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WISPHER: cooperating WIreless Sensors for the Preservation of artistic HERitage

(Case study: *Arena di Verona*)

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Abstract

We propose a methodology based on cooperating wireless sensors to diagnose, control, and better preserve artistic heritage. Our aim is to provide a feasible framework to balance preservation issues with usability issues, both for open air buildings and for closed ones. The proposed methodology benefits from networks of cooperating sensors in two respects. Firstly, sensors are used to diagnose accurately the state of a building, to draw accurate thermo-hydrographic maps, and to understand the dynamics of exchange between the building and the environment (caused either by natural seasonal fluctuations, or by the use of the building). Secondly, sensors are used in the management of a building to react effectively to sudden changes of the environment, thereby enabling a better preservation strategy. We present an application of our methodology to a concrete example: *Arena di Verona* in Italy.

The rest of paper is organised as follows. The problem we want to study is defined in Section 1, while Section 2 presents the state of the art of currently employed diagnostic methodologies and preservation strategies. Section 3 introduces our framework, whose benefits are analysed in Section 4. Section 5 applies the methods to a concrete example: *Arena di Verona*.

1. Problem definition

Water (rain, moisture, environmental humidity), often combined with atmospheric pollutants, is the main cause of damage for ancient buildings. Indeed, ancient buildings are typically made of hygroscopic materials such as tile, stone, plaster, wood. Unfortunately, it is extremely difficult to diagnose and quantify the presence of water (in all its forms) and the way it damages buildings, museums, and the objects stored in these buildings. Such diagnostic exercise is even more complex in the case of open air (or partial open air buildings), for instance ancient amphitheatres.

To worsen the situation, the amount of artistic sites in Europe and the increasing number of tourists visiting them clashes with the need of preservation strategies. Indeed, it is not possible to close artistic sites to perform accurate analysis, which may require many seasonal cycles. Moreover, the presence of tourists may alter the values of temperature and humidity in a critical way, when compared with seasonal variations.

In parallel with these issues, some of the techniques available to measure critical parameters are too destructive to be performed on many buildings.

2. State of the art

There is no single strategy to diagnose, nor to maintain, artistic heritage, which may be explained partially by the fact that every site is different in nature. Currently, measures of rain, temperature, and humidity are typically carried out "punctually".

In closed environments, thermo-hygrometers exist to record series of data, and these instruments are actively used to monitor the state of the air in various settings. However, to the best of our knowledge, thermo-hygrometers *do not interact* with other kind of sensors, and they interact only in a limited way with air-conditioning devices.

In the case of "open" buildings, i.e., buildings without a roof, or with partial coverings, no instruments exist to monitor all the relevant dynamics of exchange between the building and the environment. Atmospheric pollutants can be measured with appropriate instruments, other devices can measure the amount of rain, the temperature distribution over a surface, and other parameters, but these devices have never been coupled in an automatic way with preservation strategies. Moreover, the possibility of remote control of these devices is very limited.

In essence, apart from few cases in closed environments, diagnostic campaigns and preservation strategies are implemented manually, *in situ*. These factors negatively affect the cost of evaluating the state of a building, thereby reducing the number of possible interventions. Even worse, the current preservation strategies may not be sufficient and/or they may be too slow to cope with sudden changes in the environment, both because of unexpected weather conditions, and because of the number of tourists visiting a particular site under particular circumstances.

3 Proposed solution

The aim of the proposed solution are:

1. To increase and improve the quality of the diagnostic procedure.
2. To plan and deploy low-impact protection strategies, which are easily reversible.

The outcome of the strategies devised in this way is a preservation procedure for artistic heritage, which allow people to access sites (both museums and open air buildings) without causing irreversible damages. A network of wireless cooperating objects may be implemented both for point 1 and 2 above, which correspond to two distinct phases in a project. For a generic building, the first phase of the methodology we propose will typically span over three years, and will includes the following items:

PHASE 1 - DIAGNOSIS

- Micro-climate analysis: a wireless network of sensors for temperature, relative humidity, wind speed of air; these sensors may be placed at different height levels, both indoor and outdoor, and communicate with an appropriate repository. Measures can be made to evaluate seasonal and short-term variations.
- Psycrometric analysis: sensors for the temperature, humidity, water content of the structures, connected with a central repository. These measures will be paired with the data from the previous point, to evaluate the reaction of the structure to micro-climate changes.
- Thermographic map: infra-red sensors will keep track of surface temperature variations with micro-climate changes. These measurements permit the evaluation of humidity spots caused directly by rain or by moisture.
- Rain analysis: apart from the absolute amount of water, radio emitters could be spread over a surface to trace the outgoing flow of water; measures of this parameters will be coupled with the remaining data to obtain the dynamics of water in a building (in our case study presented below, tracing the water flow with radio emitters could establish whether or not the ancient roman aqueduct is still in use).
- Pollutants analysis: sensors for pollutants (both in air and on the surface of structures) will return data to be coupled with the other parameters.
- Endoscopic, remotely controlled sensors may penetrate large sections of walls to investigate the composition of the structures. These would be occasional measures to characterise further the structures of a building.

