USE AND EFFICACY OF THERMOGRAPHY FOR STRATIGRAPHIC ANALYSIS OF HISTORICAL BUILDINGS

Cesare Crova*
Istituto Superiore per la Conservazione ed il Restauro,
Ministero per i Beni e le Attività Culturali
Rome, Italy

Francesco Miraglia
Dipartimento di Architettura, Università della Campania "Luigi Vanvitelli"
Naples, Italy

Keywords: thermography, historical buildings, stratigraphic analysis, restoration

1. Introduction

Non-destructive investigation techniques based on thermography in the infrared spectrum are well known in the scientific literature, which provides a lengthy list of publications. Most of these deal with its use in the field of civil and industrial maintenance; checking heating systems; predictive maintenance and safety; checking of components for electricity generation installations; and for checking energy containment [1] [3] [6] [8-9].

On the same wavelength are the UNI NorMal Recommendations: recommendation n. 10824:2009 specifies the method for identifying defects of adhesion to the substrate of thin coverings (on the order of microns and of millimetres), applied to industrial products and system components. The regulation applies to all industrial components with a geometry that is such as to permit direct examination using a thermographic system. Recommendation n. 18434:2011 provides a guide to the use of infrared thermography (IRT) as part of a status monitoring programme and for the diagnostics of the machines. Recommendation n. 16714-1:2016 describes the general principles for applying thermography in non-destructive tests, to detect and locate discontinuities (for example, hairline cracks, cracks, detachments and inclusions) in different materials (composites, metals, and coverings).

In construction, this technique verifies the presence of anomalies due to flawed insulation, humidity, air infiltration, and the presence of pathologies, such as masonry discontinuities. In the field of cultural heritage diagnostics, in-depth studies have been performed at the environmental Physics and Control laboratory of the *Istituto Superiore per la Conservazione ed il Restauro* since the early 1980s, yielding many articles on the use of this technique for studying the causes and mechanisms of decay [11], and initiating a series of more in-depth analyses on the issue of diagnostics aimed at conserving the cultural heritage [5] [6] [8] [10].

Non-destructive diagnostics is now frequently used by cultural heritage operators, thanks to the spread – due to the contained costs and ease of use – of qualitative

* Corresponding author: cesare.crova@beniculturali.it

and quantitative tools to analyze historical construction. Its development is fostered by operating needs that characterize conservation of materials, especially with regard to investigating pathologies of decay and structural stability [5] [10]. Moreover, the availability of non-invasive diagnostic techniques like thermography has led to its use on a large scale, enabling the collection of data for more in-depth research or, alternatively, creating a knowledge base for restoration interventions. Among the diagnostic techniques used in the field of restoration, thermography is also preferred over slightly invasive ones, like endoscopy, and over-invasive, mechanical-type ones, such as flat jacks (in masonry), or pull-outs (in plaster structures) [1] [3].

The assay focuses on the use of this investigation technique in the non-invasive analysis of architectural surfaces, not only as work site preparation activities but aimed at the critical knowledge of the structure, of the elevation's stratigraphy, and of its state of conservation. This technique was applied to examine the building fabric of the old centre of Sessa Aurunca, in the province of Caserta (Italy). The centre presents a palimpsest of Medieval construction techniques, in which successive layers of plaster, laid onsite over the course of centuries, have obliterated the information useful for documenting the growth of the inhabited area, still largely to be investigated.

The inspiration for the research project was provided by the removal of a portion of plaster from the Church of San Giovanni in Piazza (Figures 1-3), which cast light on a construction technique where recovered stone blocks were used as well as on the use of a corner column.

These particulars recall a manner of construction characteristic of the territory of Campania and Lazio (Benevento, Capua, Salerno, Sessa Aurunca, Fondi, Gaeta) [7]. This made it possible to move the construction of the religious complex from the fourteenth back to the twelfth century. This then led to the decision to investigate the architecture with the aid of thermography, used as an instrument for reading the elevation's stratigraphy [6].

It emerged that the use of thermography is a knowledge process to be directed not only towards understanding the conditions of conservation, stability, deformations in progress, and a building's alteration processes, but also towards investigating construction techniques. This is due to the fact that removal of the plaster is no longer required, as the work of studying the surfaces of the architecture can be done in an exclusively non-invasive manner. This results in the possibility of planning projects aimed at restoration, as well as historical investigation, thereby enabling an inspection of those previously inaccessible places, and providing information which would otherwise be unavailable or, in general, very limited in archival documents C.C.).

