Detection of cracks in building facades using Infrared Thermography

Tiago Fonseca[1], and Joao C Ferreira[1,]

[1] ISCTE - University Institute of Lisbon, Lisbon 1649-026, Portugal

jcafa@iscte.pt

Abstract. Cracks in building facades can deteriorate the health of a building, putting in risk the well being of the people who use it or that are in its surroundings. Identifying the cracks and assessing the damage degree of a facade is essential to the maintenance life cycle of a building. Infrared thermography has been playing a major role in identifying cracks and other defects in building facades. The aim of this paper is to develop a simple quantitative model to assess the damage degree of the facades of two public schools managed by Lisbon city council using infrared thermography. It is observed that the measurement of Thermal Contrast profiles of the facades produces effective results in identifying cracks in the facades.

Keywords: Sensor, Data Analytics, Data transmission, Machine Learning.

1 Introduction

The health of a building is of great importance to society. The deterioration of building facades can not only cause problems in the normal function of a building but also cause problems with the structural integrity of the building, putting at risk people inside it and in its surrounding areas. Cracks in building facades affect the integrity, compromise thermal and water insulation and promote the degradation of the building by allowing erosive elements to infiltrate into the structure of the building [5]. Therefore, the detection of cracks is of great importance for assessing the health of a building.

Even though the inspection of the physical state of a building usually resorts on visual methods, those might not reveal the full extent of the damage, not showing the full dept of the cracks [2]. In recent years, infrared thermography has been playing an important role in assessing the damage degree of buildings. Being a non-destructive technique, it captures of radiation emitted by a building, displaying it as an image which represents the temperature distribution of the facade, that can be used to detect irregular patterns which can reveal damage in the facade of a building. The Lisbon City Council has a multitude of public buildings that need to function properly in order to provide a good and safe environment for the community and for its users. The need for a non-destructive method to evaluate the damage degree of public buildings has been identified by the City Council. The aim of this paper is to conduct an initial approach of a pilot study about the development of a method based on quantitative infrared thermography to assess the damage degree of building facades in public buildings of the Lisbon City Council (Camara Municipal de Lisboa) and qualify the gravity of the cracks.

2 Literature Review

A literature review was made to provide insight into work that was previously done regarding the detection of cracks in building facades using thermography and provide guidelines to explore different approaches to solve the problem. The search was conducted using the PRISMA methodology for systematic reviews [7], correlating the results of two searches of the same keywords ((”Infrared Thermography” OR ”Thermography” OR ”Thermal imaging”) AND (”Building Facades” OR ”Buildings” OR ”Facades”)) in two different citation databases (Scopus and Web of Science). The results were filtered by relevance according to the PRISMA Methodology [7]. Grinzato [8] described a quantitative time-based method for the use of passive infrared thermography for defect assessment in buildings, where simplified models to interpret the temperature profile of the surface and the thermal aspects of different defects are studied. It was concluded that while is possible to use infrared thermography to identify cracks size and location, the characterization of the degree of damage requires additional research. Fox [9] compares the use of Walk-past Thermography (the capture of external building thermal imaging, which is much faster and cheaper to perform) against the more traditional approach, Walk-through Thermography. The study shows that while Walk-through Thermography had a higher rate of success considering assessing defects, being more suitable for a detailed survey, Walk-past thermography is effective for a simpler approach to detect defects. According to Bauer [3], cracks in building facades can be classified by their severity, according to its depth and width, by measuring thermographic contrast between the temperature emitted by the region of the crack and the temperature emitted by the region without the crack. Bauer [1] highlights that being a technique characterized by the measurement of radiation emitted by surfaces, thermography for facade diagnosis is limited by depth and is most commonly used in detecting superficial and subsurface defects.

Depending on whether the exterior surface is warmer or colder than the inside, temperature monitoring over time enables determining the heat flow inward or outward [10-11]. The disruption of the heat flux brought on by the flaws enables the detection of the flaws and measurement of the damaged area. The thermograms collect and identify various temperature patterns that are caused by this disruption [12–16]. Even when the defect is not evident on the surface, each alteration in the flux pattern affects the thermogram and enables the identification of the damaged region [17-18]. The intended analysis may be influenced by and constrained by variables including thermal conductivity, moisture content, and the presence of structural components [19].

