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NONINVASIVE TECHNIQUES OF INVESTIGATING MOISTURE IN THE CASE OF HISTORIC BUILDINGS

BY

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Abstract. Moisture is a recurring issue in the degradation of old buildings. The researchers showed their interest in investigating moisture since the early nineteenth century, but the techniques available at that time were approximate and mainly based on the specialists' previous experience, and not on actual data. Lately, the scientific progress has generated a series of modern, noninvasive techniques of investigating moisture content and hygrothermal phenomena encountered in old buildings. The paper aims at presenting some new investigation techniques, such as IRT (Infrared Termography), FOM (Fibre Optique Microscopy), US (Ultrasonic Testing), NMR (Nuclear Magnetic Resonance), GRP (Ground Penetrating Radar), DIP (Digital Image Processing) and LTCC (Low Temperature Co-fired Ceramic). In addition to the description of the operating principles of these modern techniques, the advantages and the disadvantages of their use will be detailed.

Keywords: investigation; noninvasive techniques; humidity; historic buildings.

1. Introduction

The scientists' concern regarding old building moisture issues dates back from the end of the nineteenth century (Massari, 1971), following the

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degradation of the existing building construction elements. On the other hand, the doctors of those times found out that various respiratory diseases could be associated with the unsanitary conditions produced by dampness and mold, commonly found in old buildings.

Many research activities have been conducted in Europe, especially in France and Italy, where degradation phenomena manifested intensely because porous building materials, such as ceramic elements for masonry, calcareous stones and lime mortar or cement, have been used in historic buildings. At that time, the investigation methods were largely based on the visual analysis of the building elements affected by moisture. Of course, this method is approximate and it cannot grasp all aspects of the degradation phenomena such as moisture content, wet section diagram, source of humidity etc. As a complementary method, sampling cores from building walls or foundations is often practiced, in order to determine the moisture content in the laboratory. This method is more accurate, but it is invasive, affecting both the integrity of the building elements, as well as their aesthetic features. In the case of the walls containing paintings or decorative elements, the core sampling method cannot be used.

Taking into consideration the fact that masonry strength qualities are reduced due to the moisture (Diaconu *et al.*, 2011) and the principle according to which any intervention on historic buildings must be reversible (Carta de la Veneția 1964), when it comes to old building humidity, it is necessary to design more accurate noninvasive investigation techniques, so they can be used on as many building types possible.

2. Noninvase Techniqes of Investigating Humidity

In the past, historic building restoration techniques were based on the specialists' previous experience, fact which led to the adoption of some solutions which generated the more pronounced degradation of the restored buildings. This leads to the hypothesis that each case must be studied separately, in order to determine the degradation mechanism. This is composed of two indicators: macro-indicators, which determine the degradation type, and micro-indicators, responsible for establishing the degradation rate and the thermodynamic characteristics of the encasing elements [4]. Noninvasive investigation techniques can be used to determine both indicators since the adopting of the intervention solutions must be based on studies on the compatibility of the authentic materials with those proposed, on the material service time, adopted solutions and the socio-economic impact of rehabilitation.

In order to establish a diagnosis, the issues presented in Fig. 1 must be investigated.

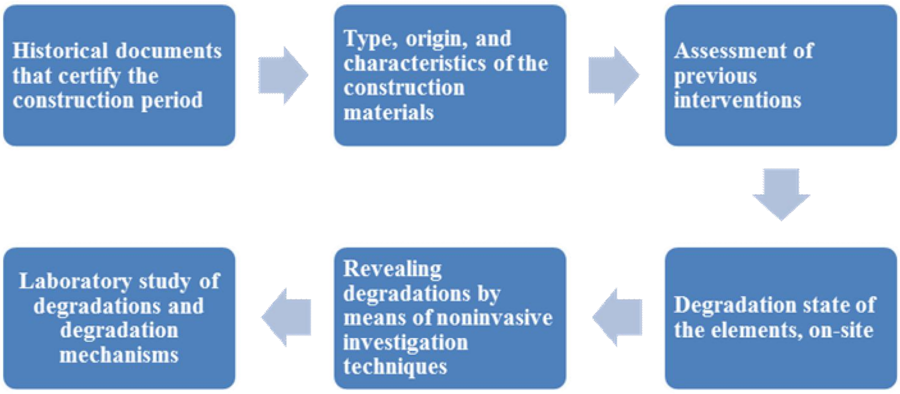

Fig. 1 – Aspects to be studied in order to diagnose the degradations caused by moistrure.

