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MORE COMPREHENSION, MORE PROTECTION: NON-DESTRUCTIVE TECHNIQUES IN THE SURVEY OF THE FORMER S. SALVATORE HOSPITAL IN L'AQUILA, ITALY

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Abstract

Non-destructive techniques are fundamental tools for a thorough knowledge of the construction aspects, structural conditions and pathologies of buildings. These tools become indispensable in the investigation of the Architectural Heritage subject to protection, guaranteeing the minimum invasiveness of the surveys in compliance with the architectural constraints. This paper shows the contribution that thermographer and thermofluometry have given in the knowledge and communication of the Former S. Salvatore Hospital in L'Aquila, Italy. The building, following the damage suffered by the 2009 earthquake, has been the subject of numerous studies but the analyses presented in this work represent an element of novelty and a fundamental step for the upcoming restoration interventions.

Keywords

Non-destructive techniques, architectural heritage, documentation, interpretation, communication

1. *Introduction*

The Architectural Heritage under restoration, that aimed at preserving and enhancing its values and usage, needs to be in-depth investigated throught exhaustive and complete surveys in order to offer to the designers a full comprehension of the artifacts involved.

Moreover, in emergency contexts where valuable buildings have been damaged by natural disasters such as earthquakes – as the case presented – a recovery process presupposes investigations and analyses designed to guarantee also an adequate safety during the *in-situ* surveys (Binda et al., 2006; De Vita et al., 2018).

The knowledge process is related to the study for all the characteristics of the building to analyse, and in particular way its historical, constructive, material and structural aspects.

The approach described in this paper is one of the recommended preliminary steps for the Cultural Heritage restoration project and, at the same time, fundamental for a multidisciplinary approach based on specific and differing core competencies where is needed to acquire the in-depth knowledge before intervening in a more invasive way on the buildings (Ascione et al., 2017; Grinzato et al., 2002; Moropoulou et al. 2013; Soares et al. 2019).

The preliminary analyses shown in this paper allow us to identify the features that need to safeguard as well as the aspects that characterize the buildings state of degradation and its structural vulnerability. On the basis of these analysis, the effective restoration project starts with coherence in method and targets. Lastly, a deep-knowledge of the constructions and degradation aspects of the building permits to evaluate its retrofit accurately.

The purpose of this paper is to show how thermograhic and thermofluximeter analyses, thanks to their communication and interpretation data tools, contribute to restoration projects guiding the retrofit solutions and ensuring the interventions compatibility manteining the building preservation as an aim.

2. *Non-destructive techniques and constrainted contexts*

The recovery of valuable historical architecture and its retrofit will be complex, especially considering the Cultural Heritage as a central issue. In order to preserve and valorise valuable historical buildings, in-depth knowledge is the main aim of the first steps in a reconstruction process.

Using diagnostic non-destructive techniques during the knowledge process, has been shown to be most effective in responding to different restoration needs: non-destructive techniques, if properly exploited, provide uniform data useful for the deepening of the different aspects of the building, supporting the multidisciplinary approach and ensuring that investigations are carried out safely both for the building to preserve and the technicians working on site (De Berardinis et al., 2018; Napolitano et al., 2019).

Among these, thermal imaging is a non-invasive technique used in the work presented that provided accurate information concerning the buildings analysed, its structural aspects and envelope degradation, detecting moisture, presence of water, voids or hidden unexpected materials (Maierhofer et al., 2015).

In fact, thermal imaging data combined with historical survey on the buildings, allowed us to trace back transformations such as the sealing or opening up of different rooms, integrations, planning accretions or interventions subsequently covered up by further stratification, clarifying the aspects related to construction techniques (Balaras & Argiriou, 2002).

From environmental issues point of view, these kind of analyses also permitted to establish the thermal capacity of masonries, useful for the energetic retrofit, as well described in this work.
In order to accurately define the thermal transmittance of the masonry, the investigation with the thermal imaging camera has been combined with a thermofluximeter survey, as described below.

The two techniques also represent a fundamental resource for the design of the structural investigations. In fact, thanks to a complete knowledge of the morphology and to the state of the envelope is possible to optimize the subsequent destructive surveys, limiting them in quantity and allowing to establish the ideal position of the destructive tools - such as the flat jack - on the supporting wall.

