

Compatibility of Energy Efficiency with the Protection of Historic Buildings: A Systematic Literature Review

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Abstract

Achieving improvement of energy performance in listed buildings remains a complex challenge due to the need to combine innovative solutions with preservation of the characteristics that define the historical and architectural value of these buildings. The aim of this study is to better understand the state of the art regarding the compatibility of energy efficiency measures with the protection of listed buildings. A systematic review was performed that included peer-reviewed publications in English and Italian from Scopus, Web of Science, and Google Scholar (last search: November 2025). Sixty-nine studies were included and organized into methodological, applicative, review and theoretical-reflective studies. Results show a European predominance, particularly Italian, and identify four recurring themes: balancing efficiency with conservation, decision-making processes, evaluation criteria, and technological strategies. Current research is focusing on developing objective evaluation methods, moving toward multi-criteria methodologies that quantify aesthetic, technical, and environmental compatibility. While there is a preference for minimally invasive and reversible technological solutions, the review reveals a lack of shared protocols and limited generalizability of results. The study concludes that a strategic shift is required: moving from isolated experiments to integrated urban policies. Furthermore, it highlights a need for increased technical training to bridge the gap between research and practical application. Future research should focus on validating evaluation criteria using real cases and developing regional policy tools to support decision-making. This review was not registered.

Keywords: energy efficiency; historic buildings; heritage conservation; compatible interventions



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1. Introduction

The energy upgrading of buildings is one of the key challenges in the ecological transition outlined by European directives, which set targets for reducing consumption and emissions by 2030 and 2050. The construction sector contributes significantly to overall energy consumption and greenhouse gas emissions, making it a strategic field of action for achieving climate neutrality. However, the possibility granted to Member States to exclude historic buildings from energy efficiency requirements raises crucial issues in countries such as Italy, where they represent a significant part of the building stock.

The main problem therefore remains the reconciliation between energy sustainability and preservation of cultural values. On one side, this balance is guided by a long-standing tradition of heritage protection, following international documents such as the Venice

Charter (1964), the Amsterdam Declaration (1975), and the Krakow Charter (2000), which define the principles of conservation, prioritizing the safeguarding of historical elements. On the other side, the urgency of the climate crisis pushes for the integration of performance standards even within protected contexts. This study stems from the need to bring together current research on the subject to form a theoretical basis for the construction of a shared and replicable methodology for the implementation of energy renovation projects that consider and respect the value of historic buildings.

2. Materials and Methods

The methodological approach of this study is based on a systematic literature review to assess the state of the art, identify gaps in the scientific literature, and provide an overview of current strategies for improving energy performance in listed buildings. This systematic review was not registered, and no formal review protocol was prepared. No amendments were made. The aim of the review was to identify the main issues encountered and the solutions proposed in the literature for the energy renovation of historic buildings. Future research prospects consist of defining a set of shared criteria and a methodological protocol for assessing the compatibility between energy efficiency measures and historical heritage.

The research results were summarized following the guidelines of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol. Academic articles were selected from three main databases, Scopus, Web of Science and Google Scholar, with the last search conducted in November 2025 for all databases. The complete PRISMA 2020 checklist and PRISMA 2020 for Abstracts checklist are provided in the Supplementary Materials.

The following paragraphs show the research questions, the inclusion and exclusion criteria for publications and the stages of identifying studies via databases.

The starting point for the systematic review was the formulation of the research questions:

1. What are the issues encountered in energy efficiency measures in historic buildings?
2. What methodologies have been developed to address the energy retrofitting of historic buildings?
3. What technological solutions are preferred in energy efficiency measures for historic buildings?
4. What are the most common criteria for assessing the compatibility of interventions in historic buildings?

At this stage, various inclusion and exclusion criteria were formulated, as shown in Table 1. The search was first conducted using the Scopus database and then using the WoS database. Table 2 shows the search strings used.

The study selection process was conducted by a single reviewer. Titles and abstracts were initially screened against the inclusion and exclusion criteria. Studies considered potentially relevant were retrieved as full-text articles and assessed for eligibility. All decisions regarding inclusion and exclusion were made by the reviewer. Figure 1 summarizes the steps of the protocol.