2.1. IRT (Infrared Termography)

The noninvase IRT technique is frequently used, based on the principle according to which each material emits infrared radiations differently, thus allowing the identification of materials, cracks, degradations, material discontinuities, and moisture content (Moropoulou *et al*., 2013) (Fig. 2). In the current practice, there are two measurement types: passive thermography, used to investigate damages or defects, and the active one, used to investigate heat transfer.

In terms of the relationship between the water content within the material and its thermal conductivity, concrete results were obtained in a study carried out on brick masonry walls (Duverne & Baker, 2013): with the sample water increase, the thermal conductivity is approximately 3 times higher.

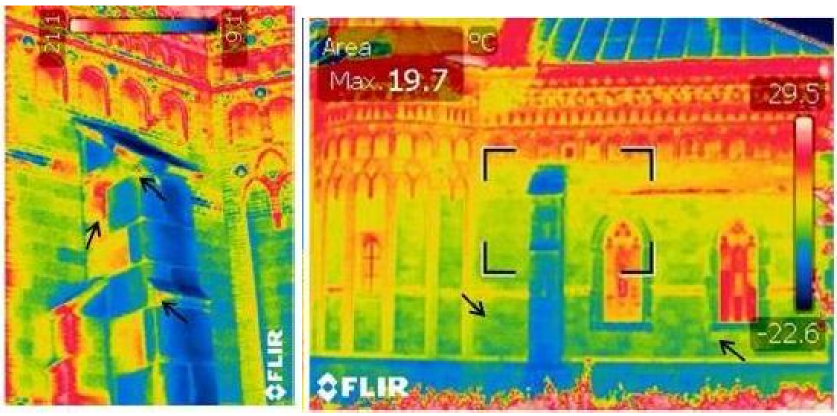

Fig. 2 – Infrared image taken at a worship halidom (Soveja & Budescu, 2015).

Taking into consideration that investigating heritage building invasive techniques must be avoided, in order to preserve their structural and architectural integrity, it is mandatory to use infrared thermography to determine the degradation state of the historic buildings. The IRT technique is noninvasive, its cost is low, and the results are highly reliable. In conjunction with the IRT technique, in order to determine the intervention measure, three fundamental aspects must be considered: the historical analysis (it requires the understanding of the concept, of the techniques used in the construction work execution, and the investigation of the events which, over time, produced degradations in the construction elements); the qualitative analysis (it involves the on-site examination of structures and degradations, in order to determine the degradation mechanisms, to include the building in a risk class); and the quantitative analysis (it refers to the determination of the physical, chemical, and mechanical properties of the building materials) (Paoletti *et al*., 2012).

2.2. FOM (Fibre Optique Microscopy)

The FOM technique is an investigation which uses a system with a built-in microscope, that can be used on-site to identify the construction materials used, to investigate their degradations (Fig. 3), to determine the efficiency of the applied solutions, (Fig. 4), to establish the compatibility between materials, and to identify the degradation type (Moropoulou *et al*., 2013).

Fig. 3 – Physical (first image on the left – cracks of the material) and biological (images from the middle and on the right) degradations, investigated with the FOM technique (Moropoulou *et al*., 2013).

Fig. 4 – Assessment of the intervention measures, investigated with the FOM technique (on the left – untreated area; in the middle and on the right – areas treated with solutions intended to reduce porosity) (Moropoulou *et al*., 2013).

The device can magnify the images 600 times and it is provided with an internal memory, where it stores them, for later access (Moropoulou *et al*., 2013). This technique can identify degradations caused by the action of water in the building elements, such as the presence of efflorescences, micro-organisms or of the cracks produced by freeze- thaw.

2.3. US (Ultrasonic Testing)

The US investigation technique is noninvasive and it uses high frequency sound waves to reveal material defects, discontinuities in the volume of the investigated element. The operating principle is based on the fact that the waves crossing the material layers are reflected by any encountered surface. To determine the humidity content in a building element, the principle is that the propagation velocity is inversely proportional to the amount of contained water (Moropoulou *et al*., 2013).