All the measures presented above may be executed and checked remotely, thereby allowing a single research group to work at more sites in parallel, reducing the costs. Moreover, automatic and/or manual remote re-configuration of the devices will fine tune the results of this phase.

The expected outcomes of phase 1 are a detailed assessment of the possible causes of degradation of a building, a detailed map of the situation, e.g., the increase in humidity and temperature with tourists, the identification of weak sections of the structures after heavy rains, etc.

PHASE 2 - MONITORING AND CONTROL

The outcomes of phase 1 will be key to develop phase 2. In this phase, a cooperating network of sensors and actuators will be installed in the building / site to implement efficient preservation strategies. Typically, the following items will appear in the final strategy:

- Sensors for temperature and humidity (both for air and for surfaces). These sensors will detect sudden changes due, e.g., to the presence of tourists.
- Automatic gates: these gates will be controlled automatically by an appropriate device, communicating with the sensors for humidity and temperature. The idea is that sections of a building / site can be dynamically opened or closed, based on the number of tourists, on the humidity of air and of temperature, etc.
- Sensors detecting the amount of rain may open or close the appropriate drains, to divert the water tp the correct sinks.
- In a closed building, room-level air conditioning may be enabled automatically.

4 Benefits:

The benefits of the proposed methodology include:

- Accurate diagnosis of large buildings. This kind of analysis may be very expensive; the use of a network of semi-autonomous devices remotely controlled may reduce the costs of these operations.
- Possibility of monitoring large, open air buildings (such as amphiteatres). Similar controls exist in a small number of closed museums to control particularly sensitive rooms. However, to the best of our knowledge, no open-air or large building has been monitored yet. A network of wireless and cooperating devices is fundamental to this end.
- Rapid and effective response to sudden changes. This implies an increased safety for artistic heritage, and an increased availability to the public.

CASE STUDY: *Arena di Verona*
(and annex *Fondazione Arena per l'Opera Lirica*).

In this Section we present a scenario that may benefit from the proposed methodology: *Arena di Verona*.

<u>Historical overview:</u>
The amphitheatre was probably built during the Ist century B.C., during a peaceful period for the Roman Empire, and it was the place for public assemblies and fun events.
During the Middle Age, the *Arena* was abandoned and spoiled of its furniture, and it became an urban quarry for the stones used to build houses in the more recent centre of Verona.
The building started to be restored in 1480, according to a long public program that rebuilt the monument more or less as it appears today.

<u>Current problems:</u>
Surprisingly, there are no research reports, nor studies, concerning this important building. *Arena di Verona* is the most visited monument in the city of Verona, and one of the most popular in Italy.

Currently, the main problems are related with the presence of water. In particular, the following questions remain open:

1. The *Arena* has no roof nor coverings. Water falls in the *cavea* and dampens the whole structure. Some parts of the structure are permanently wet (see the figure in the next page). Where is the water flowing to? Are there any

preferential ways for the water flow, from the moment the water touches the *cavea* to the moment it reaches the ground? And where does the water flow to, after reaching the ground? Is the old roman aqueduct still working?

2. How does the water accumulation affect the inner microclimate and the thermo-hygrometric conditions of the structures? Is this sustainable in the future?
3. The popularity of the amphitheatre *Arena di Verona* is also due to the lyric season that crowds the amphitheatre from may to September. The *Fondazione Arena* that organises and produces the performances occupies nearly a third of a nearby building with warehouses, small rooms and spaces of service. Do the presence of tourists and the execution of performances cause problems to the structure for the sudden changes in microclimate? Is it possible to devise a relationship between the presence of people and the variations of the microclimatic conditions in order to plan solutions?

The following pages contain images recently taken from the *Arena*, showing damp surfaces in closed sections of the building. We argue that the methodology presented here may be extremely helpful in assessing the importance of such unexpected evidence.