The instruments used during the non-destructive surveys presented are the thermal camera FLIR E75 and the thermofluximeter, both illustrated in figure 1.

Fig. 1: Thermo camera and thermofluximeter used

2.1 The Italian scenario: limits and potential of a complex reality

In the last decades, the attention to the retrofit issues of the Architectural Heritage has led to the definition of a well-structured legislation both on the topics of seismic improvemet – providing the best procedures to follow in the planning, coded in a directive of the Council of Ministers President on the assessment and reduction of seismic risk of cultural heritage (February 9, 2011) – and from an environemental point of view.

However, in relation to interventions on Cultural Heritage, there is a lack in joint design methods and interventions that has to look at the protection problems too.

In October 2015 MIBACT and AICARR published *The Guidelines for the improvement of energy efficiency in the Cultural Heritage* (MiBACT, 2015) where an energy diagnosis of the building aimed at defining possible improvement interventions. The Guidelines suggest, in this sense, to intervene through interdisciplinary dialogue, approaching the project from a whole perspective and not for single and specific solutions.

The Guidelines intervene in a field of application in which is not possible to answer to the specific needs of emergency context thoroughly, e.g. characterized by past seismic events, such as the case of L'Aquila: a stratified context where restoration has to foresee huge structural and architectural interventions.

From this scenario, it can be concluded that in the preliminary steps of the restoration process, the choice of investigating the envelope intervening in a minimal manner – ensured by the tools used in non-destructive surveys – represents the best solution in order to guarantee the architectural values protection.

2.2 More comprehension, more communication

The surveys carried out on the former Hospital using non-destructive techniques, represented a procedure able to deeply investigate the masonries of the buildings involved without damaging them and gave results of great importance for the planning of the structural and architectural interventions, safeguarding the historical values of the constrained façades.

Overcoming the fundamental contribution that these surveys made to the analysis of the current state of the envelope, the support in terms of communication of the collected data was not secondary. In fact, as previously analysed, the restoration project of the protected heritage, involves very different professionals and this fact causes many difficulties in a coherent resolution of the design process. Having a clear, tangible, visible and irrefutable map of the conditions of the artifact represents the uniform basis on which all the designers are called to confront each other and with which they return to relate in the subsequent stages of retrofit interventions to define.

3. Case study

The former S. Salvatore Hospital of L'Aquila is characterized by an intricate history which finds a mirror in the evolution of the architectural phases and its constructive stratifications, as can be seen from the aerial view in figure 2: the structure, as we can see it today, is made up of several buildings, the majority of which were built during the 20th century.

The architectural complex is currently owned by the University of L'Aquila and it is situated near

Fig. 2: Aerial view of the Hospital S. Salvatore

Fig. 3: The *muratura listata* visible thanks to the detachment of the plaster

the ancient city walls, in the north of the city. Following the Abruzzo earthquake of 2009, the building is in a state of serious damage: since then the University of L'Aquila has been involved in numerous technical analyses and studies about the structure, including several degree thesis (Massari, 2018), a feasibility study (University of L'Aquila, 2017) and a pending research project.

The work carried out in the feasibility study concerned an accurate analysis of the additions present in the architectural complex. This analysis aimed at identifying new destinations of the buildings - in particular the student residence and an underground conference hall – completely in coherence with its history. The analysis involved accurate archive investigations, a drone survey and a first thermographic survey carried out exclusively in the most ancient building area characterized by mixed stone masonry (Berardinis et al., 2018).

The work presented in this paper belongs to the aforementioned context and, in particular way, aims to investigate the distinctive part of the architectural complex corresponding to the 1931 extension and characterized by a singular *muratura listata* (figure 3) in which there are reinforced concrete pillars, probably confering a greater rigidity to the structure which presents some fragility mainly due to its irregular shape and a big internal court, as it can be seen in figures 4, 5.

The numerous successive modifications undergone by the former San Salvatore hospital are now widely documented in literature (De Berardinis et al., 2018; Bartolomucci, 2017).

