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Case study

A qualitative method for combining thermal imprints to emerging weak points of ancient wall structures by passive infrared thermography – A case study

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ABSTRACT

The significant number of buildings constructed in the world before the appearance of compulsory earthquake projecting norms, as well as the subsequent construction in the safe seismic zones, requires a constant re-evaluation of the strength of the structures. For example, the 2009 earthquake happened in L'Aquila city (Italy), killed about 300 people. Furthermore, many old buildings, seriously damaged, were considered as historical monuments and their importance is still critical both from a cultural standpoint and for the city itself. On the basis of the surveys carried out by the Las.e.r. Laboratory (university of L'Aquila) before and after 2009 earthquake, this paper introduces the infrared thermography (IRT) as a mean to characterize particular thermal imprints that appear on ancient facades, employing the passive thermography, discussing the infrared images collected during several years, and analyzing their relationship with all kinds of influence factors, in order to validate the effectiveness of the technique and its role in preventive diagnosis.

1. Research aims

Infrared thermography (IRT) for building diagnostics can identify abnormalities that could otherwise go undetected and could evolve to more serious problems.

In this paper, the performance and the effectiveness of IRT in the preventive diagnosis for consolidation and in the evaluation of the risk of damage after the 2009 seismic event based on an experimental campaign of the historical cultural heritage of L'Aquila city (Italy) and its surroundings are discussed.

2. Introduction

IRT is a proactive troubleshooting and predictive maintenance tool [1–3]. In building diagnostics, it is an excellent tool for fast identification of masonry textures and discontinuities, hidden structures, cracks pattern, structural failures, moisture and humidity problems. In the investigation of historical structures, where a restoration or conservation treatment can cause irreversible damage to the structure, it is considered to be of most importance, and together with other NDT methods can be also used on panel paintings, mosaics and frescos [4–7].

This method is excellent for subsurface investigations through acquisition of surface thermal patterns: temperature varying in space and time may reveal discontinuities beneath the surface, moisture growth, cracks or other kinds of defects. This is why it has been recently proposed [8] as a method to prevent historical building structures from damages caused by earthquakes. Moreover, there is the experimental evidence [9] that some subsurface cracks not detectable to the naked eye and evidenced by thermographic analysis represent the baselines of the damages produced by an earthquake. To go through this, an IRT diagnostic campaign was conducted before and after the 2009 earthquake that seriously damaged L'Aquila (Italy). In this paper, we present the results of the preventive thermographic campaign reconsidered by comparison with new measurements and inspections performed in the years 2009–2010. This investigation involved a relatively large number of historical buildings in order to give account of the potentiality and limits of this new application of IRT. In the following, a synthetic presentation of the area and of the buildings (§3) and then the experimental results (§5) will be presented. For the sake of brevity, we kindly ask the reader to check the references for a detailed description of the IRT technique and potential applications.

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3. Location and characteristics of the historical buildings considered in the research

All the historical buildings considered are located in the surroundings of L'Aquila (AQ) the regional capital of the Abruzzo region, in Central Italy. The area is full of historical buildings and monuments of different ages. In April 2009, it was hit by a shocking earthquake and most of these structures were seriously damaged. In this case study, five historical buildings are considered.

3.1. Santa Maria ad Cryptas, Fossa (AQ)

Santa Maria ad Cryptas is among the best examples of Gothic art in Abruzzo. It is at about 1 km from the center of Fossa, a fine ancient village 12 km East of L'Aquila (Italy). The investigation of this church was described in detail in a previous paper [9].

3.2. San Silvestro, L'Aquila

Built between the XIII and the XIV century in the surroundings of the West side of the city walls, the church presents a medieval structure with an elegant Romanesque-Gothic façade made of stone. On the right, there is a bell tower (XVIII century). The interior is typically gothic; paintings of rare beauty and frescoes are present.

3.3. Santa Maria di Roio, L'Aquila

The church of Santa Maria di Roio was built in 1391 and suffered extensive damage due to earthquakes over the centuries. The reconstruction changed and simplified the original façade, which is now divided in three bands by pilasters. The central part contains the portal and the great XIV-century rose window, whose dimensions are disproportionate to the overall church, consisting of radial columns variously made.