The process was completed using the Google Scholar database through two distinct approaches. Manual sampling involved the use of specific keywords searched on Google Scholar, such as “historic buildings,” “energy retrofit,” “energy efficiency,” “heritage conservation,” etc. Subsequently, a snowballing approach was adopted, analyzing the bibliographies of the most relevant articles to identify additional relevant contributions. This resulted in the addition of 16 further articles.

Of the 411 articles, 356 were excluded because they were not relevant to the research topic. After the screening process, a total of 69 articles were included in the review.

Table 1. Inclusion and exclusion criteria used for the data identification phase.

Inclusion Criteria	Exclusion Criteria
Peer-reviewed open access articles ¹ Language: English or Italian Articles addressing the issue of compatibility between energy efficiency measures and heritage preservation The article: - identifies problems with retrofitting historic buildings; - proposes methodologies for retrofitting listed buildings; - describes measures considered compatible; - develops criteria for assessing compatibility; - proposes tools for assessing effectiveness, impact or visibility (indices, models, etc.).	Articles that do not concern historic buildings, listed buildings, or buildings considered to be heritage sites. Articles that mention cultural heritage only in the introduction or abstract but do not develop the topic further. Articles focused on economic and social aspects without analyzing their compatibility with historical and architectural values.

¹ Inaccessible articles are listed in Table A5.

Table 2. Databases and queries used to identify potential studies for inclusion in the literature review.

Database	Search String ¹
Scopus (328)	TITLE-ABS-KEY (("Energy transition*" OR "Energy retrofit" OR "energy efficiency") AND ("historic* building*" OR "listed building*" OR "heritage building*" OR "UNESCO")) AND (EXCLUDE (SUBJAREA, "PSYC") OR EXCLUDE (SUBJAREA, "HEAL") OR EXCLUDE (SUBJAREA, "BIOC") OR EXCLUDE (SUBJAREA, "AGRI") OR EXCLUDE (SUBJAREA, "MEDI") OR EXCLUDE (SUBJAREA, "BUSI") OR EXCLUDE (SUBJAREA, "ECON") OR EXCLUDE (SUBJAREA, "DECI") OR EXCLUDE (SUBJAREA, "CHEM") OR EXCLUDE (SUBJAREA, "CENG") OR EXCLUDE (SUBJAREA, "PHYS") OR EXCLUDE (SUBJAREA, "EART") OR EXCLUDE (SUBJAREA, "MATH") OR EXCLUDE (SUBJAREA, "COMP")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English") OR LIMIT-TO (LANGUAGE, "Italian")) ((TI = (("Energy transition*" OR "Energy retrofit" OR "energy efficiency") AND ("historic* building*" OR "listed building*" OR "heritage building*" OR "UNESCO")) OR (AB = (("Energy transition*" OR "Energy retrofit" OR "energy efficiency") AND ("historic* building*" OR "listed building*" OR "heritage building*" OR "UNESCO")) OR (AK = (("Energy transition*" OR "Energy retrofit" OR "energy efficiency") AND ("historic* building*" OR "listed building*" OR "heritage building*" OR "UNESCO")))))
Web of Science (179)	((TI = (("Energy transition*" OR "Energy retrofit" OR "energy efficiency") AND ("historic* building*" OR "listed building*" OR "heritage building*" OR "UNESCO")) OR (AB = (("Energy transition*" OR "Energy retrofit" OR "energy efficiency") AND ("historic* building*" OR "listed building*" OR "heritage building*" OR "UNESCO")) OR (AK = (("Energy transition*" OR "Energy retrofit" OR "energy efficiency") AND ("historic* building*" OR "listed building*" OR "heritage building*" OR "UNESCO")))))

¹ The asterisk (*) replaces zero or more characters and is used to retrieve all terms sharing the same root (e.g., "historic*" finds "historic", "historical").

Data was extracted from each included report by a single reviewer. Relevant information was extracted and organized in a data table including the following fields: methodology used for the analysis, technological solutions analyzed, compatibility criteria (when applicable) and main results of the study, including problems encountered. Other variables extracted included country, year, source of publication, authors. When information was unclear or missing, it was recorded as not specified. As the review was qualitative, no data preparation or conversion was performed.