In fact, archive documents and on-site visits revealed how the hospital had changed since its foundation in 1875, recovering pre-existing structures from the monastery of Saint Agnese –

which dates back to the 14th/15th century and was abandoned, in 1807, after the Napoleonic suppression and several of its buildings were subsequently incorporated into the new hospital. The subsequential changing concerned also the monumental church of Santa Maria del Guasto: at first it was decided to double the size of the building and incorporate the church into the new structure, but in the end it was demolished.

Fig. 4: Graund flor plan. In red: 1931 extension

Fig. 5: Part of the south façade analysed

Althought the hospital received light damages in occasion of the 1915 earthquake, several structural improvements were made, while an overall renovation programme was started in 1930 and in 1931 appeared the first project to extend and renovate the architectural complex, with the demolition of external walls and the construction of a new wing behind the existing structure, which was mainly conserved and that is the subject of this study.

3.1 The thermographic analysis

The thermographic tests were carried out on the South, West and North façades. The planning of the termographic test was fundamental: after the first inspections, an operational sequence of the test was drawn up, defining the time slots, the façades to analyse, the methods and phases of the tests and the goals to achieve (table 1).

A suitable distance to point the camera from was chosen and was around 7 meters from the building; from this distance, it was possible to

Tab. 1: Operational sequence

Time	Facade	Test Mode	Phase	Objective
07:00	EAST	Passive	-	Presence of water
09:00	EAST	Active	1° Heating	External detachments
10:00	SOUTH	Passive	-	Presence of water
10:30	EAST	Active	2° Heating	Wall texture
12:00	SOUTH	Active	1° Heating	External detachments
12:30	WEST	Passive	-	Presence of water
13:30	SOUTH	Active	2° Heating	Wall texture
14:00	EAST	Active	Cooling	Wall texture
14:30	WEST	Active	1° Heating	External detachments
15:00	NORTH	Passive	-	Presence of water
15:30	WEST	Active	2° Heating	Wall texture
16:00	SOUTH	Active	Cooling	Wall texture
17:30	WEST	Active	Cooling	Wall texture

analyse a very large portion of the façade elevation without exceeding the inclination of +/-45° of the instrument: binding condition to achieve a successful test.

After calibrating the thermal camera by setting the emissivity data, the adopted distance, the unit of measurement and the temperature scale, the scans were carried out in a vertical direction, moving the instrument to the next position and performing the following vertical scan progressively. The operating sequence shows all the tests that have been realized at different times and through different methods.

Taking the elevation with the highlighted south façade as an example (figures 6 and 7), it is possible to understand the used methodology. The façade was analysed at 10:00 a.m. in passive mode, detecting the energy emitted under stationary operating conditions, which is when the element is in thermal equilibrium.

The objective of this specific test was the thermohygrometric verification of the masonry, which results in determining the presence of water inside the wall caused by water infiltration, or the lack of it, as shown in figure 8.

The same façade was analysed in active mode at 12:00 and 13:30 during the first and second heating of the wall, which means that the camera was used during a thermal stress. In this condition the variations in temperature of the objects under investigation are taken into account, allowing the user to determine the existence of external detachments or a different stratigraphy throughout the wall, as shown in figures 9 and 10.

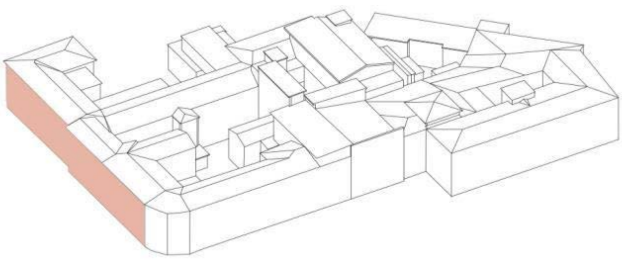

Fig. 6: South façade highlighted in red

After having carried out the tests established in the initial planning phase, through the use of the FLIR TOOLS+ software, it was possible to import, modify and analyse the images previously acquired with the thermal camera. The software allows the calibration of the colors and temperature scales without losing their thermal significance; moreover, it was possible to blend the photos of an entire façade together, thanks also to the geolocation feature of the thermographic camera during the test in situ and the fact that the images were shot so as to have an overlap of at least 30%.

