The Energy Efficiency of Building Components. The Case of Historical Masonry Through a Multidisciplinary Approach

Marianna Rotilio[1](✉), Chiara Marchionni[1], Pierluigi De Berardinis[1], and Federica Cucchiella[2]

[1] Department of Civil, Construction-Architectural and Environmental Engineering, University of L'Aquila, 67100 L'Aquila, Italy
marianna.rotilio@univaq.it

[2] Department of Industrial and Information Engineering and Economics, University of L'Aquila, 67100 L'Aquila, Italy

Abstract. In the Italian context, about 65% of the buildings were built prior to the first law which introduced criteria for energy saving. According to Istat data, of the entire stock of historic inhabited buildings, almost two out of ten were built before 1919. This was the historical moment of the progressive abandonment of traditional construction techniques. In general, therefore, there are more than 2.1 million inhabited historic buildings. From a quantitative point of view, these buildings have a consistent "weight" in order to achieve the Sustainable Development Goal 7 set by the 2030 Agenda. For this reason, a question to be answered concerns the search for compatible methods, techniques and intervention strategies to implement the energy efficiency of historic buildings, with the aim of responding to the sustainability demands of the international community. Many scholars have dedicated time and research to the topic of energy efficiency in buildings, but the study of the state of the art has highlighted the presence of numerous research gaps to be overcome. In light of the arguments, multidisciplinary research was developed to define strategies and methodologies to promote the energy efficiency of traditional masonry. This is a very complex issue, therefore it was faced from three main points of view or topics: the lack of information regarding the thermal performance of the historic masonry; problems relating to the compatibility of design interventions; analysis of the sustainability of design solutions from an environmental, energy, social and economic point of view.

Keywords: Energy efficiency · Traditional masonry · Holistic approach · Compatibility

1 Introduction

In the Italian context, about 65% of the buildings were built prior to the first law which introduced criteria for energy saving (in particular the 373.76 Law). According to Istat data, of the entire stock of historic inhabited buildings, almost two out of ten were

A. Marucci et al. (Eds.): INPUT 2023, LNCE 467, pp. 599–608, 2024.
https://doi.org/10.1007/978-3-031-54118-6_53

built before 1919 [1], historical moment of the advent of reinforced concrete technology and the consequent gradual traditional construction techniques abandonment. In general, therefore, there are more than 2.1 million inhabited historic buildings. From a quantitative point of view, these buildings have a consistent importance in order to achieve the Sustainable Development Goal 7 set by the 2030 Agenda [2]. This goal wants to ensure access to affordable, reliable, sustainable and modern energy for all. They also have a strong weight in light of the indications of the current European Directives for energy efficiency. These directives have often found a lot difficulties of application in Italian regulatory transpositions, due to the specificity of the italian context, rich in historic buildings and minor centers. In fact, there is a lack of the laws on energy building works on the historical buildings, and the instrument of waiver often appears for them.

In this context, the government's tax incentives are a great opportunity for building energy upgrading. Among this the so-called "Superbonus 110%", introduced with the D.L. n. 34/2020 [3], converted by Law n. 77 of 17/07/2020, is a measure instituted as a tool to contrast the economic crisis in the building sector triggered by the health emergency by Covid19. It can be described as "the most controversial amendment for the preservation and protection of Modern Architecture because, while it aims to modernize its performance aspect, it also undermines the survival of its historical and cultural identity" [4]. It has proven not to be easy to apply, due to an everchanging regulatory framework, the numerous difficulties encountered by designer to get to the definition of the paperwork, the shortage of materials and construction companies.

The new regulatory provisions came alongside those already in force regarding tax deductions due for energy upgrading interventions in buildings (so-called "Ecobonus"), and Law 160/2019 regarding the "Facade Bonus", with which the practice of maintenance of historic buildings was spreading again, which was gaining momentum but whose recent enactment of the Budget Law marked its reduction from 90% to 60%, as well as its definitive end on Dec. 31, 2022 [5].