Generative artificial intelligence (ChatGPT, OpenAI, GPT-4 model, free version) was used to assist in organizing bibliographic references and summarizing data. Each article was read and analyzed by the authors, who prepared an initial summary of the main points. Only then were these texts given to the AI to produce an even shorter summary, which was useful for organizing them into a table. All outputs generated by the AI were reviewed, edited, and integrated by the authors.

A formal risk of bias assessment of included studies was not performed. The study selection and data extraction were conducted by a single reviewer, which may introduce bias. All decisions were made according to predefined criteria.

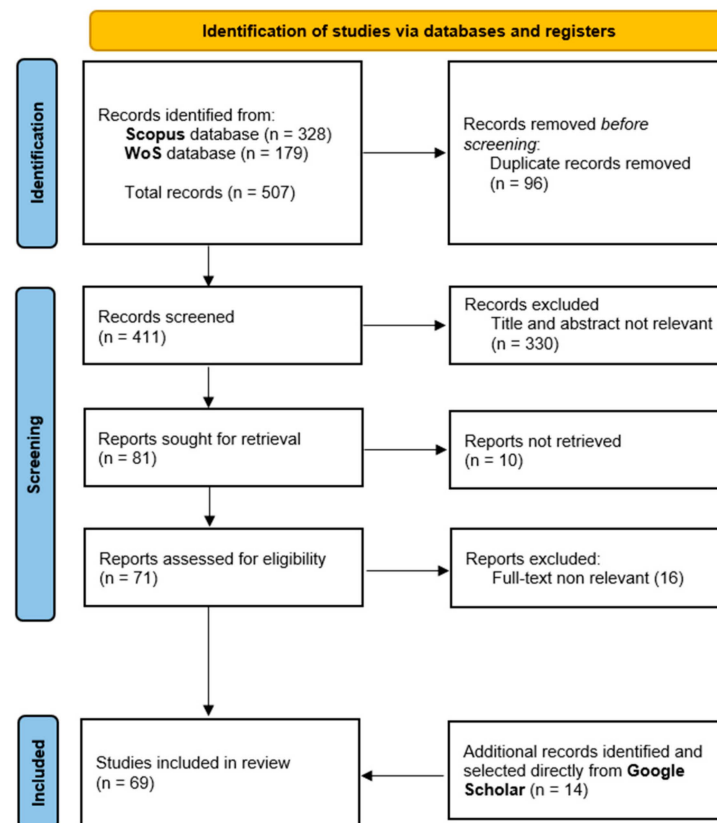


Figure 1. PRISMA workflow protocol for identifying papers.

Studies were synthesized through a qualitative narrative approach. Publications were divided into categories (methodological, applied, review, and theoretical-reflective) and subcategories (quantitative and qualitative analyses). Tables and descriptive summaries were used to present the findings (see Appendix A).

3. Results

From the 69 selected studies, it was possible to implement scientometric analysis based on the following (see Section 3.1): (1) number of publications per year; (2) number of publications per country; (3) mapping of the co-occurrence network of keywords; and (4) number of publications per journal.

The publications were then divided into categories (see Section 3.2): (1) methodological studies, which propose approaches, models, or tools for evaluating and designing retrofit interventions; (2) applied studies, based on analysis and simulation of real buildings; (3) review studies, which summarize and compare the results of previous work; (4) theoretical-reflective studies, which address the topic of retrofitting through theoretical discussions. For each category, we further classified the type of analysis conducted by the authors into two modalities: (i) quantitative analyses based on numerical data, modelling, simulations, or measurable indicators; and (ii) qualitative analyses, based on expert judgement, descriptive evaluations, interviews, surveys, or comparative reasoning.

The criteria for evaluating the interventions were then identified from the subclasses (see Section 3.3).

3.1. Analysis of Emerging Trends in the Literature

3.1.1. Number of Publications per Year

Figure 2 shows a graph representing the number of publications per year. Between 2013 and 2025, the number of publications increased, reflecting the growing interest in

the topic of energy retrofitting in heritage buildings. In the early years, from 2013 to 2016, the number of publications was low (1–2 publications per year). From 2017 onwards, the number of publications increased, peaking at 12 publications in 2021 and again in 2023.