2. Objective and study methodology

Thermography makes it possible to acquire images in the infrared field (Figure 6), invisible to the human eye, without creating contacts between the diagnostic instrument and the analyzed object. In thermographic investigation, different materials are thermally excited, delivering different infrared radiations. The thermographic camera analyzes the heat an object emits in the infrared band, in order to build a radiometric-digital image in which surface temperatures can be displayed. The afore-mentioned temperatures are depicted in false colours that can consequently be distinguished by the human eye: the “cold” colours correspond to low temperatures and the “warmer” colours to higher temperatures.

In general, the temperatures are “described” with a palette of colours, widely used in the construction field. In other cases, in consideration of the operator’s needs, one may opt for a depiction in shades of grey or other colour combinations. The current devices – usually provided with an uncooled microbolometer detector like the one used in this investigation – are portable (of contained size and weight), precise (they can assess temperature differences in the order of hundredths of a degree) and affordable. They also make it possible to record digital videos and photos, which can be optimized using dedicated software.

For a good thermographic investigation, the item – free of reflecting or insulating materials – must be thermally excited: an appropriate thermal gradient between its surface and the surrounding environment must be allowed [1] [3]. When it is conducted in the open, the investigation may be altered or compromised by wind, rain, direct sunlight, or proximity of extraneous, high-temperature objects.

For this reason, the choice of the time for conducting the thermographic survey is also important and should be scheduled during afternoon hours, when the materials begin to release the absorbed heat. If this is not possible, then the support should be heated artificially to create conditions useful for the analysis.

Figure 1. Sessa Aurunca (Caserta), orthophoto extract (from Google Earth). The highlighted area shows the location of the church of San Giovanni in Piazza, between Corso Lucilio and Via Delio, on the north-south axis that characterizes the articulation of the historic city.

Not only does thermography make it possible to learn about the condition of a structure as regards its conservation and stability, the deformations and the alteration processes, such as humidity fronts and gaps in the plaster [9], it also allows the stratigraphy of its elevations to be investigated. It therefore takes on an important role in the science of restoring and conserving cultural heritage, representing an initial aid for acquiring information on a structure's material characterization.

The investigation presented here, carried out by means of remote sensing thermography, employed mainly in construction, regards a religious building located in the old province of Terra di Lavoro (in northern Campania), a territory now belonging to the province of Caserta: the Church of San Giovanni in Piazza in Sessa Aurunca (F.M.).

Figure 2. Sessa Aurunca (Caserta), Church of San Giovanni in Piazza. View of the façade on Corso Lucilio, highlighting the mediocre state of conservation of the finishings (photo: Francesco Miraglia).

3. Context and applications

Sessa Aurunca rises on a tuff plain over a very large territory, representing, from the western side, the outer boundaries of Campania towards lower Lazio. A *colonia* under Latin law, it became a *municipium* in 90 A.D. With the fall of the Roman Empire, it underwent a slow decline. It was one of the first Christian dioceses in northern Campania and in the late ninth century became a Lombard *gastaldato*. With Norman/Swabian domination, Sessa Aurunca began again to grow in importance, thanks to a vast programme of urban development.

The Angevin presence, on the other hand, was characterized by increased population in the northern quadrant of the settlement and fostered the development of new religious buildings. The city took on a role of major importance during the fourteenth century, with the rise of the Marzanos, the powerful family in the Kingdom of Naples who made it the capital of their feudal holdings.

Then, during the Aragonese domination, the Marzanos themselves made an important and thoroughgoing transformation and strengthening of the masonry wall. When Aragonese rule ended, Sessa was governed, starting in 1507, by Consalvo Ferrando de Cordoba, the first Viceroy of Naples. In the early nineteenth century, the city saw a phase of slow decline, without the influential families and the many religious orders that for centuries had characterized its sociocultural arrangement [4].

Figure 3. Sessa Aurunca (Caserta), Church of San Giovanni in Piazza. The base object of the thermographic investigation. The portion on the left is substantially intact, although marked by evident decay of the material; the portion on the right highlights a large gap in the plaster (photo: Francesco Miraglia).

The small sacred building is situated in the city's ancient square from which it takes its name (the Church was once known by the name "*de platea*") and has already been the object of an initial analysis by the authors [14]. It is dated to the fourteenth century, with reports of additional interventions dating to the eighteenth century. Despite this, it reveals complex stratigraphic traits. In fact, thermographic investigation has allowed it to be dated to at least two centuries earlier.

At about five metres above the road level, the second phase in the construction of the Church (Figures 4-5) was visible, as ashlars of local grey tuff were used which, also in this case, can be observed in a gap in the plaster of the upper portion of the façade, revealing the masonry above (C.C.).