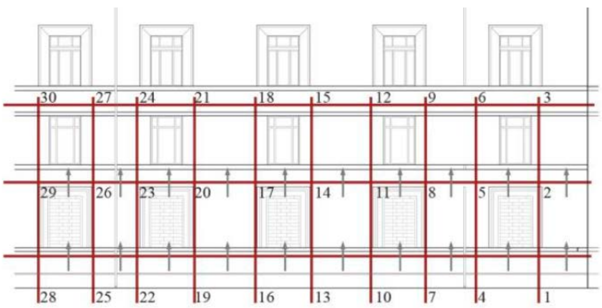

Fig. 7: Thermographic scanning mode on south façade

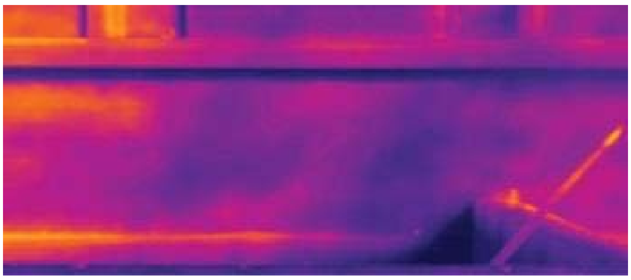

Fig. 8: Presence of water detected on the South façade

In the figure 11 it is possible to see the reconstruction of the south façade analysed in passive mode and in the figure 12 the reconstruction of the south façade analysed in active mode. The reconstruction of the north and west façades is shown in the figures 13 and 14.

3.2 The thermofluximeter analysis

During the inspections of the building, the portion of masonry to analyse was chosen as the specimen for the following considerations.

The necessary conditions for successful monitoring of a specimen masonry are: the temperature difference must be of at least 10°C between the outside and the inside environment, the chosen wall must be homogeneous, far from

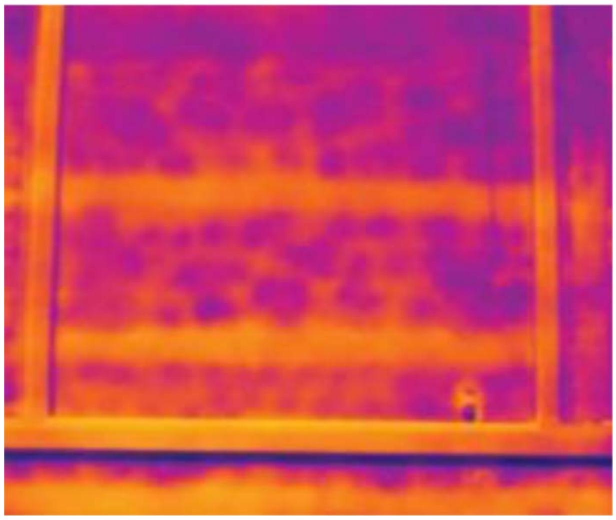

Fig. 9: Wall texture - masonry striped with stones with double recourse of brick

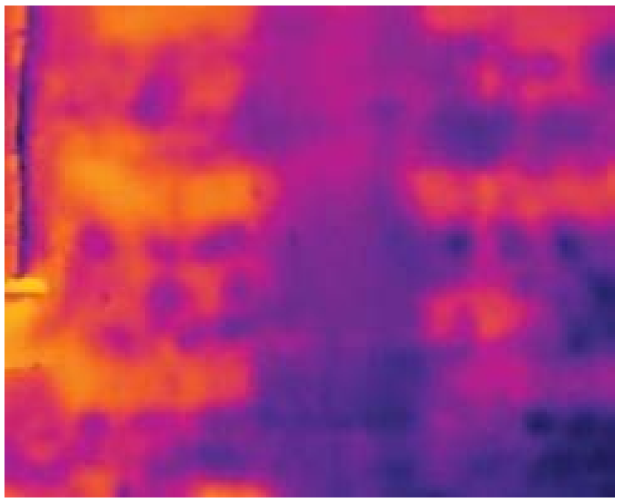

Fig. 10: Wall texture - mixed structure consisting of masonry walls and reinforced concrete pillar