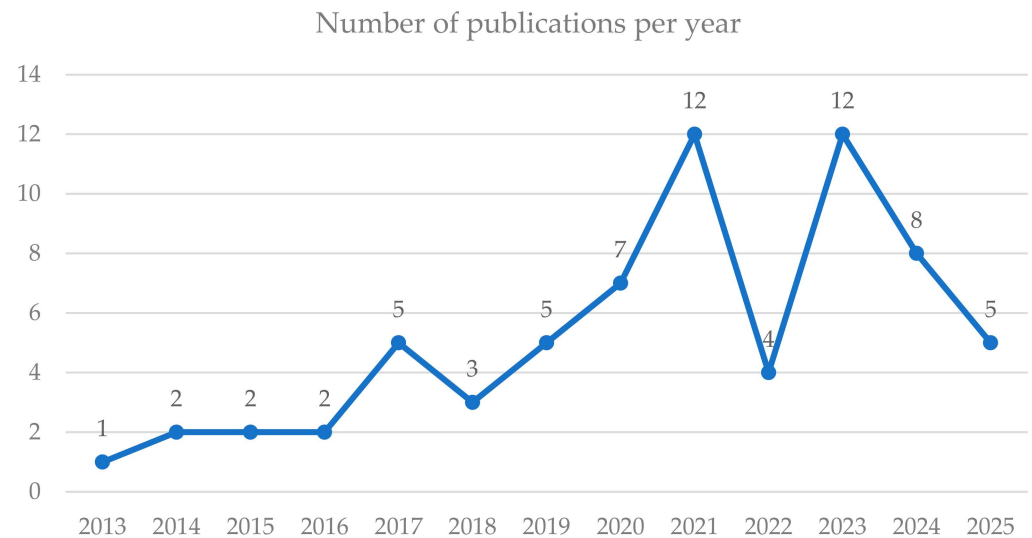


Figure 2. Number of publications per year. Source(s): Authors' work.

The analysis reveals a significant upward trend, with over 70% of studies published in the last five years (2020–2025). This growth reflects the increasing urgency of integrating retrofitting with heritage preservation.

3.1.2. Number of Publications per Country

Figure 3 shows a graph representing the number of publications per country. For the purposes of the analysis, papers with authors from multiple countries were counted once for each country indicated.

Italy is the most represented country, with 39 publications, which represent more than 55% of the total dataset, far exceeding all other countries. It is followed by the United Kingdom (7 publications), Switzerland (6 publications), Spain (5), Sweden (4), Denmark and Turkey (3). France, New Zealand, Egypt and Norway each have 2 publications, while the other countries included in the analysis (South Korea, China, the United States, Germany, Austria, Iraq, Chile, Ireland, Belgium, Lithuania, Latvia, Algeria and Poland) are represented by only one contribution.

It is interesting to note that the countries with the highest output are all European, (representing over 85% of the total output), suggesting that the continent's dense historical fabric and climate regulations are the primary drivers of this scientific trend. It is not surprising that Italy, thanks to its rich cultural heritage and theoretical tradition in the field of conservation and restoration, continues to play a leading role in the protection of cultural heritage.

This geographic distribution highlights that globalized protocols have yet to be fully developed. Emphasizing these trends is crucial to guide future efforts toward more international collaborations, ensuring that the methodologies developed in countries like Italy can be adapted and tested in different climatic and regulatory contexts.