3.4. Santa Giusta, Bazzano (AQ)

According to tradition, it was built in the XIII century. The structure was altered over the years: the three original naves now can be seen only for the short initial section, while the rest of the building continues with two naves. The façade is the most noticeable part of the church, as it is composed by a grid of small columns and cornices dividing it in three tiers, where anthropomorphic or zoomorphic forms are present. On the left side there is the bell tower, perhaps erected together with the church.

3.5. San Domenico, L'Aquila

The church of San Domenico is part of a vast complex comprising also a monastery and two cloisters. The church, with its Latin cross structure, has two entrances: the main one, with a great Romanesque portal and two circular windows, and a secondary entrance, at the south transept. The plant, with its three naves, transept and apse, is typical of a XIV century church, while the interiors are mainly Baroque, due to the 1700 restoration works.

4. Materials and method

A qualitative comparison between an analysis based on naked eye survey (before and after the earthquake) and an analysis based on passive IRT (before the earthquake) is proposed herein in order to link the thermal imprints detected to the damage arose and affirm their contribution as key factor in a preventive diagnostic campaign. Qualitative analysis may involve direct observation of the structure to identify decay and damage, to determine whether or not the phenomena have stabilized and to decide whether or not there are immediate risks and therefore urgent measures to be taken.

The application of IRT in building diagnostics involves the evaluation of surface thermal patterns: temperature varying in space and time may reveal discontinuities beneath the surface that modify the heat flow. Once material properties and boundary conditions are roughly known or uniform everywhere, it is possible to locate the defects (discontinuities in masonry, filled openings etc.) of the wall by a map of the surface temperatures.

Generally speaking, each building should be analyzed in detail, clearly identifying the type damage and the resulting temperature pattern in an IR image. This task is made difficult by the great variety of existing masonry. Furthermore, to gain better insight into the structure, quantitative approaches should be used; currently, for the external façades, they are applied on small areas, working without expensive wide-angle lens, using a passive hybrid method, i.e., acquiring several images of the same part for hours during the natural thermal cycle [10]. Instead, for the internal façades, an active approach, i.e. using lamps, is usually used [11]. However, there is an interest also for qualitative and simple approaches that could be used on a large number of buildings and (as in the present case) on the results of previous surveys.

In the current investigation, the thermographic surveys have been repeated several times during the day and for many days, preferably in the early morning before sunrise and in the evening after sunset. Particular attention was paid to the definition of the distance from the instrument to the building, to assure the best fitting resolution for evidencing the irregularities of the structure. Basing on a virtual grid ideally dividing the buildings in parts, thermal images were acquired, post-elaborated and matched to obtain only one radiometric image. The device used is a Flir Systems ThermaCAM S65, based on a microbolometric non-cooled FPA detector, sensible to the spectral range 7.5–13 μm. The environmental conditions have always been recorded during the measurements by means of the thermo-hygrometer De Lorenzo Instruments DLIN TH500.

5. Experimental results

All the buildings were investigated by passive IRT in the period 2003–2008 and then after the 2009 seismic event.

Comparing the information of naked eye and thermographic surveys before the earthquake, it is possible to recognize some warnings of decay: capillary humidity coming from the ground (the coldest areas), incipient formation of cracks, and lack of homogeneity among different materials used. After the 2009 earthquake, the situation became so critical that safety measures were required to prevent further damages.

As shown in detail in [9], the state of cracking after the earthquake is quite superimposable to the map of decay detected before the earthquake, confirming the preventive value of thermographic diagnosis: although the damage was not visible by naked eye before the earthquake, traces of lack of mortar on the masonry and discontinuities were detectable by IRT.

By comparing the images on Figs. 1–4, the main damages can be detected:

- in S. Silvestro (Fig. 1), the overturning of the left upper part of the façade, as well as damages to the bell tower;
- in S. Maria di Roio, the damages are evident in the left upper part (Fig. 2);
- in S. Giusta, the bell tower crashed, and all the roof, especially near the central window is seriously damaged (Fig. 3). This is particularly interesting, because historical reconstruction studies [12] demonstrated a substantial remodeling of the façade in the