Fig. 11: South façade - time: 10:00

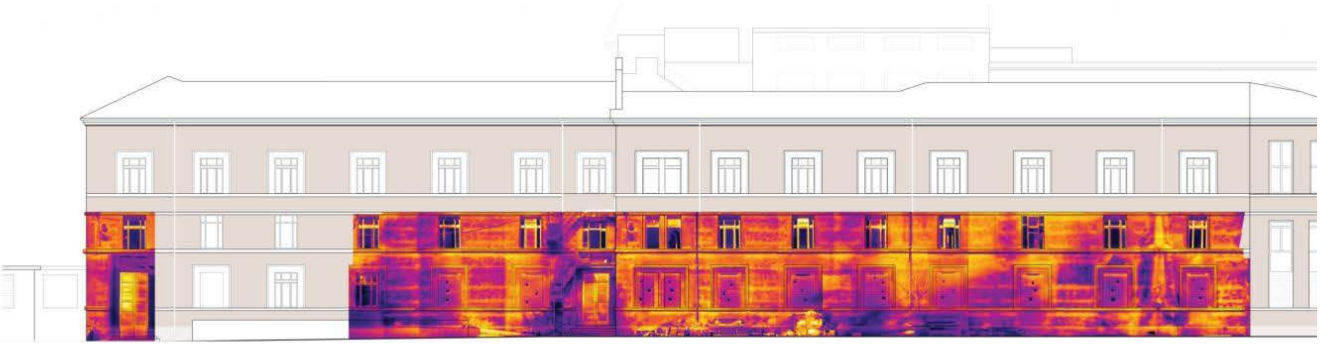

Fig. 12: South façade -time: 13:30

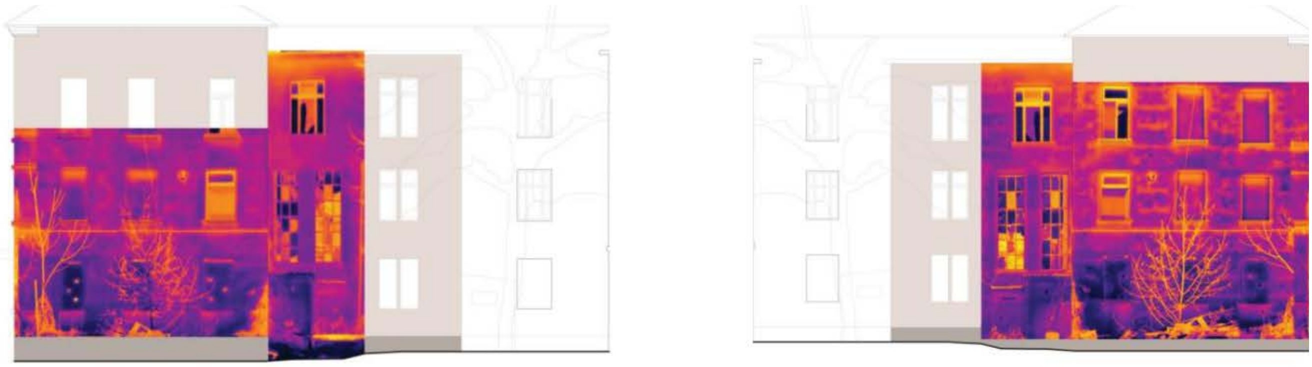

Fig. 13: North façade -time: 11:00 and 15:00

Fig. 14: West façade -time: 12:30 and 15:30

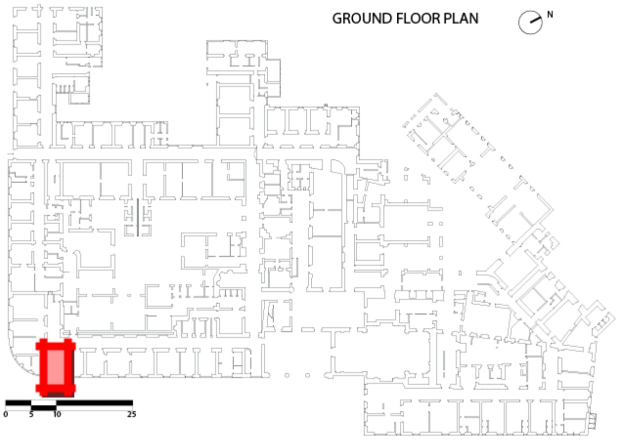

Fig. 15: In red: position of the room analysed

Fig. 16: The plate on the inner side of the mensory to analyse

thermal bridges and not directly exposed to sunlight.
The room indicated in the figure 15 was chosen for its orientation, as it has a wall facing East - protected by a building cloth cover that avoids direct sunlight - for its small size and for being the only room on this front that does not have concrete pillars, which would have been thermal bridges. The room has an area of 18 m^2, a volume of 60 m^3 and an external wall with a thickness of 0.70 m.

As the building had been in disuse for many years, simple interventions had to be carried out to achieve the necessary conditions for a good monitoring: the window was insulated with a polystyrene panel to avoid heat dispersion, the door was sealed and a gas-fired hot air generator was activated during the 12 hours before the thermofluximeter was installed.

Another inspection was done with the thermal camera to verify the homogeneity of the wall and therefore the actual absence of thermal bridges, and to identify the exact point where to place the probes of the instrument. This was a necessary procedure to avoid the lines of horizontal bricks that intersected with the natural stones masonry structure in order to monitor the thermal flow on the masonry stone wall itself.

The instrument was positioned on January 23 2019. The thermofluximeter plate was fixed - in the point previously checked by the thermocamera - using an adhesive tape and making sure that the logo was not covered to avoid insulating the sensor, as shown in figure 16. On the outside, the probe was fixed in correspondence with the thermofluximeter plate and set to send the data every 10 seconds. In figure 17 it can be seen how the probe was fixed to the scaffold that supports the building cloth cover. The instrument, once connected to the thermofluximeter plate, was activated. The monitoring was set in the automatic mode, with a measurement frequency of every ten minutes which adds up to a total number of 430 measurements during 72 hours.

