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Characterisation of thermo-hygrometric conditions of an archaeological site affected by unlike boundary weather conditions

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ABSTRACT

This paper applies statistical techniques to analyse microclimatic data (temperature and relative humidity) recorded at the archaeological site of Plaza de l'Almoina (Valencia, Spain). This study has allowed us to quantify the effect of certain measures that were adopted for preventive conservation. The first monitoring campaign took place in 2010 at this archaeological site, showing harmful effects on the conservation state of the remains due to the presence of a skylight that partly covers the remains and causes a greenhouse effect. This skylight was covered with a water layer to prevent overheating of this archaeological site. However, this layer was removed in 2013 due to water leaks, and the indoor conditions changed. Over the summer, a temporary canvas was installed over the skylight to avoid heating of the archaeological site below by preventing the incidence of direct sunlight. The main importance of this work was to characterise the effect of unlike boundary weather conditions of different years in the indoor microclimate of the archaeological site, and to study the effect of the new boundary situation. This paper shows that the removal of water from the skylight caused a temperature increase inside the museum; meanwhile, the subsequent installation of the canvas cover allows appropriate daily cycles of temperature and relative humidity, especially in areas under the skylight. This work also shows that the replacement of a water ditch near the archaeological site by a PVC pipe was also detected by the sensors due to the difference in water vapour pressure.

1. Introduction

Preventive conservation of artworks has been improved in recent decades through scientific research that has provided a better understanding of the deterioration processes. The main causes of deterioration are environmental: temperature, humidity, light and atmospheric gases. Additional causes include mechanical damage due to inappropriate maintenance and assembly, chemical damage from contact with reactive materials and damage caused by biological organisms, plants, insects and animals.

All these factors can be controlled in most cases, although the effect of some of them such as air pollutants can rarely be eliminated. By controlling these factors, it is possible to significantly slow the deterioration processes, but not to stop it completely. The methodology of preventive conservation is therefore indirect: deterioration is reduced by controlling its causes [1].

Currently, there is growing interest in monitoring the climatic parameters in cultural heritage [2–13]. In the case of archaeological sites, temperature differences between various minerals in block surfaces and differences in surface and substrate temperature are sources of thermal stress. Experience shows that thermal and humidity stresses are important causes of micro-fractures between the mineral grains of blocks [14]. Moreover, thermal variations

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affecting mechanisms, such as salt crystallisation, may indirectly induce damage. Thermal cycles are more important for surfaces exposed to direct solar radiation [14]. The study of microclimatic conditions surrounding archaeological sites is essential to prevent deterioration and identify eventual consequences of corrective measures [15–18].

Some authors have studied the materials composing the roofs [19] and walls [20] of buildings and how they affect the thermal comfort inside, but always focused on the welfare of people, rarely in terms of preventive conservation of archaeological heritage. In our case, we must take into account both the people who visit the museum and the archaeological remains. Nor should we forget the importance of the microclimate on the energy demand in public buildings in the context of climate change [21].

The city of Valentia (Valencia, Spain) was founded by the Romans in 138 BC, and the exact founding point where the city started is located in Plaza de l'Almoina. Evidence of Roman settlement can still be seen in the excavated remains of the Roman forum and baths [22]. The archaeological subsurface gathers a group of monumental buildings that form a complete compendium of history and urban development of Valencia, from its origins until today.

L'Almoina is an archaeological museum located in a building about 3 m below the current city sidewalk level. The archaeological remains are covered by a concrete structure, which forms an elevated plaza above the sidewalk. This cover connects with sidewalks through steps with different heights along its perimeter due to the slope of the sidewalk. There is no vertical retaining wall inside the museum to isolate the remains from water diffusion through capillarity from the surrounding areas. The archaeological remains cover an area of 2500 m^2 and retain vestiges ranging from the second century BC (Roman) until the fourteenth century (medieval). In 2007, an external concrete structure adapted to the archaeological site was built, and a skylight (25 × 25 m) covered with a water layer was installed, allowing passers-by a glimpse of the archaeological remains below.