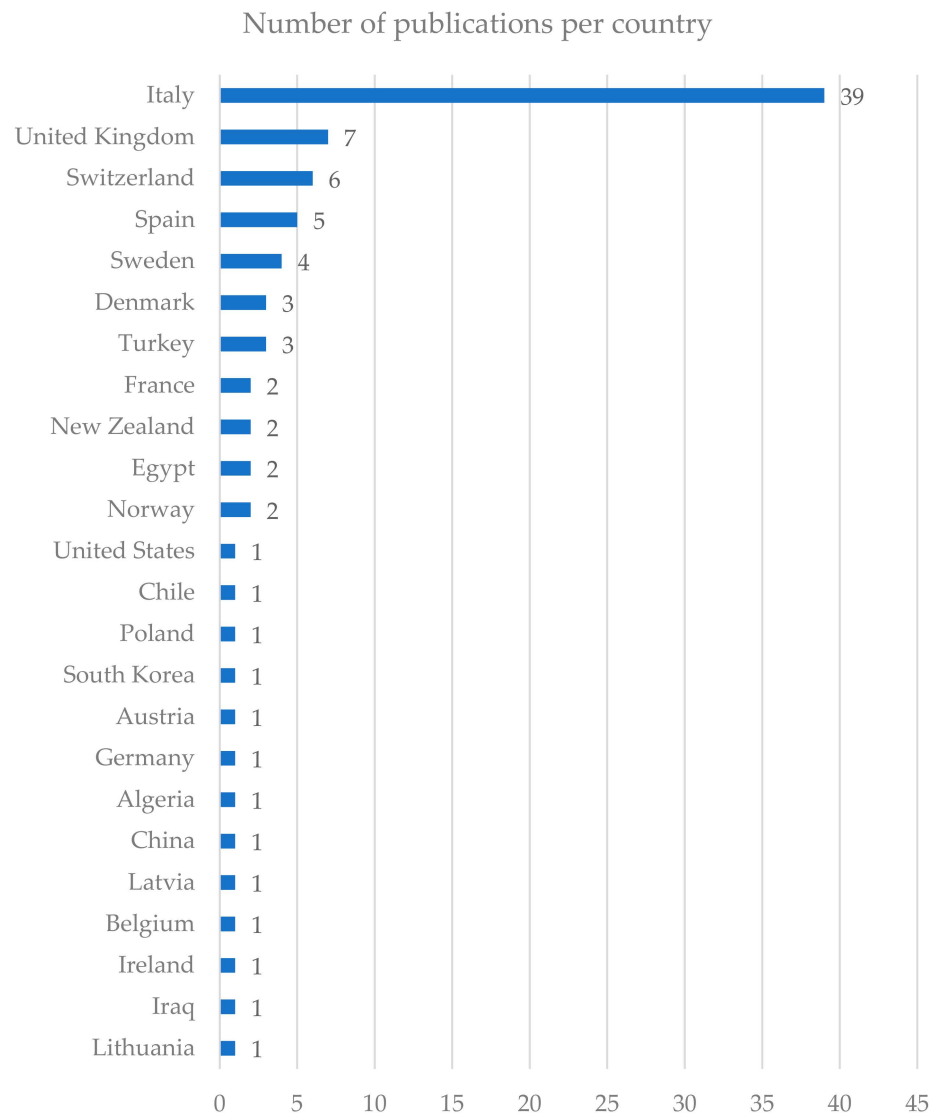


Figure 3. Number of publications per country. Source(s): Authors' work.

It is important to emphasize that the higher number of Italian publications is not linked to the inclusion of Italian-language papers in the analysis. Rather, most of the studies considered, including those authored by Italian researchers, were published in English. Specifically, 7 papers in our dataset were published exclusively in Italian (see [1–7]).

3.1.3. Mapping of the Co-Occurrence Network of Keywords

Using VOSviewer (version 1.6.20), the co-occurrence network of keywords was mapped, showing the interrelationships (see Figure 4). The larger the node, the more frequently the keyword appears. The more intense the color, the stronger the connection between the two keywords. Keywords with a frequency of less than 4 were discarded. A total of 43 keywords were identified. The most frequently recurring terms are “energy efficiency” (45 occurrences), “historic buildings” (33), “historic preservation” (26), “buildings” (21), followed by ‘retrofitting’ and “heritage buildings” (17).