Moreover, when it comes to the redevelopment of the built environment, special attention and care is required, as well as the right amount of time, free from peremptory deadlines. Time for the diagnostic phase and thus for the identification of real problems, time for detailed design of individual specifics in search of compatible solutions and sustainable materials, time for the accurate execution of the work.

A rehabilitation intervention becomes a "sartorial" activity when, for example, one has to intervene on historic masonry where first of all one there is a lack of data regarding knowledge of pre-intervention hygrothermal performance [6], as well as a whole series of legislative constraints that make difficult to identify compatible strategies [7]. Second, preference should be given to the application of natural and recyclable materials. The same legislation related to the Superbonus, although it obliges the application of CAM-certified materials [8, 9], does not place any incentives related to the use of sustainable insulation materials (mineral and natural), fire-resistant or capable of mitigating issues related to summer overheating and regulating hygrothermal conditions. Instead, it places cost-related limitations, without distinctions related to the characteristics of the building, and imposes speed in the time of implementation, with the only exception of the well-known tool of the waive in paragraph 2, Article 119 of Law 77/2020 for listed buildings. Moreover, the application of standard solutions in historic buildings, of the same interventions for each environmental and cultural context, and without specific design guidelines is not permissible.

For this reason, a question to be answered concerns the search for compatible methods, techniques and intervention strategies to implement the energy efficiency of historic buildings, with the aim of responding to the sustainability demands of the international community.

Many scholars have dedicated time and research to the topic of energy efficiency in historic buildings. By searching the scopus database (Fig. 1) with the keywords "Historic building*" and "Sustainable Development Goal", it was found that 188 papers have been written on this topic since 2000 to today with increasing interest over time. The greatest productivity occurred in Italy and the areas of more interest were Engineering (21.0%) and Environmental Science (17.9%). But the study of the state of the art has also highlighted the presence of numerous research gaps to be overcome. In light of the arguments, multidisciplinary research was developed to define strategies and methodologies to promote the energy efficiency of traditional masonry.

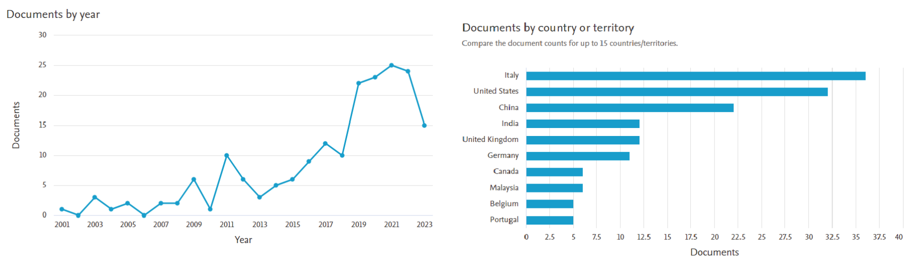

Fig. 1. Scopus analysis using "Historic building*" and "Sustainable Development Goal" as keywords (source: Scopus database, 02.08.2023). On the left, documents by year; on the right documents by country or territory.

2 Methodological Approach: Analysis and Knowledge

This research illustrates the multidiscipli-nary approach taken to promote the energy efficiency of traditional masonry. This turns out to be a very complex issue and wanting to try to discretize the problematics, three major topics emerged:

1. lack of information about the thermal performance of historical masonry;
2. problems regarding the compatibility of design interventions;
3. sustainability of design solutions from an environmental, energy-social and economic point of view.

This section is organized according to the three topics previously identified (Fig. 2).

2.1 Topic 1: Lack of Information Regarding the Thermal Performance of Historic Masonry

Given the wide variety of building types in the study area, a survey campaign of wall types was conducted, summarized by homogeneous types with similar characteristics.