Figure 4. Sessa Aurunca (Caserta), Church of San Giovanni in Piazza. The portion of façade (right side) is useful for understanding the revealed masonry composed of blocks of reused limestone with a corner column and superimposed rows of ashlars making use of grey Campanian tuff (photo: Cesare Crova).

Figure 5. Sessa Aurunca (Caserta), Church of San Giovanni in Piazza. The portion of façade (left side), does not show any useful elements for understanding the characterization of the masonry (photo: Cesare Crova).

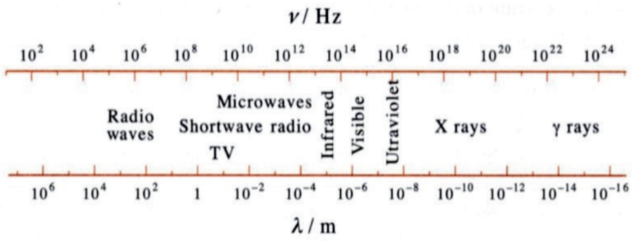

Figure 6. Representation of the electromagnetic spectrum indicating the thermal infrared field [12].

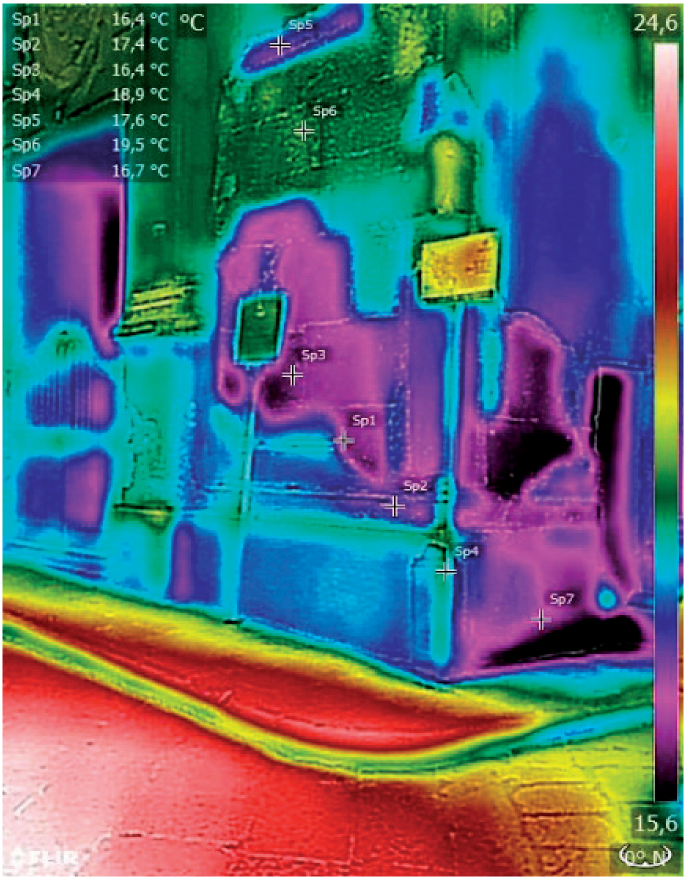

Figure 7. Sessa Aurunca (Caserta), Church of San Giovanni in Piazza. Thermogram of a portion of the façade (right side) with seven surveys performed in the 15.6-24.6°C range, for a total variation of 3.1°C (photo: Francesco Miraglia).

4. Discussion

The validity of the results obtained from the thermographic investigations are also enhanced through a necessary phase of interpretation of the thermograms, performed using IT applications available in various proprietary or open source formats. In essence, a thermogram restores, for each individual pixel – with a range that imposes the minimum and maximum temperatures within which to operate – the thermal characteristics of the examined objects, thereby permitting, in the post-processing phase, an overview of the individual responses of these objects to infrared.

The thermographic investigation was programmed on the basis of the data provided by the theoretical model, in the choice both of the timing and modes of operation, in order to avoid the drawbacks that a survey conducted outdoors and in broad daylight might entail in recording surface thermal distribution [2].

The thermograms obtained with this research, done on 04 April 2018 from 2:30 to 3:30 PM, delivered the following data. Emissivity: 0.80; reflected temperature: 22.0°C; distance: 3.0 m; relative humidity: 50%; atmospheric temperature: 20.0°C; transmission: 0,0; IR window temperature: 25.0°C; IR window transmission IR: 1.00 (Figures 7-9).

