Construction and Building Materials 52 (2014) 345–352

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Integrated geophysical approach for stone decay diagnosis in cultural heritage

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HIGHLIGHTS

- Stone decay diagnosis in artistic tomb made of porous limestone.
- Self-potential (SP), seismic refraction, IR thermography and salts surveys.
- Northern part of the tomb is more humid than the southern part.
- The moisture is related to atmospheric moisture.
- The limestone is soft and the strength is slightly lower in the most humid zones.

ARTICLE INFO

Article history:
Received 9 January 2013
Received in revised form 5 November 2013
Accepted 12 November 2013
Available online 7 December 2013

Keywords:
Stone decay diagnosis
Salts
Deterioration patterns
Self-potential
Seismic refraction
IR thermography

ABSTRACT

This paper reports the results of a geophysical survey (self-potential and seismic refraction) combined with IR thermography and identification of decay products and quantification of soluble salts in a Portuguese artistic tomb made of a porous limestone that presents severe decay phenomena. The aim of this work was to study microenvironmental conditions, especially the moisture distribution and its relationship to stone decay. The self-potential and IR thermography survey allowed verifying that southern part of the tomb is more humid than the northern part and that moisture is related to atmospheric moisture. Seismic refraction showed there is no interface between sound and weathered stone, that limestone is soft and the strength is slightly lower in the most humid zones.

1. Introduction

Today experts agree that precise damage diagnosis is a vital element in stone conservation and sustainable monument preservation [1], as it provides the data needed for comprehensive characterization, interpretation, rating and prediction of stone damage. Better understanding of the stones used in monuments and the factors, processes and characteristics involved in stone decay is therefore essential to the sustainable preservation of cultural heritage. The moisture content and its distribution and the presence of saline solutions that remain a long time within porous media of stone materials, intensify weathering processes such as material dissolution, absorption of contamination gases, freeze-thaw pressure of crystallisation, hydration pressure and differential salt precipitation [2–5]. However, understanding the moisture content of a building structure and its distribution has proved to be an extremely difficult task [6].

A frequent and major obstacle to study stone decay in monuments is the impossibility of touching or obtaining samples for study in the laboratory or even in situ. So, non-invasive techniques are considered the most appropriate for assessing the quality of stones with historical or artistic value. Geophysical techniques, such as ground penetration radar (GPR), have been applied in historical monuments [7–18] since these are non-invasive and make it possible to map various physical parameters of the geological materials. Another important factor to obtain meaningful responses is to perform a survey with different methods, which can provide information on different physical aspects of the investigated media [19].

Self-potential method (SP) provides non-invasive method for sensing the presence of water in a porous media by electrokinetic

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0950-0618/$ - see front matter
http://dx.doi.org/10.1016/j.conbuildmat.2013.11.047

and electrochemical potentials. The SP method is based upon measuring the variations in spontaneous or natural potentials developed between any two points on the Earth, caused by electrochemical actions between minerals and subsurface fluids or by electrokinetic processes involving the flow of ionic fluids [20]. The self-potential method is not very often used in Cultural Heritage and its application has been mainly in the archaeological prospection field [21]. Seismic refraction method can also be used to characterize stone and assess to investigate the degree of stone weathering in monuments [22–25]. It provides useful information for detecting the thickness and position of weathered layers and the physical properties of the different materials involved, such as mechanical characteristics, state of cracking and the location of cavities, fractures and other discontinuous elements. In cultural heritage stonework, ultrasonic transducers are used for refraction studies. The ultrasonic technique uses precision instruments to produce ultrasonic pulses applying rapid potential variation to a piezoelectric transducer that emits vibrations at different frequencies. Ultrasonic pulse velocity varies according to the elasticity properties of the stone being examined.

Infrared thermography (IRT), is a non-destructive technique, that measures the thermal radiation (infra-red range in the electromagnetic spectrum) emitted by materials and it provides images of the surface area, in the form of temperature maps, in pseudo-colors which are related to a temperature scale. It provides information on the surface and subsurface structure and heterogeneities in the investigated material, such as voids, cracks, moisture accumulation and material decay.

IRT investigations are carried out typically in to two distinct methods: (i) passive method, where the temperature is monitored without employing any heating of the sample induced by the measurement procedure and (ii) active method, where the temperature is monitored by means of adequate artificial heating usually produced by the absorption of the light emitted by flashed or dc lamps, lasers or other light sources [26].