The US technique is used in historic buildings to determine the elastic constants of old materials and to assess the adherence between the authentic materials and those used in rehabilitation or restoration (Moropoulou *et al*., 2013).

2.4. NMR (Nuclear Magnetic Resonance)

Given the fact that, in hygrothermal terms, historic monuments are difficult items to rehabilitate, they consume a lot of energy, and the need to design some systems to monitor and to investigate their behavior becomes imperative (Litti *et al*., 2015).

The investigation of water content and water-soluble salts within a construction element can be carried out using the noninvasive NMR technique (Capitani *et al*., 2012). In the case of protected buildings, on whose walls there are painted valuable works, the only hygrothermal investigation method is Nuclear Magnetic Resonance. The intensity of the signal detected by this device is directly proportional to the amount of contained water, which allows drawing diagrams that show the water content associated with each surface of the investigated building material (Capitani *et al*., 2012).

2.5. GRP (Ground Penetrating Radar)

This technique has been used for a long time in archeology to discover buried artifacts or sites. The GRP technique is noninvasive and it uses electromagnetic radiations to discover the discontinuities in the material, defects in structures, cracks (Fig. 5), inner material layers, water presence, moisture content, and the effeciency of the adopted rehabilitation solutions (Moropoulou *et al*., 2013).

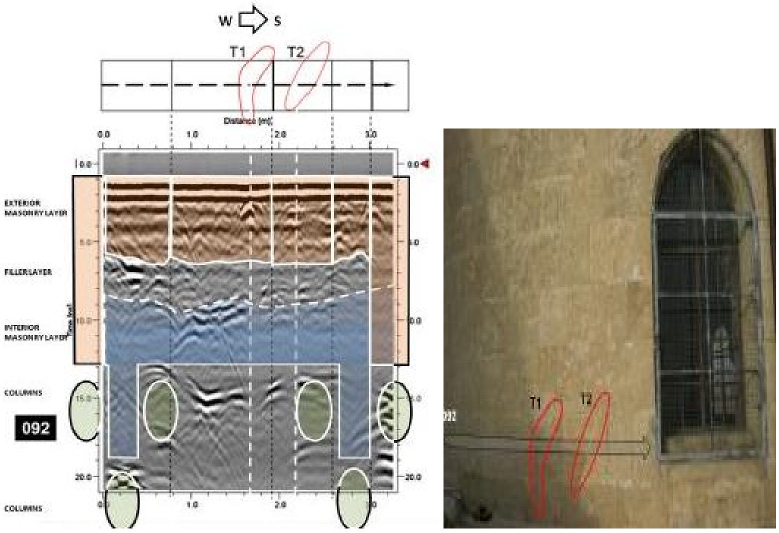

Fig. 5 – Area from a brick masonry wall, investigated with the GRP technique (Moropoulou *et al*., 2013).

For a correct interpretation, this investigation method must be corroborated with an analytical method or with other noninvasive method.

2.6. DIP (Digital Image Processing)

This type of investigation involves photographing the elements to be analyzed and their interpretation by means of a software that processes the digital image, allowing the classification and the identification of the tested materials. The method is based on the principle according to which each material reflects and scatters the light differently, which allows their classification by comparing them with the characteristics of other materials from the database of the used software (Moropoulou *et al*., 2013). Furthermore, by means of the DIP technique, degradations or discontinuities in the structure of the building materials can be discovered (Fig. 6).

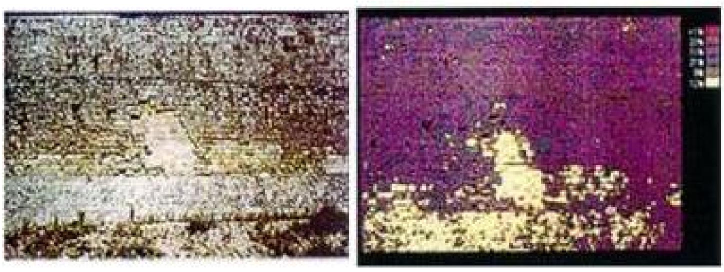

Fig. 6 – Degraded area investigated with the DIP technique (Moropoulou *et al*., 2013).

Methods, technologies or materials incompatible with the authentic ones were used in many rehabilitation or restoration cases, which accelerated the degradation of the buildings. With the DIP method, the compatibility between the materials brought by Moropoulou *et al*., (2013), can be clearly determined and the intervention measures previously adopted can be identified.