The values were analysed using the Testo Comfort Software Professional 4, which can store and read the collected data and draw graphs with it. In figure 18 it is possible to see the graph of the monitoring data: in the first hours of it, the values were very fluctuating while in the last 24 hours they stabilized, providing the correct U-value (W/m^{2}K).

3.3 The results of the surveys

With the thermographic tests, through the prospectus reconstruction, it was possible both to find anomalies in the building and to verify the data of which there was not absolute certainty. One of the problems detected was the capillary ascent, highlighted in the façades analysed through passive mode. The examination of the masonry texture was interesting, which was instead highlighted in the façades analysed in active mode. The historical sources of the building had provided information on the type of wall texture, composed by striped masonry of stones

Fig. 17: The thermofluximeter probe, external view

with double bricks recourse every 0.60 m and information on the presence of reinforced concrete pillars in some areas of the building. By means of the thermographic analysis, it was possible to verify both the exact position of the double recourse of bricks and the actual presence position of the pillars. It was also possible to detect the presence of ring beam of which we did not have certain information before the surveys carried out.

Althought it was not possible to examinate the the entire masonry envelope of the architectural complex, from the intersection of investigations between non-destructive tests and the retrieval of historical sources it was possible to state that this type of wall texture is present throughout the portion of the building corresponding to the 1931 expansion.

Thanks to the thermo-fluximeter analysis it was possible to measure an average transmittance value of the masonry, obtained during the 72 hours of in situ monitoring.

Considering the last 24 monitoring hours, during which the internal conditions of the room have been stabilized (constant temperature), the U-value has been measured making an arithmetic average of all the valid values obtained (table 2).

The results of both tests types greatly contributed to the characterization of the building under exam. A good level of knowledge about the product can be achieved by acquiring qualitative information concerning the thermographic test and quantitative information from the thermo-flowmetric test.

