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DISCRETE AND CONTINUOUS MONITORING TO CHARACTERISED THE THERMO-HYGROMETRIC STATE OF WALL-BUILDING MATERIALS IN OSTIA ANTICA ARCHEOLOGICAL SITE

CARACTERIZACIÓN TERMOHIGROMÉTRICA DE MATERIALES DE CONSTRUCCIÓN DEL LUGAR ARQUEÓLOGICO DE OSTIA ANTICA MEDIANTE TOMA DE DATOS DISCRETA Y CONTINUA

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Abstract:

Nowadays, the procedures and instruments for measuring temperatures on the air and materials surface are normed and amply used, through direct and indirect techniques, with the aim to evaluate the conservation status of ancient buildings. In this work, two monitoring procedures are discussed in order to characterise materials, bricks and mortar aligned with "*opus caementicium*" technique, that make up the framework of "Casa di Diana" *Mithraeum*, a roman building (130 CE) sited in an Italian archaeological site (Ostia Antica, Rome). In this sense, for one year the wall-building materials and the surrounding air were monitored with two different procedures: a direct multi-points measurement with several handheld instrument which different physical systems conduced in predetermined periods and a long-term monitoring campaign with sensors specially developed placed along the walls. Preliminary data analyses show that the discrete monitoring with punctually procedure gives important information like the evaporating and condensing risk for both materials and areas particularly critical associated at lower level (0-70 cm). Continuous monitoring allows the individuating of punctual characteristics in time and space, planning recovery actions, although it requires more data treatment. Preliminary data treatments show the potentiality and advantages of both methodologies: general information and more data treatment with automatic method and specific information and more time spends in data adquisition with a manually proceeding.

Key words: indoor monitoring, thermos-hygrometric measurements, archaeological site, materials surface and air measures, preventive conservation

Resumen:

En la actualidad, con el objetivo de evaluar el estado de conservación de edificios antiguos, los procedimientos e instrumentos para la medición de temperaturas del aire de y de la superficie de los materiales están estandarizadas y son ampliamente utilizados a través de técnicas directas e indirectas. En este trabajo, se discuten dos procedimientos de control con el fin de caracterizar los materiales, ladrillo y mortero, colocados con la técnica de "opus caementicium", que constituyen el marco del Mitreo de la "Casa di Diana", un edificio romano (130 dC) situado en el yacimiento arqueológico italiano (Ostia Antica, Roma). En este sentido, durante un año los materiales de construcción de muros y el aire circundante fueron monitorizados con dos procedimientos diferentes: uno mediante medición manual directa de múltiples puntos con varios instrumentos, realizado en períodos predeterminados y una campaña de monitorización continua a largo plazo con sensores especialmente desarrollados para este fin emplazados en las paredes. Análisis preliminares muestran que el sistema discreto aporta información importante de riesgo, como la evaporación y la condensación, tanto para los materiales como para las zonas especialmente aquellas más críticas (zona baja, 0-70 cm). La monitorización continua permite la individuación de las características puntuales en tiempo y en espacio, aunque requiere de un tratamiento de datos más extenso. Los análisis preliminares muestran la potencialidad y las ventajas de ambos métodos: información general con el método automático y un tratamiento de datos más extenso e información específica con un mayor consumo de tiempo en la toma de datos con un procedimiento manual.

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Palabras clave: monitorización interior, mediciones termohigrométricas, lugar arqueológico, materiales y superficie, conservación preventiva

1. Introduction

In term of technology building materials performance (Cardinale *et al.* 2010) or to individuate changing occurred along the time or to assess the rising damp or masonry (Sandrolini and Franzoni 2006), thermo-hygrometric buildings investigation is a practice amply available in the preventive conservation (Grinzato 2010). In the archaeological contest, where the building materials suffer of harsh climatic conditions, the environment monitoring temperature (T) and relative humidity (RH) is the first step to evaluate the status of historic materials (Merello *et al.* 2013). In the literature, very few works present a methodology based on the combination of complementing monitoring techniques, and they are mainly focused on moisture analysis of buildings, or for air pollution (Nava *et al.* 2010). In this work, a combination of two monitoring systems, discrete and continuous, was applied on Casa di Diana *Mithraeum*, a roman building (130 A.D.), sited in Ostia Antica, characterised by several conservation problems (Scatigno *et al.* 2016). The first method is based on multi-point measurements within a systematic measurement in predetermined locations on wall-building materials and the second method based on continuous measurements through an array of sensors, both performed in a sufficient number of walls, in order to represent different climatic zones in the building. Specifically, the manually method was performed with a multi-handheld instruments to individuate behavioural differences between mortar and bricks, measures repeated in different seasons throughout the year. The automatic approach, consists of 28 thermo-hygrometric sensors linked each other and positioned along walls surface, in order to record the air thermo-hygrometric near the building materials.

Data treatment was performed with Principal Component Analysis (PCA) and multivariate statistical analysis individuating advantages of both procedures and data were stored in Burrito software (Fernández-Navajas *et al.* 2013). The main goal of the paper is to determine the potentiality and advantages of both methodologies with preliminary data treatments.

2. Materials and method

2.1. Discrete monitoring (T, RH)

2.1.1. Instrumental technology

Three different instruments were used. The Protimeter Surveymaster (SM BLD5360) that evaluates the conditions of moisture both on the surface by a conductive method and under surface layer of about 19 mm by an electromagnetic method using a needle electrodesanda non-invasive inspection through radio frequency technique (RFE). The electromagnetic method measures with two different modes: by LED scale, identifying degrees of dampness below the surface and by directly RH percentage values. A Multimeter PM 2521 Philips (PT100 probe) and IR Thermometer TESTO 810 were used for the contact and air temperature measurements, respectively.