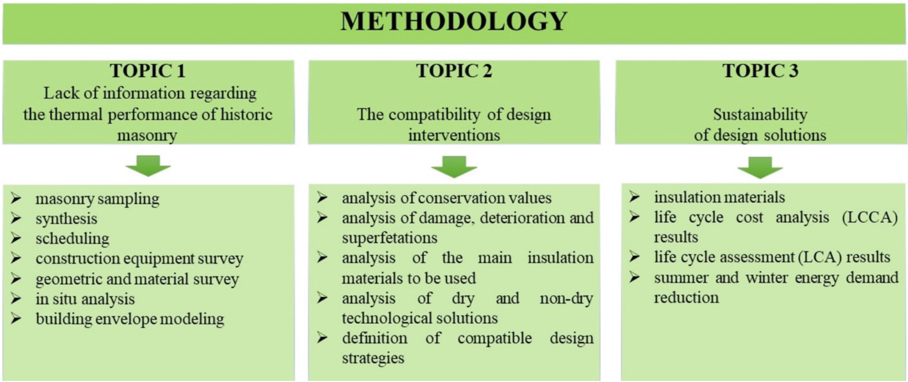

Fig. 2. The proposed approach.

The purpose was to identify representative masonry varieties in the reference context, both from a qualitative and quantitative point of view. Then the survey of the constructive system, including geometrically and materially, was carried out, with the analysis of building and constructional elements [10]. The study focused on the thermal characterization of representative wall types, and therefore buildings, or parts of buildings, in which in situ analyses could be carried out were sought (Fig. 3).

Going into detail, in order to identify the most probable thermal transmittance value of the masonry of interest, the UNI ISO 9869 standard [11] was used, which sets very strict test conditions that cannot always be verified in the reference context of the study. The standard requires that the masonry under investigation be homogeneous, have no thermal bridges and be representative of the face under analysis. The selection of a homogeneous portion of masonry is conducted with the help of infrared thermographic technique [12]. Moreover, it must also belong to a confined volume, a difference between external and internal temperature of 10–15 °C must be recorded, and thermal inversion must not occur. Finally, the test must continue for at least 72 consecutive hours. These conditions have not always been easy to achieve, since the reference context is that of the so-called "L'Aquila earthquake crater": infact, we were often confronted with damaged buildings, non-confined volumes, and lack of electricity or heating [13]. Therefore, the phase of identifying the buildings that were suitable for the study was also complex.

The execution of the in situ investigations made it possible to obtain the most probable thermal transmittance value of the masonry types constituting the historical envelope under study, and thanks to the surveys carried out and previously described, the next step was to model the building using software support (Design Builder). This modeling was developed ad hoc for the building under study, reconstructing each element consistently with the surveyed state of affairs, both from a constructional, material and energy point of view, without resorting to standard and/or pre-defined solutions.

This kind of approach is essential, since the building with which we are confronted belongs to the historical building heritage; so any design intervention to be carried out cannot disregard a process of recognition of the values to be preserved and the peculiarities present [14, 15].