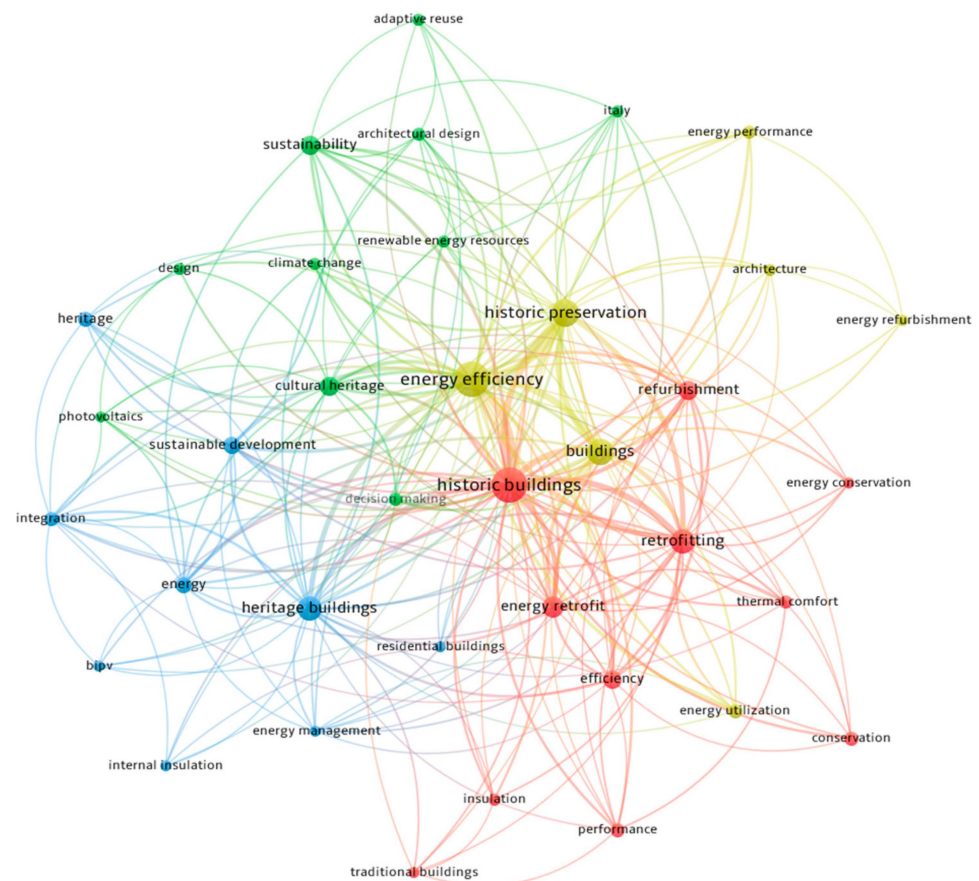


Figure 4. Map of the co-occurrence network of keywords (with a recurrence greater than or equal to four) obtained using VOSviewer software. Source(s): Authors' work.

The co-occurrence network analysis highlighted four thematic areas:

- Sustainability in cultural heritage management (green);
- Technologies for energy efficiency in heritage buildings (blue);
- Energy retrofiting of historic buildings (red);
- Integration of energy efficiency and historic preservation (yellow).

The themes derive from the correlation between keywords, grouped by the tool according to their frequency of co-occurrence in the selected studies.

These clusters highlight a growing interest in integrating cultural heritage protection with energy efficiency objectives. The green cluster highlights the focus on sustainability in historic building management strategies. The blue cluster underscores the preference for specific technological solutions, such as integrated photovoltaics and internal insulation. The red cluster reflects the focus on improving the energy and thermal performance of historic buildings. Finally, the yellow cluster indicates the search for a balance between conservation and innovation through interventions that are compatible with architectural values.

3.1.4. Number of Publications Per Journal

Figure 5 shows a graph representing the number of publications per journal. The analysis shows publications in both specialized journals and broader journals dedicated to energy, sustainability, and the built environment. The journals with the highest number of contributions are *Energy and Buildings*, *Sustainability*, and *Heritage*. Following these are numerous specialist journals focused on architecture, spatial planning, economic and environmental assessment, and building technologies. The presence of many journals with only one publication suggests that the topic is addressed across different disciplinary fields.