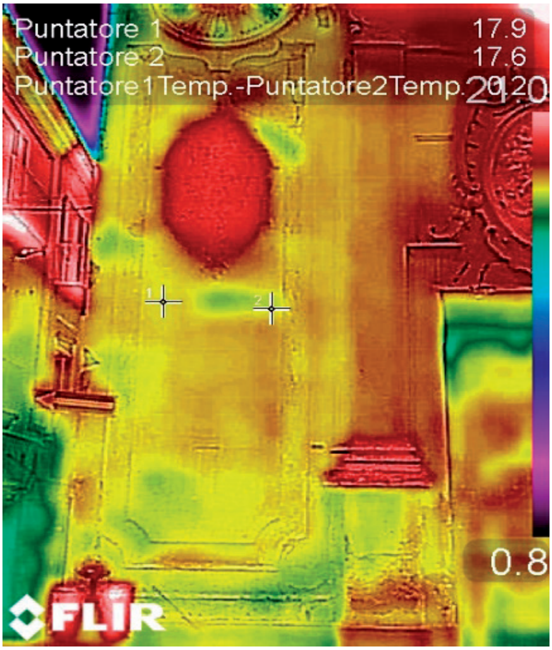

Figure 8. Sessa Aurunca (Caserta), Church of San Giovanni in Piazza. Thermogram of a portion of the façade (left side). Two surveys are highlighted with an almost imperceptible relative variation (photo: Cesare Crova).

With a resolution of 640x480 pixels (considered high definition from a thermographic standpoint), the thermograms were obtained with a Flir[tm] thermographic camera using MSX (Multi Spectral Dynamic Imaging) technology (Figure 10). Its integrated processor allows it to produce detailed images. With this technology, the details of the digital photo are superimposed onto the thermal one, offering a sharper analysis spectrum than that rendered by other devices. This technology makes it possible to take advantage of the considerable amount of graphic information only found in digital photographs (for example: overhanging elements, wall texture, etc.) (F.M.).

5. Conclusions

The experimentation presented here, originating from the loss of plaster on the right side of the Church of San Giovanni in Piazza, shows that, with the use of thermography, details of a structure different from those for which this type of investigation is preferred by technical operators, may be easily analyzed.

The initial knowledge phase which, with thermography, provides qualitative and "surface" type values, must often be supplemented by additional diagnostic techniques, in order to create a synergy among various methods. This achieves a broader path of knowledge useful above all in the field of restoration, in which the interdisciplinary approach helps to discern complex problems and to define appropriate guidelines after evaluating the results [8] [13].

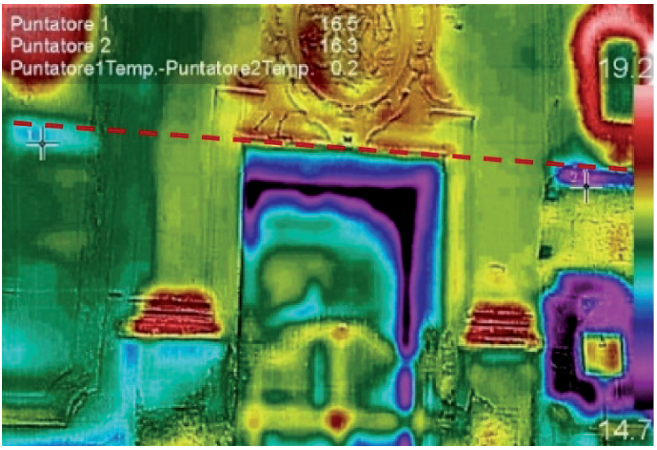

Figure 9. Sessa Aurunca (Caserta), Church of San Giovanni in Piazza. Thermogram of the lower portion of the façade, obtained by comparing the temperatures of the analyzed points. Two readings are highlighted, included in the 14.7-19.2°C range. Of note is the substantial correspondence of emissivity (0.2°C), which demonstrates its thermal homogeneity. The dotted line marks the coplanarity of the two readings: pointer 1, the horizontal break highlighted in infrared on the left portion; pointer 2, the change in pitch in the masonry on the right (photo: Francesco Miraglia).

In conclusion, it is important to point out, however, that the use of non-invasive, non-manipulative and non-destructive analytical technologies, including thermography, is of great value for diagnostic-analyses and enables significant results to be obtained, even though of a qualitative order, relating to the object being investigated. It is also true that, considering the appropriate methodology used, it is also useful to use suitable invasive technologies, thus correctly and comprehensively providing a quantitative analytical framework.