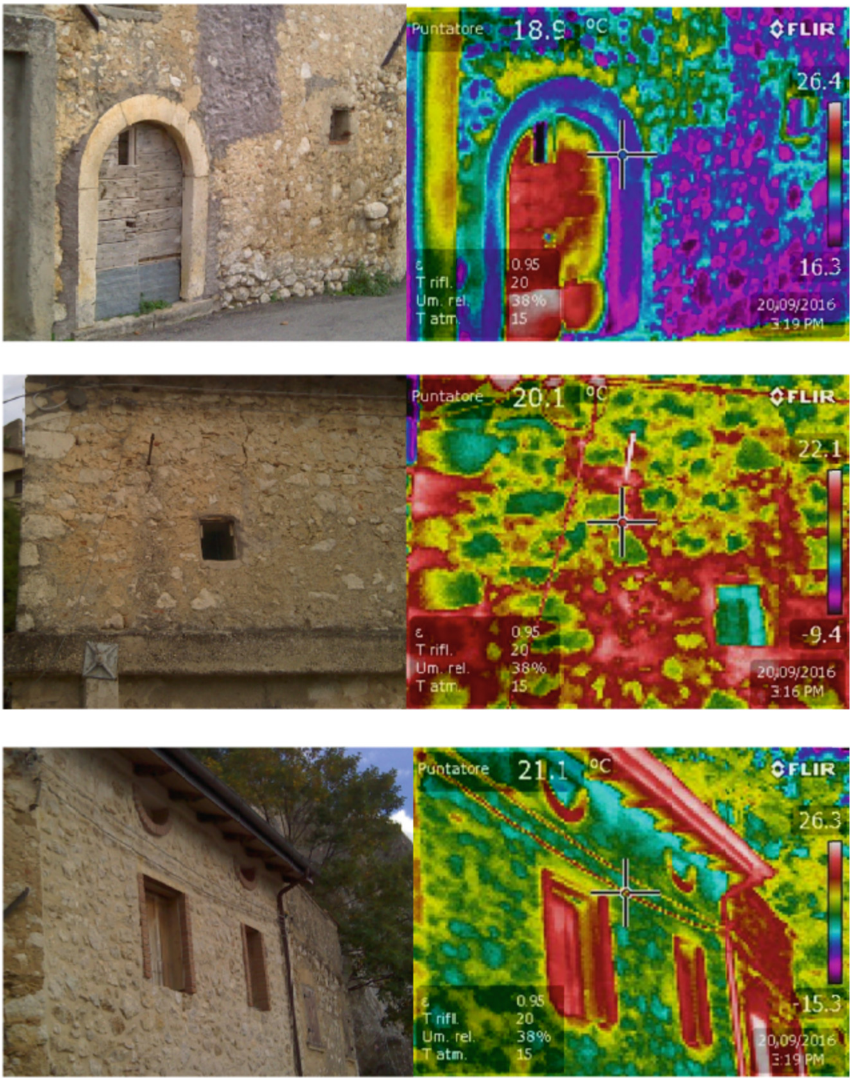

Fig. 3. Application of infrared thermographic technique in Atessa (Aq).

Wanting to carry out a summary, for the topic 1, the research steps were the following:

- masonry sampling;
- synthesis;
- scheduling;
- construction equipment survey;
- geometric and material survey;
- in situ analysis;
- building envelope modeling.

2.2 Topic 2: Issues Concerning the Compatibility of Design Interventions

The issue of "building on the built" [16] poses complex problems and implies solutions in which a wide range of theoretical solutions can be found. The design confrontation with a building belonging to the existing heritage imposes the performance of specific analyses aimed at the recognition of existing historical, architectural, constructive, environmental, and landscape values [15].

These analyses make it possible to define the limits and constraints within which the technician can develop the energy efficiency project, with the aim of preserving the present values through compatible strategies (Fig. 4). For this reason, again, the research was articulated by successive steps of in-depth study:

- analysis of conservation values;
- analysis of damage, deterioration and superfetations;
- analysis of the main insulation materials to be used;
- analysis of dry and non-dry technological solutions;
- definition of compatible design strategies.

In particular, analyses were drawn up not only to recognize the aforementioned values to be preserved, but also to identify damaged elements in a deteriorated condition and existing superfetations. The synthesis of the elaborations made it possible to define the transformability level of the investigated masonry, according to a certain value scale. The study then continued by researching the insulation materials on the market, going on to classify them according to their origin, mineral, vegetable, ani-mal, fossil and recycled, in order to assess their environmental impact. The research therefore advanced by researching the main technological solutions, dry and non-dry, available [7]. The synthesis of all the analyses performed allowed the identification of compatible design strategies. Finally, in addition to issues related to the knowledge of the thermal performance of historic masonry (topic 1) and the important issue of the compatibility of the intervention (topic 2), community instances impose reflections related to the sustainability of the project, which will be discussed in the following section.