2.7. LTCC (Low Temperature Co-fired Ceramic)

In the case of rehabilitated or restored historic buildings, monitoring the sources that may produce degradations, such as the humidity content of the building elements, is extremely important. To this end, the use of a LTCC (Low-Temperature Co-fired Ceramic) sensor to monitor the old building humidity is proposed. The sensor consists of an inductor and a built-in capacitor and it can emit warnings when the microclimate parameter safety values are exceeded, fact which can lead to preventing degradation (Maksimivic *et al*., 2012). The features of the LTCC sensor are: significant sensitivity to the presence of water, fast response via wireless, resistance to the actions of aggressive factors, durability, plain design, low cost, adaptability to any old or new building system (Maksimivic *et al*., 2012).

This historic building monitoring method is very useful because it can quickly emit warnings when safety parameters are exceeded and, thus, it can facilitate the adopted intervention measures.

3. Conclusions

In the case of historic buildings, where rehabilitation or restoration solutions are very few and difficult to adopt, the investigation (Table 1) and the noninvasive assessment techniques play a decisive role in diagnosing the degradation mechanisms of buildings.

Despite the fact that modern noninvasive investigation techniques have a high accuracy degree and that they do not affect the integrity of the studied building elements, for the validation of the obtained data, they must be corroborated with analyses carried out in the laboratory, with numerical analyses or with other on-site investigation techniques.

Noninvasive techniques have a positive influence on the cultural heritage conservation and management, contributing to a sustainable development.

Table 1
Table Summarizing the Presented Noninvasive Techniques

Noninvasive techniques	Advantages	Disadvantages
DIP	- it allows the classification and identification of the on-site tested materials; - it contains an extensive database; - it establishes the compatibility between the studied materials.	- the on-site obtained data must be validated by laboratory tests, to achieve a greater accuracy degree.
IRT	-it can identify materials, cracks, degradations, discontinuities in the material; - it allows the identification of the areas affected by humidity; - it can evaluate heat transfer through casing elements.	- it is influenced by environment conditions [9].
GPR	- it has been used in archeology for a long time; - it can discover discontinuities in the material, defects in structures, inner material layers.	- the technique must be corroborated with an analytical method or with other noninvasive method, to verify data.
US	- it can identify material defects, cracks, caverns; - it can determine the amount of water contained in a material.	- the technique must be corroborated with an analytical method or with other noninvasive method, to verify data.
FOM	- it can identify the building materials, their degradations; it can assess the compatibility between materials; - it enlarges the images 600 times and it stores them in the memory of the device, for later access.	- the on-site obtained data must be validated by laboratory tests, to achieve a greater accuracy degree.
NMR	- it can evaluate the amount of water contained in a construction element and it can assess the decay state of the investigated elements.	- the technique must be corroborated with an analytical method or with other noninvasive method, to verify data.
LTCC	- thanks to the fact that the warning system is a wireless one, the sensor contributes to a rapid intervention, which diminishes damages.	- it has not been used on a large scale, to be validated

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TEHNICI NONINVAZIVE DE INVESTIGARE A UMIDITĂȚII LA CLĂDIRILE ISTORICE

(Rezumat)

Umiditatea este o cauză recurentă în degradarea construcțiilor vechi. Preocuparea cercetătorilor pentru investigarea umidității s-a manifestat încă din secolul al XIX- lea, însă tehnicile disponibile în acea perioadă erau aproximative, bazându-se, în mare parte pe experiența anterioară a specialiştilor şi nu pe date concrete. În ultima perioadă, progresul ştiințific a generat o serie de tehnici moderne, noninvazive de investigare a umidității şi a fenomenelor higrotermice întâlnite la clădirile vechi. Lucrarea are ca scop prezentare unor tehnici noi de investigare, cum ar fi IRT (Infrared Termography), FOM (Fibre Optique Microscopy), US (Ultrasonic Testing), NMR (Nuclear Magnetic Resonance), GRP (Ground Penetrating Radar), DIP (Digital Image Processing) şi LTCC (Low Temperature Co-fired Ceramic). Pe lângă descrierea principiilor de funcționare ale acestor tehnici moderne, se vor detalia avantajele şi dezavantajele utilizării acestora.