On the basis of the results achieved, it was also possible to carry out an energy diagnosis based on real transmittance values of the investigated masonry that, following the analysis with the thermal imaging camera, it is characterized continuously on the surface. In addition, the energy diagnosis, supported by this type of tests, is essential not only in the *ante-operam* phase but

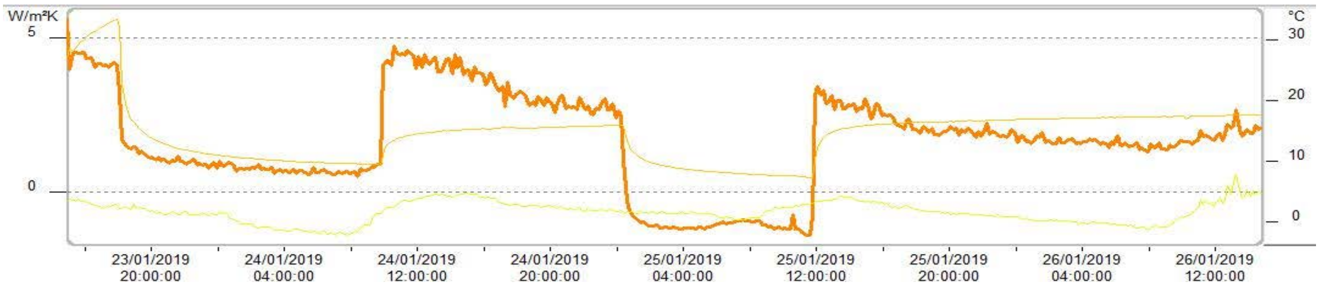

Fig. 18: Graph of the monitoring results

Tab. 2: Calculation of the average U-value

		Unit of measure	Time schedule	Minimum value	Maximum value	Average value
Trasmittance	U	W/m2k	From 25/01 02:55 p.m. To 26/01 02:55 p.m.	1.29	2.87	1.817
Internal temperature	Ti	°C	From 25/01 02:55 p.m. To 26/01 02:55 p.m	15.9	17.7	16.9
External temperature	Te	°C	From 25/01 02:55 p.m. To 26/01 02:55 p.m	-1.3	7.7	1.3

also in the *post-operam* phase, as a control tool to assess the actual improvement of building energy performance.

Finally, the results from non-destructive surveys provide not only useful elements for energy retrofit but also support data for other analyses, such as structural ones. In particular, the thermography tests were a valid tool to verify the effective correspondence of the concrete structure compared to what was highlighted in the historical sources: especially, it was very helpful to detect the actual presence of a mixed structure consisting of masonry walls and uneven reinforced concrete pillars. In general, it was very useful to observe structural deficiency, thermal bridges, and check the adhesion state of the façade elements.More communication, more protection

The use of the non-destructive techniques presented in this work allow designers to follow a methodological approach to better understand and control the following design steps, highlighting the characteristics of the structure before intervening, representing the environment in which all the analyses can be coherently hypothesized and verified and ensuring a good degree of safety on site.

The results obtained with non-destructive analyses were a fundamental tool for tuning the design of retrofit interventions. The test outputs clearly reveal the state of the building, both from a structural and damage point of view. The vulnerability is easily interpreted and classified in all its components: structural deficiency, the surface damage, architectural values and the energy performance of the walls.

The immediacy in reading the results obtained represents an irrefutable reality that stands as the limit and boundary within which to define the restoration intervention aimed at protecting the building.

In this sense, the communication and interpretation of the acquired data are configured as useful means to ensure the enhancement and protection of the architectural heritage, by limiting the conflicts and facilitating constructive dialogue among the involved interests.

4. Conclusion[1]

This study aims to show how non-destructive techniques applied to a restoration site contributes to protection aims declared for the Cultural Heritage greatly damaged by extraordinary events such as earthquakes. The degree thesis from which the present work was extrapolated is configured as the test where the approach suggested in this paper has confirmed its success (Massari, 2018).

In particular, the analyses reported in this paper show, through the presented results, how the communication tools of thermography and thermofluximeter surveys favour the interpretation of the constructive characteristics of historical artefacts, representing a fundamental moment for the protection and enhancement of the historical architectural heritage.

[1] This research was designed by all the authors. Mariangela De Vita conceived the paper and wrote paragraph 1, 2, 3, 4 and 5. Giulia Massari wrote section 3.1, 3.2, 3.3 and elaborated the results. Pierluigi De Berardinis and Luis Palmero Iglesias supervised the work.