2.3 Topic 3: Sustainability of Design Solutions from Environmental, Energy, Social and Economic Point of View

The last topic of the complex issue of energy efficiency of traditional masonry research methodologies able to give life to design solutions that are environmentally, energetically, socially and econo-mically sustainable. For this reason, intervention scenarios have been developed based on the following parameters:

- insulation materials;
- life cycle cost analysis (LCCA) results;
- life cycle assessment (LCA) results;
- summer and winter energy demand reduction.

The results obtained were organized in matrix form [2] in order to make all parameters immediately comparable. Specifically, in the columns each material related to the individual design strategies was reported.

In the rows, on the other hand, the results inherent in the LCCA analysis, LCA and reduction of summer and winter energy demand. The use of this approach and of matrices such as the one mentioned makes it possible to compare results and orient choices toward sustainability and the least possible impact of compatible design solutions.

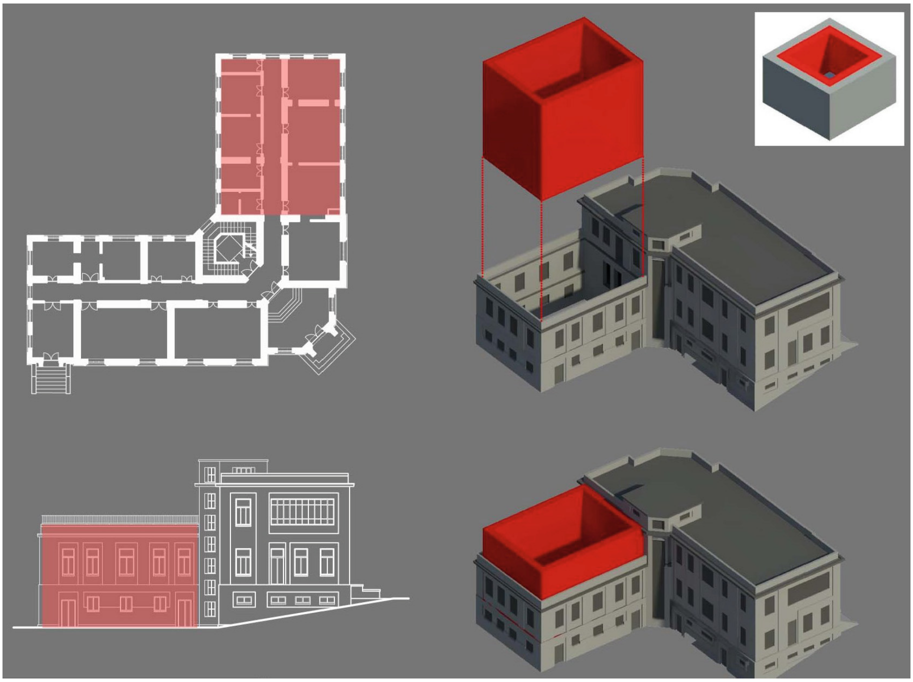

Fig. 4. Processes of compatibility of the design intervention with the pre-existence.

3 Conclusions

In order to make an energy-efficient intervention on traditional masonry compatible, reversible, low impact, and, in general, sustainable, the co-presence of several conditions summarized below is necessary:

- in-depth knowledge, i.e., reading of the built and climatic context to solve critical issues and direct the project in respect of the material culture of the places;
- centrality of the project, since it is the only tool that can respond to the heterogeneity and specificity of different contextual situations;
- multidisciplinary approach to project design: only the involvement of different disciplines can lead to an intervention that is respectful of the pre-existence and sustainable;
- respect for values/openness to the future, in a balanced relationship between project of the new and design with traditional criteria, attention to the case case case by case, element by element (Fig. 5);

- reduction of operating/maintenance costs, in order to improve the quality of life, raise performance levels, and make it attractive to return to permanent living in historic contexts.