The infrared thermography (IRT) has been successfully applied to the study of historic structures and buildings most of the time by means of the passive approach, such as those developed by [27–30].

The non-invasive techniques addressed in this work were used to study and evaluate stone decay of a fifteenth century Portuguese tomb located inside a church Igreja da Graça (Santarém, Portugal). The appraisal of the mechanisms involved in stone decay and the measurement of the extent and severity of stone decay processes in progress, is vital to the conservation and sustainable preservation of tomb.

2. Materials and methods

2.1. Description of the site and the tomb

Igreja da Graça is a church in Santarém, Portugal, classified as a National Monument. It was built between the fourteenth and fifteenth centuries in a mix of mendicant and flamboyant Gothic styles. It is located in downtown Santarém, where groundwater is close to the surface. One of its special features is a high gap between the interior and exterior of the church. The church has suffered several modifications as well as restoration works during its history. A magnificent Gothic tomb of the first governor of Ceuta Pedro de Meneses (died 1437) and his wife with their recumbent figures holding each other's hands (Fig. 1a) is located on the South Transept of the church. The tomb (approximately 1.50 m wide × 2.90 m length × 2.00 m high) consists of a large ark of limestone, supported on eight limestone sculptures representing lions with human remains and animals between claws. The lid of the tomb contains the two sculptures holding their hands and their heads resting on pillows, under elaborately ornamented baldachins (Fig. 1a). The friezes are decorated with angels, cherubs, gargoyles and flowering strings. The four faces of the tomb have branches of oak. Some small painted surfaces, with red, green and ochre pigments are still observed (Fig. 1a).

In what concerns the stone material used to sculpt this tomb, it was not found, so far, registration of its provenance. It is a light, whitish-yellow, fine-grained, compact, very soft and homogeneous limestone. This limestone is bioclastic and calciclastic with an oolitic tendency.

A detailed survey of the stone decay phenomena was carried out on the tomb and several weathering forms were identified [31], including powdering, multiple exfoliation and scaling (Fig. 1b and c), as the most relevant. On the lid were also identified grey crusts mainly in the overlying sculptures (Fig. 1d). These figures clearly demonstrate the severe stone damage presented by the tomb, leading to important stone losses.

2.2. Methods

2.2.1. Infrared thermographic survey

Measurements were conducted using a Fluke TI45 camera with Focal Plane Array detector operating in the band 8–14 μm. The system has a thermal resolution of 0.08 °C and a instantaneous field of view of 2.60 mrad. The natural heat sources of the building as the solar radiation or the slow microclimate temperature varying were used, i.e., the passive approach was adopted for infrared thermographic survey and it was carried out on the sides and lid of the tomb and also on the walls and floor around the tomb (Fig. 2a and b). Data processing was conducted with Fluke Smartview 3.1 software.

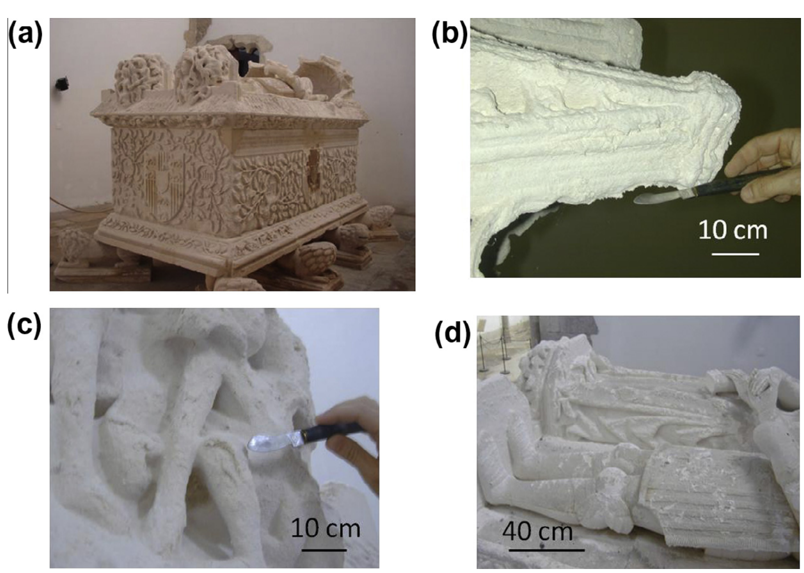

Fig. 1. The fifteenth century stone tomb located inside Igreja da Graça (Santarém, Portugal) with some decay phenomena. (a) General view; (b) multiple exfoliation; (c) scaling and (d) grey crusts.