REFERENCES

Ascione, F., Ceroni, F., De Masi, R. F., de' Rossi, F., & Pecce, M.R. (2017). Historical buildings: Multidisciplinary approach to structural/energy diagnosis and performance assessment. *Applied Energy*, 185, 1517-1528.

Balaras, C. A., & Argiriou, A. A. (2002). Infrared thermography for building diagnostics. *Energy and buildings*, *34*(2), 171-183.

Bartolomucci, C. (2017). Il complesso dell'ex-ospedale San Salvatore a L'Aquila: Il contributo del restauro per il progetto di un nuovo polo universitario. In *Proceedings of the International Conference "Scienza e Beni Culturali"* (pp. 559-572). Venezia-Marghera: Edizioni Arcadia Ricerche.

Binda, L., Cardani, G., Saisi, A., & Valluzzi, M. R. (2006). Vulnerability analysis of the historical buildings in seismic area by a multilevel approach. *Asian Journal of Civil Engineering (building and housing)*, 7(4), 343-357.

De Berardinis, P., Bartolomucci, C., Capannolo, L., De Vita, M., Laurini, E., & Marchionni, C. (2018). Instruments for Assessing Historical Built Environments in Emergency Contexts: Non-Destructive Techniques for Sustainable Recovery. *Buildings*, 8(2), 27.

De Vita, M., Trizio, I., Savini, F., & De Berardinis, P. (2018). Cultural Heritage and earthquakes: a multidisciplinary approach to restoration sites. *VITRUVIO-International Journal of Architectural Technology and Sustainability*, 3(2), 79-88.

Grinzato, E., Bison, P.G., & Marinetti, S. (2002). Monitoring of ancient buildings by the thermal method. *Journal of Cultural Heritage*, 3(1), 21-29.

Maierhofer, C., Krankenhagen, R., Myrach, P., Meinhardt, J., Kalisch, U., Hennen, C., Mecke, R., Wilde, T. & Weber, M. (2015). Monitoring of Cracks in Historic Concrete Structures Using Optical, Thermal and Acoustical Methods. In: L. Toniolo, M. Boriani, G. Guidi G. (Eds.) Built Heritage: Monitoring Conservation Management. Research for Development. (pp. 93-102). Cham, Switzerland: Springer.

Massari, G. (2018). *Linee guida per la riqualificazione energetica e valutazione sismica dell'ex Ospedale San Salvatore*, degree thesis in Architectural Engineering (tutor Prof. P. De Berardinis, cotutor Eng. Mariangela De Vita and Prof. Angelo Di Egidio), University of L'Aquila, Italy, a.a. 2017/2018.

MiBACT. (2015). Linee di indirizzo per il miglioramento dell'efficienza energetica nel patrimonio culturale. Retrieced from https://www.beniculturali.it/mibac/export/MiBAC/sito-MiBAC/Contenuti/MibacUnif/Comunicati/visualizza_asset.html_156066123.html

Moropoulou, A., Labropoulos, K. C., Delegou, E. T., Karoglou, M., & Bakolas, A. (2013). Non-destructive techniques as a tool for the protection of built cultural heritage. *Construction and Building Materials*, 48, 1222-1239.

Napolitano, R., Hess, M., & Glisic, B. (2019). Integrating non-destructive testing, laser scanning, and numerical modeling for damage assessment: The room of the elements. *Heritage*, *2*(1), 151-168.

Soares, N., Martins, C., Gonçalves, M., Santos, P., Silva, L. S., & Costa, J. J. (2019). Laboratory and in-situ non-destructive methods to evaluate the thermal transmittance and behavior of walls, windows, and construction elements with innovative materials: A review. *Energy and Buildings,* 182, 88-10.

University of L'Aquila, DICEAA & National Research Council, ITC. (2017). *Studio di fattibilità per il progetto di un polo universitario nell'ex ospedale San Salvatore*. Scientific contributor P. De Berardinis, work group: C. Bartolomucci, F. Giancola, L. Capannolo, M. De Vita, E. Laurini, C. Marchionni.