The methodological approach illustrated and applied in several case studies located in the Province of L'Aquila, can lead to achieve significant results not only from a qualitative point of view, but also from a quantitative one, when considering the fact that often the materials and construction techniques used are recurrent in certain contexts. Therefore, by standardizing the measurements made on several masonry types and on several

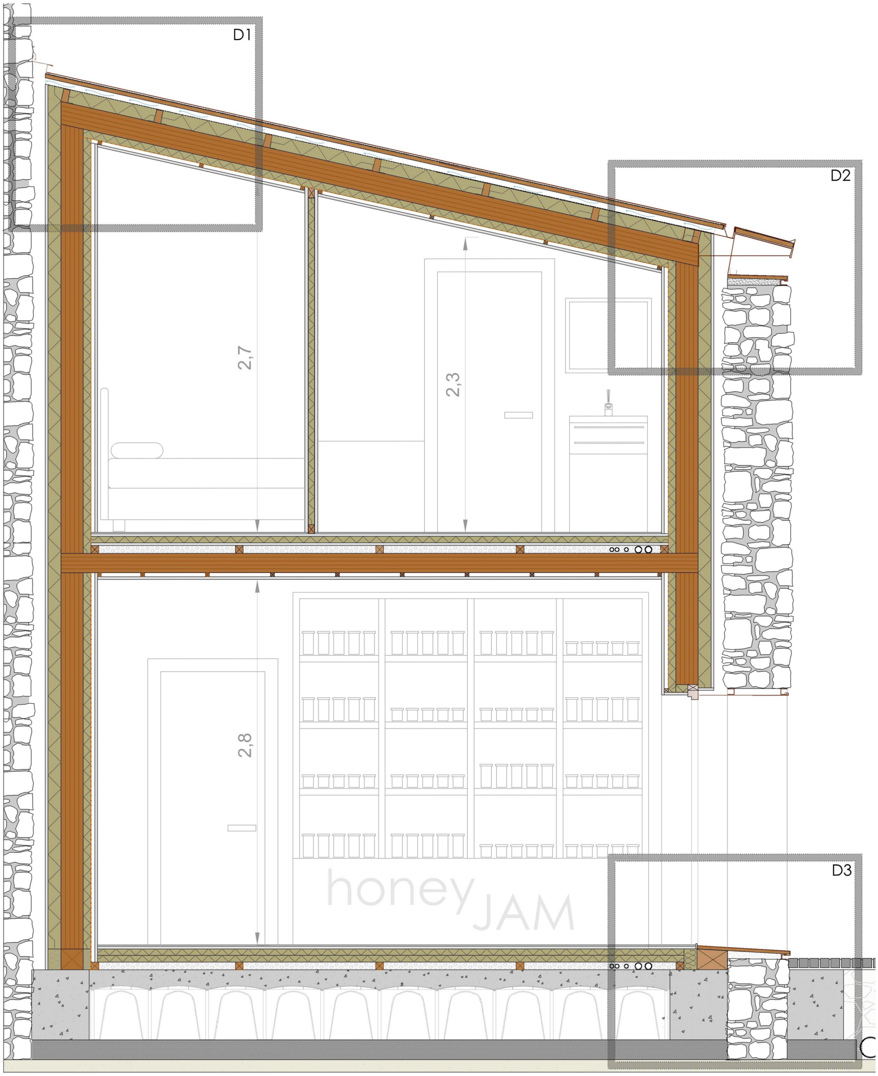

Fig. 5. Construction section of a compatible project intervention.

sample buildings, a database could be defined to be made available to professionals and institutions in order to implement territorial knowledge and to better direct choices at the central governmental level. In fact, the attempt of Italian policy to push on the efficiency of the building stock, without further soil consumption, is also commendable from the perspective of circular economy, safeguarding resources and achieving the Sustainibility Goals set out in Agenda 2030. But it must not turn into a missed opportunity due to a lack of knowledge of the territorial peculiarities and history of the national built heritage. Let alone it become a tool for the destruction of this unique and priceless heritage due to short-sighted choices.

Contributions. The research on the energy efficiency of traditional masonry is the result of a study started in 2012 by Prof. Pierluigi De Berardinis and Prof. Marianna Rotilio, with the participation of Eng. Ph.D Chiara Marchionni. This research has been implemented over the years thanks to the introduction of new topics in a multidisciplinary perspective and according to a holistic approach, also thanks to the collaboration with Prof. Federica Cucchiella on LCCA.