2.1.2. Multi-point measures

A measurement in predetermined locations on wall-building materials of each wall was performed. In order to measure both brick and mortar and reveal differences along the vertical wall, a multi-point set was individuate, for a total of 22 measurements/walls.

2.1.3. Recorded data

The measurements, along the entire year, started on spring of 2014 and precisely from the exact day of the beginning equinox/solstice, obtaining a matrix of 3290 data.

2.2. Continuous monitoring (T, RH)

2.2.1. Instrumental technology

The instrumental technology consists of multiple sensors (DS2438 - Maxim Integrated Products, Inc., Sunnyvale, CA, USA dual sensors and HIH-4000 - Honeywell International, Inc., Minneapolis, MN, USA) that can be used in the system simultaneously with only one data line (1-wire communication protocol) (García-Diego and Zarzo 2010).

2.2.2. Positioning sensors

A total of 28 probes were installed, 27 in the interior - along the wall) and one placed on the sill of a window as an outdoor climate control.

2.2.3. Recorded data

The continuous monitoring campaign system was started since the 29th June 2014 and finished the 31th August 2015, obtaining matrix of 5.342.400 data.

3. Results and discussion

3.1. Discrete Monitoring

Regarding T, the air temperature (Ta) is hotter than contact temperature (Tc) measured for both brick and mortar, especially in summer facilitating evaporating and condensing processes (Fig. 1a). Regarding RH, considering the average value for each one season, in general the brick has moisture content greater mortar, from 2% ±0.5 up to 15%, value reached in the summer time (Fig. 1b). PCA data treatment reveals that there is also a difference between the surface and inside material (19 mm). Podia are particular cases: the values are closed to saturation. The data collection takes a couple of weeks for each campaign.

3.2. Continuous Monitoring

In general, T remains stable between July and the end of October. During the winter season, there was greater amplitude than in summer-autumn. RH shows more

fluctuation. Two clear groups were found for T and RH in a preliminary data treatment with PCA. For each parameter the sensors clustering according if their positions were in protected area, closed, (sensors situated away from openings, window and frontal walls to these, where the outdoor exchanges are frequent) or placed in area more ventilated (near to openings: window and main entrance presence).

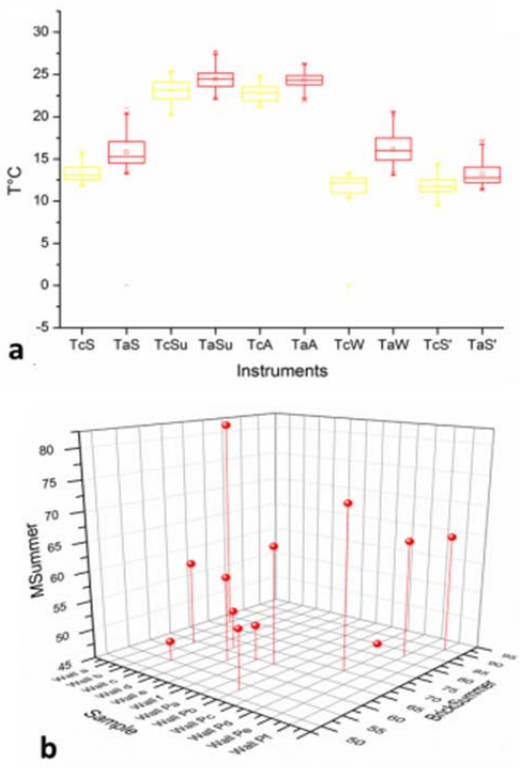

Figure 1: a) Box chart. T (contact and air measurements) in the seasons ("S" pring, "S" ummer, "A" utumn, "W" inter, "S'" Spring 15'"); b) 3D Scatter. RHaverage (mortar and brick). The graph shows the RH behaviour in the different walls.

4. Conclusions

We have compared to two innovative monitoring procedures completely different one from each other. The data analysed reveal the potentiality and disadvantages of each one. The discrete monitoring, thought a detailed mapping measurements and the employment of different instruments, was built to study the materials building and to correlate the indoor environment with the materials, representing a full method. The wall surface measured with and without contact instruments was investigated in order to put into light the risk of particular phenomena like the evaporating and condensing, to which depend damages caused by the salt efflorescences. This method employs a strategy that consists of a fixed number of measures repeated in selected days for one year. The advantages are widely discussed. The disadvantage is the manually procedure and the time spent into measuring, which can be considerably reduced by the continuos monitoring. The continuous monitoring is the practice more used into characterising the microclimate campaigns. The innovative of the method used consists into sensors technology: dimensions sensors (0.5 cm), high memory of data storing (10 years and more) and high frequency of data recording (1 minute). Also the data store is innovative (Fernández-Navajas *et al.* 2013) and used in others historical building (Merello Giménez 2013). This monitoring procedure allows to characterise the trends of physical parameters (T, RH) and individuate the episodes that occur during the year and can compromise the conservation and safeguard of ancient buildings. The procedure was allowed to individuate differences between Mithraeum and pre-Mithraeum. The disadvantage is the data treatment during its manipulation. This last statement is surpassed thanks to software used (Fernández-Navajas 2013).

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