Preventive conservation of the archaeological site at Plaza de l'Almoina includes maintaining stable and adequate temperature and relative humidity levels and managing light exposure, among others. An initial campaign of thermo-hygrometric monitoring in Plaza de l'Almoina [23] showed a relevant effect of the skylight on the variations in temperature and relative humidity, causing sharp rises and falls during daylight hours. Possible solutions to this problem were proposed [23], based on the experience of a previous monitoring study in the ruins of Ariadne's house in Pompeii [11].

In early summer 2013, water leaks from the skylight occurred, dripping onto the archaeological site. As an initial solution, Valencia City Council, which manages the archaeological site, eliminated the water from the skylight to prevent further leaks. Later, in August, the City Council placed a waterproof canvas over the skylight, preventing rainfall leakage and the direct impact of sunlight. Moreover, in the year 2011 a water ditch built with porous bricks passing near the archaeological site [23] was substituted by a 110 mm PVC pipe. In general, microclimatic characterisation of an archaeological site must be repeated whenever environmental or boundary conditions change [23,24]. So, a second monitoring campaign in Plaza the l'Almoina was carried out in 2013.

In Ref. [25], the same problem of comparing the effect on thermo-hygrometric conditions of implemented measures is described, aimed at attributing the different levels of temperature and RH to these corrective actions. In this paper, the same data selection is performed and the selected data periods have similar outdoor environmental conditions (mainly in temperature). Now, the same procedure is applied in a buried archaeological site.

The main aim of this work is to assess the effect of different corrective measures and changes implemented in the archaeological site of Plaza de l'Almoina using statistical methods sparsely used in cultural heritage and with proven effectiveness [11,15,23], as well as to quantify the improvements achieved by the proposed solution which could be taken as an example for other similar archaeological sites in the future.

2. Materials and methods

2.1. Data loggers and installation

The same data-loggers were installed as in the first monitoring campaign [23], in the same place (in this paper, sensor positions are shown in Figs. 3 and 7) and with the same calibration methodology.

The second monitoring study began on 22 July 2013 and ended on 11 September 2013, resulting in a total period of 51 days. All data loggers were programmed to register one measurement every 30 min, which entails a total of 2448 recorded values (i.e., 51 days × 24 h/day × 2 data/h).

Sensor coded as number 8 (#8) was stolen; therefore no data are available for this location. Sensors #3 and #4 were manipulated by third parties causing data loss for one week, from 09/05/2013 (at 18:00) to 09/11/2013 (at 23:59).

2.2. Corrective action implemented

As aforementioned, on 20 August 2013 the City Council of Valencia installed a canvas cover directly on the skylight. The canvas was white and 625 m^2 in area. It was installed directly onto the glass without a fixing system (Fig. 1).

2.3. Statistical analyses

2.3.1. Data selection

In order to compare data obtained in the first monitoring campaign (2010, before removing the skylight water and installing the canvas) with data from the second campaign (2013), a data selection was performed because the two periods monitored are very different: the entire year was monitored in 2010, while only summer was monitored in 2013.

As was done in Ref. [25], to compare the effect on thermo-hygrometric conditions of implemented measures and in order to attribute the different levels of temperature and RH to these corrective actions, the time periods compared must have similar outdoor environmental conditions (mainly of temperature). This is necessary to avoid the confusion of effects such as attributing differences, for example, to a warmer period.

In this paper, we work with two different data matrices that correspond to similar thermo-hygrometric outdoor conditions (Fig. 2): one matrix to compare data recorded in 2010 with data registered in 2013 before installing the canvas, and another matrix to compare data recorded in 2010 with data obtained in 2013 after installation of the canvas cover (Table 1).

The results are discussed according to international standards [26,27]. The recommended range of RH and temperature for stones and rocks is 40–60% and 19–24 °C, and a maximum daily variation of 6% in RH (no recommended daily variation is available for temperature).

2.3.2. Contour plots

Contour plots were analysed in this paper as done in Refs. [15,23]. These plots were obtained with a CAD program. The graduation of the parameter was obtained by triangulation from the physical parameter value (its daily mean value) in a sensor and its closest neighbour. This was performed for all sensors. Next,