The paper was structured and administered by M.R.. She wrote the paper (Sect. 1, 2 and 3) with C.M. (Sect. 1 and 3). M.R. is the corresponding author.

References

1. Istat, Paesaggio e patrimonio culturale, Bes 2018 – Il benessere equo e sostenibile in Italia
2. Annibaldi, V., Cucchiella, F., De Berardinis, P., Gastaldi, M., Rotilio, M.: An integrated sustainable and profitable approach of energy efficiency in heritage buildings. J. Clean. Prod. **251**, 119516 (2020)
3. D.L. 19.05.2020 n.34, "Decreto Rilancio": "Misure urgenti in materia di salute, sostegno al lavoro e all'economia, nonche' di politiche sociali connesse all'emergenza epidemiologica da COVID-19"
4. Currò, G., Fiandaca, O., Russo, G.F.: The energy requalification of an author's social housing complex Ridolfi's INCIS Houses: a challenge for heat-reflective coatings. In: Varum, H., Furtado, A., Melo, J., Book of proceedings of "Xth ReUSO Edition. Documentation, Restoration and Reuse of Heritage", pp. 371–384. Porto, Portogallo (2022)
5. Feiffer, C.: Tra Bonus e meno bonus. Recupero e Conservazione Megazine 167 (2021)
6. Litti, G., Khoshdel, S., Audenaert, A., Braet, J.: Hygrothermal performance evaluation of traditional brick masonry in historic buildings. Energy Build. **105**, 393–411 (2015)
7. De Berardinis, P., Rotilio, M., Marchionni, C., Friedman, A.: Improving the energy-efficiency of historic masonry buildings. A case study: a minor centre in the Abruzzo region Italy. Energy Build. **80**, 415–423 (2014)
8. Decreto 11/10/2017: "Criteri ambientali minimi per l'affidamento di servizi di progettazione e lavori per la nuova costruzione, ristrutturazione e manutenzione di edifici pubblici" (GU Serie Generale n.259 del 06–11–2017)
9. ANIT (2021) CAM e Superbonus 110%. https://www.anit.it/pubblicazione/cam-e-superbonus-110/
10. Annibaldi, V., Cucchiella, F., De Berardinis, P., Rotilio, M., Stornelli, V.: Environmental and economic benefits of optimal insulation thickness: a life-cycle cost analysis. Renew. Sustain. Energy Rev. **116**, 109441 (2019)
11. Lidelöw, S., Örn, T., Luciani, A., Rizzo, A.: Energy-efficiency measures for heritage buildings: a literature review. Sustain. Cities Soc. **45**, 231–242 (2019)

12. International Standards Organization (ISO). Thermal insulation. Building elements, in: In-Situ Measurement of Thermal Resistance and Thermal Transmittance. Part 1: Heat Flow Meter Method (ISO 9869). Geneva, Switzerland: ISO.2014
13. Fokaides, P.A., Kalogirou, S.A.: Application of infrared thermography for the determination of the overall heat transfer coefficient (U-Value) in building envelopes. Appl. Energy **88**, 4358–4365 (2011)
14. Rotilio, M., Cucchiella, F., De Berardinis, P., Stornelli, V.: Thermal transmittance measurements of the historical masonries: some case studies. Energies **11**, 2987 (2018)
15. Zordan, L., Bellicoso, A., De Berardinis, P., Di Giovanni, G., Morganti, R.: Le tradizioni del costruire della casa in pietra: materiali, tecniche, modelli e sperimentazioni. Gruppo tipografico editoriale, L'Aquila (2002)
16. Rotilio, M.: I centri storici minori. Linee guida per il recupero sostenibile. Aracne Editrice, Roma (2019)
17. Imperadori, M.: Costruire sul costruito. Tecnologie leggere nel recupero edilizio. Carocci Editore, Roma (2021)