive metallic dosimeter and based on RFID technology. Developed within the EU-SensMat project, these low cost and low visual nuisance sensors are aimed to evaluate the emission of pollutants as well as the efficiency of HVAC or absorbents and can be easily integrated to other existing RFID applications thanks to a commercial UHF-RFID reader. The work by Laborda et al. [9] presents the needs and results of CollectionCare project to achieve a low-cost wireless measurement system capable of adequately sensing environmental conditions in combination with a cloud computing platform that collects the data, analyses it using degradation algorithms and conservation standards, and provides recommendations. In particular, this paper is focused on the design choices made regarding the housing, attachment method, power source, wireless transmission technique and selection of the environmental sensors following European standards. In addition, the effective implementation of the device in three stages as a proof of concept until getting a near-production version is presented. Complementary to the design of devices with innovative functionalities is the need of accuracy and representative measurements. In this regard, the paper by Frasca et al. [10] describes specific procedures aimed at the deployment of microclimate sensors in spaces housing collections under two different scenarios (artwork-related deployment and artwork-envelope-related deployment). The paper addresses all the aspects involved in the interdisciplinary evaluation of the deployment of sensors, which considers the expertise of all the professionals involved in microclimate monitoring.

The paper by Díaz-Arellano et al. [11] proposes a procedure for the reconstruction of historical thermohygrometric data using multivariate statistical methods, enabling collections to restore their datasets for further analysis regarding the application of guidelines for PC. The paper presents the application of the European standard EN 15757:2010 as well as the characterisation of specific microclimates. In this study, the methodology was validated on the basis of real data, taking historical data collected at a partner museum of the European H2020 CollectionCare project, together with data collected for some months by a set of wireless sensor nodes as an example. Data collected over decades in heritage institutions in combination with machine learning technologies can reveal new knowledge and insights in the long-term preservation of cultural heritage objects as shown by Boesgaard et al. [12]. Their paper discusses the usability of supervised machine learning methods for predicting the occurrence of harmful environmental conditions inside buildings used for preservation of cultural heritage. By using historical environmental data from two heritage facilities and two different machine-learning algorithms (RandomForest classifier- RFC, and extreme gradient boosting algorithm -XGBoost) to forecast incidents of unwanted indoor environmental conditions (too low or too high levels of relative humidity) inside the facility, this paper explores the possibilities for developing a proactive system. This contribution also addresses the current limitations of the study and potential areas where further research is needed for this technology to develop effective data driven control of the indoor environment. Other challenging issues such as inappropriate temperature or pollutant levels, the effect of initiated climate control methods, and the energy consumption involved are addressed as relevant issues to be investigated further.

Gawronek et al. [13] discuss the need of constant monitoring of changes in the object required by the sustainable redevelopment of cultural heritage. The paper shows the potential of periodic measurements as the primary source of insight into the heritage asset, as well as into the directions and quality of changes it undergoes. More specifically, the authors assess data obtained with Terrestrial Laser Scanning (TLS), a short-range remote sensing tool for historical assets as popular as regular digital photogrammetry, which provides a spatial database for the redevelopment and functional reuse of historical structures. Periodic redevelopment scanning in cultural heritage involves the entire structure, not only its most valuable heritage components. Through simple and rapid analyses (consisting of shape analysis, determination of the pace and scope of redevelopment, detection of conservation effort results, HBIM, etc.) TLS contributes to better informed PC decision-making. In a more extreme scenario, the impact of climate change on cultural heritage in Europe has also deserved attention in this topical collection. Kotova et al. [14] present the first set of results of the KERES project, focused on the impact of future extreme climate events on the built heritage and historic gardens. For this purpose, an ensemble of climate simulations is used to analyze changes in both climatology and extreme events for several climate variables at two cultural heritage sites in Germany. More specifically, the paper presents the methodology designed to guide climate scientists on how to better tailor climate information for the needs of stakeholders in the cultural heritage sector so that they can integrate the results of climate projections into the prevention and emergency management, in particular for the risk assessment of extreme events.

Finally, a more comprehensive approach is presented by Wang et al. [15] in a paper dealing with the use of digital twins as a basis for simulation testing in a virtual environment. In this study, the potential of combining the digital twin technology for remote monitoring, prediction of potential risks and real-time data provided by in situ sensors for sustainable preventive conservation of movable wooden artifacts is shown. Such a complex approach allows to analyse and diagnose existing damage, as well as scenarios that can be simulated through the digital twins and where potential risks can be predicted at an early stage, assessing the magnitude of the risks, identifying possible treatment options and evaluating their impact, monitoring the effects of treatment in real time and providing timely corrections and feedback.

It is our hope that this topical collection provides an interesting overview of the latest research on environmental monitoring for the preventive conservation of cultural heritage in its broadest sense, as well as an inspiring insight into the next steps where further interdisciplinary research is needed.

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Declarations

Competing interests
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