This method is obviously shallow and is utilized mostly for subsurface and superficial flaws. Among others [20], examined the alterations brought on by occluded elements, internal fractures, and other materials introduced in the brickwork (wood and polymeric foams). He was able to pinpoint facade irregularities in his examination with high accuracy in depths up to 5 cm.

3 Methods and Materials

Thermography is process for measuring the radiation emitted by an object. All objects with a temperature higher than Absolute Zero (0K or -273.15ºC) emit radiation which can be detected by a sensor. Since most of the radiation that the facade of a building emits is in the form of heat, which is within the infrared spectrum, it can be captured with an infrared camera and converted into a temperature profile of the facade [3]. Passive infrared thermography in building diagnosis is the process of measuring the radiation emitted by the building without relying on external artificial heat sources as depicted in figure 1. The only relevant heat source that is considered is the sun and the regular human activity inside the building, which may include the heat emitted by people inside the building and heat emitted by traditional heaters. Using Passive Infrared thermography for building diagnoses requires special attention to transfers of heat between the outdoor environment and the indoors of the building. As described by C.A. Balaras [4], During the day, solar radiation is absorbed by the external building surfaces, which increases in temperature. Consequently, heat Thermography is process for measuring the radiation emitted by an object. All objects with a temperature higher than Absolute Zero (0K or -273.15ºC) emit radiation which can be detected by a sensor. Since most of the radiation that the facade of a building emits is in the form of heat, which is within the infrared spectrum, it can be captured with an infrared camera and converted into a temperature profile of the facade [3]. Passive infrared thermography in building diagnosis is the process of measuring the radiation emitted by the building without relying on external artificial heat sources as depicted in figure 1. The only relevant heat source that is considered is the sun and the regular human activity inside the building, which may include the heat emitted by people inside the building and heat emitted by traditional heaters. Using Passive Infrared thermography for building diagnoses requires special attention to transfers of heat between the outdoor environment and the indoors of the building. As described by C.A. Balaras [4], During the day, solar radiation is absorbed by the external building surfaces, which increases in temperature. Consequently, heat

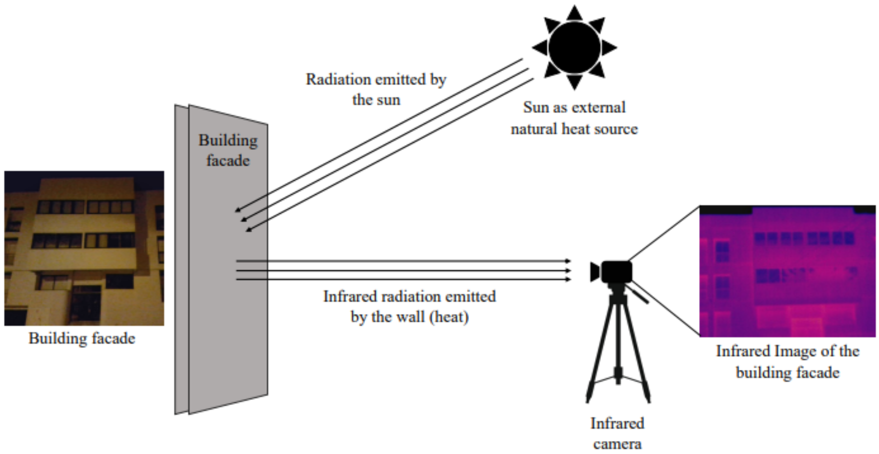

Fig. 1. The sun emits radiation that is absorbed by the facade of the building. Consequently, the building emits radiation within the Infrared spectrum, which is captured by an infrared camera and converted to an image.

4 Experimental setup

The main goal of this paper is to develop a simple quantitative method, using infrared thermography, to assess the damage degree of two public schools Lisbon City Council, located in the centre of the city of Lisbon, Portugal. Since the schools have very restricted access and a short window of time to be visited, the process had to be developed and evaluated in residential buildings with similar construction. The initial field study aimed to collect infrared images from residential buildings with similar construction as the schools. These buildings had cracks which were had been previously identified by experts via visual inspection. The final field study consisted in visiting the two public schools located in Lisbon and assessing the damage degree of the facades of the school buildings. 4.1 Instruments The infrared camera that was used is the Teledyne DALSA Calibir GXM320, equipped with a 13mm lens, outputting images of 320x240 pixels. The camera has an operating temperature range of -35ºC - 60ºC and an accuracy of ±4ºC when exposed to air in stable conditions. The sensor of the camera, which is a microbolometer (an uncooled thermal sensor), is sensitive to thermal energy in the long wave infrared wavelength, having a spectral range of $8 - 14\ \mu$m (the infrared spectrum extends from 710 nm to 1mm) as depicted in Figure 2.