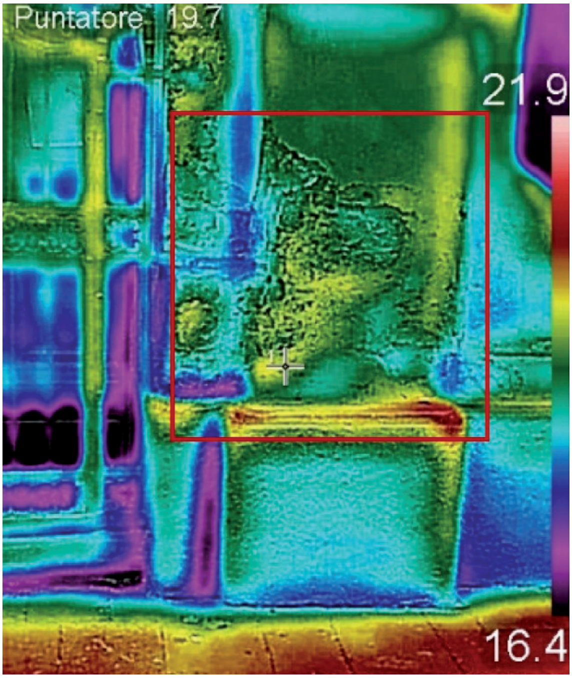

Figure 10. Sessa Aurunca (Caserta), Church of San Giovanni in Piazza. Thermogram of lower portion of the façade, performed to the right of the entrance portal. The application of MSX technology emphasizes a large number of details that would otherwise be impossible to highlight in a thermographic investigation, such as the texture of the various materials that have been examined (photo: Cesare Crova).

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Biographical notes

Cesare Crova graduated in Architecture; he is a specialist in Restoration of monuments and has a Ph.D. in Conservation of architectural heritage; he is a professor in Architecture Pathology at ISCR SAF. He has carried out teaching and research at IUAV, the "Sapienza" University of Rome, the University of Molise and the Cultural Heritage Department at the University of Padua. He works in the field of cultural heritage conservation, where he is part of several working groups at MiBACT, in addition to

planning and directing restoration work. He is the National Vice President of Italia Nostra and a member of the CDA of the Circeo National Park; he is a committee member of the UNI Technical Corps at UNI / CT 033 / SC 01 / GL 01 “Guidelines and terminology” and a member of MiBACT Unite 4 Heritage (MiBACT H4U), “Blue Culture Helmets “; he is an ordinary member of the “Centro di Studi per la Storia dell’Architettura” (Rome).

Francesco Miraglia graduated in Architecture; he has a Ph.D. in Conservation of architectural heritage; he is an architect, Honorary officer for the protection and supervision of the architectural heritage in the provinces of Caserta and Benevento (MiBAC), former Adjunct Professor of “Caratteri costruttivi dell’edilizia storica” (Università della Campania). He is the author of many studies on the protection of cultural heritage; he has been a member of local commissions for the landscape protection of several Italian municipalities. He is the coordinator of the scientific committee of “Terra Laboris. Itinerari di ricerca” (Caramanica Editore). Since 2006 he has been a member of “Società Napoletana di Storia Patria” (Naples). Since 2017 he has been an ordinary member of “Centro di Studi per la Storia dell’Architettura” (Rome). His professional activity is focused on the restoration and conservation of cultural heritage.

Summary

The use of thermography made it possible to investigate an ancient church viewed from a historical perspective, in order to learn more about its construction characteristics. This non-destructive diagnostic technique enabled a stratigraphic investigation of the structures in elevation to be conducted, resulting in the acquisition of new information and confirming the validity of its use in this complex field of application.

This initial phase of knowledge acquisition provided an opportunity to propose a line of study to be conducted through the application of various instruments and techniques, starting with thermography, in accordance with a rational order. Instrumental results of the investigations as they are carried out, might suggest the location of points in which to continue with subsequent investigations, while at the same time defining appropriate guidelines in assessing the results.

Riassunto

L’uso della termografia ha permesso di studiare un’antica chiesa vista da una prospettiva storica, per saperne di più sulle sue caratteristiche costruttive. Questa tecnica diagnostica non distruttiva ha permesso di condurre un’indagine stratigrafica delle strutture in elevazione, ottenendo l’acquisizione di nuove informazioni e confermando la sua validità in questo complesso campo di applicazione. Questa fase iniziale dell’acquisizione delle conoscenze ha offerto l’opportunità di proporre una linea di studio da condurre attraverso l’applicazione di vari strumenti e tecniche, a partire dalla termografia, secondo un ordine razionale. I risultati strumentali delle indagini man mano che vengono eseguiti possono suggerire l’ubicazione dei punti in cui continuare le successive indagini, definendo allo stesso tempo linee guida appropriate per la valutazione dei risultati.