The infrared radiation emitted by an object strikes the sensor, heating it, and consequently changing its electrical resistance. The resistance variation is converted by an analog-to-digital to a 16bit value, which is used to create an image. To measure the temperature profile of a building facade, the camera had to be calibrated to measure accurate temperatures. The temperature of each pixel can be calculated by the formula 1. The process for calibrating the camera is to measure the temperature of a black body at different temperatures and use the measures to calculate the Radiometry Gain and the Radiometry Offset.

$$TC = \frac{pixel\ value - radiometry\ offset}{radiometry\ gain} \quad (1)$$

The black body is set at different temperatures ranging from 35ºC to 45ºC. To calculate the Radiometry Gain, a linear regression is preformed between the Pixel value and the actual temperature of the black body with the following equation: $pixel\ value = b \cdot temperature + a$. The gain to apply is 100 over the computed slope ($100\ b$). This provides a nominal response of 100 DN per °C. To calculate the Radiometry Offset we calculate the mean of the deviation of the real temperatures in relation to the temperatures the camera was measuring. To measure the exact temperature of a facade, the formula 1 is applied to all pixels of the image.

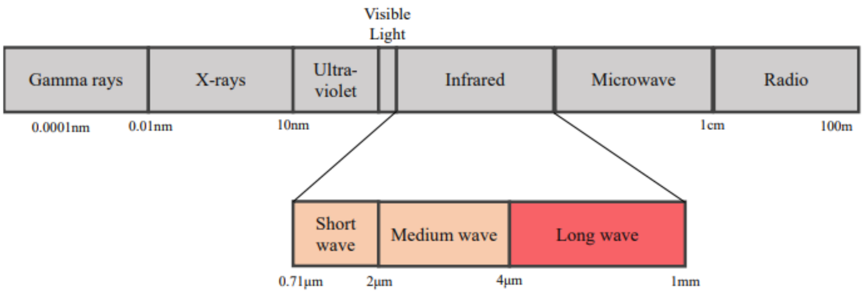

Fig. 2. Infrared Radiation and Electromagnetic spectrum

5 Results

The analysis of the residential buildings infrared images and thermal contrast profiles revealed that the process of radiometry used is able to identify most of the cracks that alter the thermal contrast profile of the facade of the building, thus compromising thermal insulation, which can be seen in figure 3. For plotting the thermal contrast profile, a section of the image, perpendicular to the crack, is selected and the thermal contrast is calculated for each pixel by subtracting the temperature in each pixel by the average temperature of the other pixels of the section, as described by [1]. There were some cases where this method was not able to detect smaller cracks. The reason for that is that those cracks apparent to be very superficial cracks in the painting layers of the buildings. However, there were also found some patterns in the thermal contrast profiles of the facades that appear to be cracks that were not visible by the human eye. Unfortunately, since those cracks were not previously identified by the experts, no conclusions can be made about those.

The analysis of thermal contrast profiles of the buildings that comprised the two schools showed no relevant signs of cracks in the facades. Some examples are shown in Figure 4.

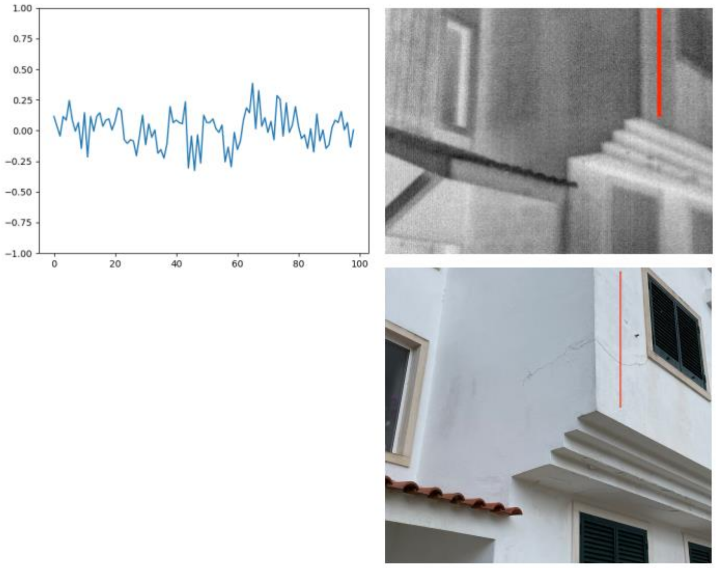

Fig. 3. Example of a facade of a residential building which had a crack that was detected. The top-right image shows the image captured by the infrared camera, in red is highlighted the section that was used to do the plot of the thermal contrast profile (top-left). A spike around the 65th pixel is visible, which corresponds to the crack. In the bottom-right is displayed a regular image, taken with a traditional camera that shows the facade of the building and the crack.

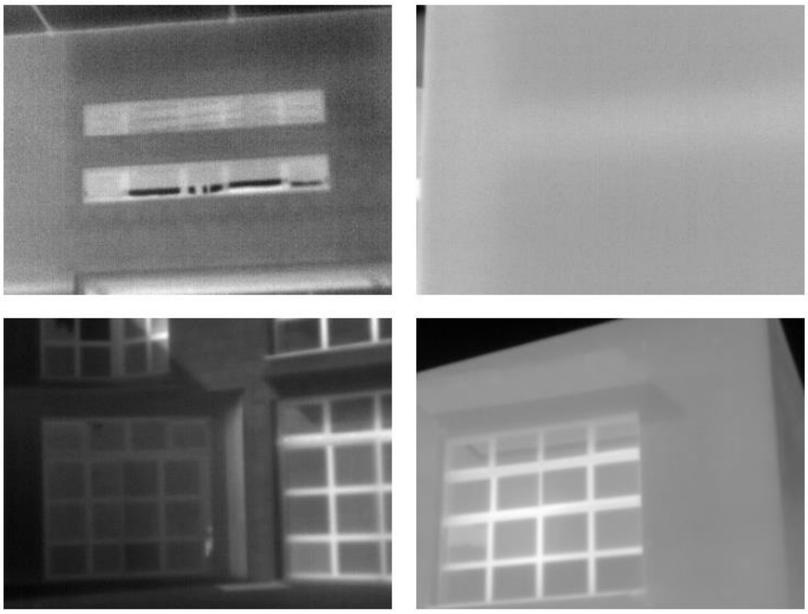

Fig. 4. Example of one of the public schools where no relevant signs of cracks were found

6 Conclusions

The aim of this study was to conduct an initial approach in the development of a quantitative method for damage assessment in the facades of the buildings by crack identification using infrared thermography. It was determined that the use of thermal contrast profiles of sections perpendicular to the crack is a viable option for crack identification. The method was evaluated in three residential buildings in Lisbon that was previously visually inspected by experts, showing appropriate results for crack detection. Since infrared thermography is a delicate technique, highly sensitive to environmental factors, such as currents of hot and cold air and air humidity, and this initial approach being conducted in the open air, by applying the method we were able to identify most of the cracks that were previously classified by the experts, producing good results. This first approach study shows that while the method described is useful for detecting and identifying the position and size of cracks in building facades, the classification of the crack and its absolute degree of severity requires further consideration. Furthermore, a preliminary study was conducted in the two public schools buildings managed by the city council. After applying the same method described above by measuring the thermal contrast profile of each section of the thermal images of the facades of the building, no signs of relevant cracks of patterns of damage caused by cracks were found. In conclusion, the results of this first approach study describe an effective method for the identification of cracks in building facades, which forges a path for future studies that might be conducted by the Lisbon City Council. And proposes an experimental setup that can be used to carry out further research on the topic. In future work, we intend to use a camera with more sensibility to explore small cracks and check the thermal efficiency of the buildings.

This was a first approach pilot study to assess the possibility of the identification of cracks in building facades using infrared thermography. In this work it was determined that the use of thermal contrast profiles produces relevant results in identifying the presence of cracks, however it was also determined that the quantitative classification of the depth and width of cracks needed further consideration. In future works, it is purposed the study of different use cases for the use of thermal contrast profiles to classify the depth and width of the cracks.

Acknowledgment: This work is partially funded by national funds through FCT—Fundação para a Ciência e Tecnologia, I.P., under the project FCT UIDB/04466/2020 and UIDP/04466/2020. Tiago has in the project UIDP/04466/2020 from Fundação para a Ciência e Tecnologia (FCT) e a Unidade de I&D, with the reference 4466

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