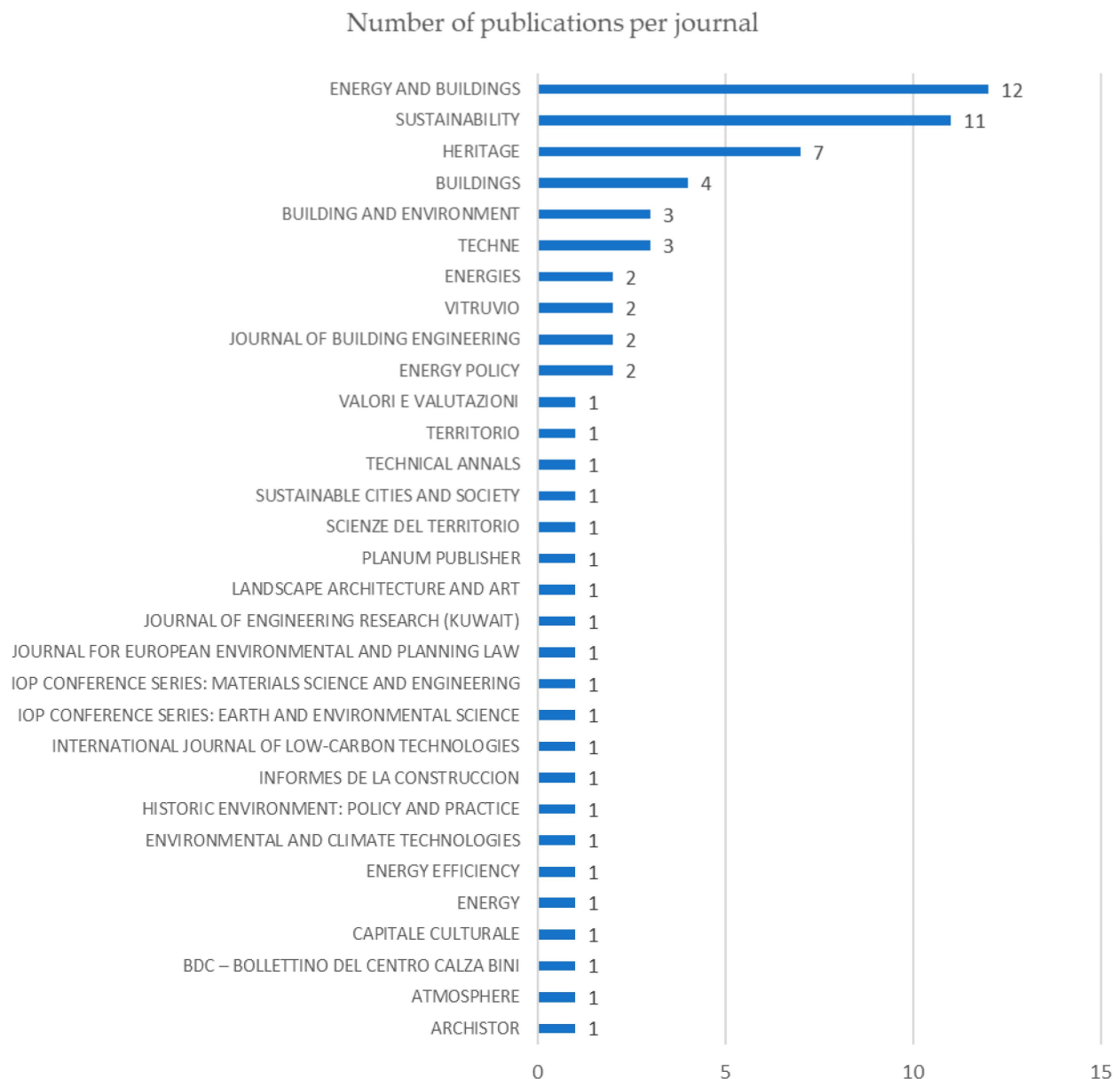


Figure 5. Number of publications per journal. Source(s): Authors' work.

3.2. Classification of Records

The selected studies were categorized into four main groups (see Appendix A, Tables A1–A4). Quantitatively, the dataset is dominated by Applicative (36%) and Methodological (32%) contributions, which together represent nearly 70% of the total research output. This concentration underscores a strong focus on practical implementation and the development of frameworks.

Table A1 (Appendix A) shows publications concerning methodological contributions. A total of 22 publications were selected for this category. Table A2 (Appendix A) shows publications concerning applicative contributions. A total of 25 publications were selected for this category. Table A3 (Appendix A) shows publications concerning theoretical-reflective contributions. A total of 6 publications were selected for this category. Table A4 (Appendix A) shows publications concerning review contributions. A total of 16 publications were selected for this category.

This numerical distribution reveals an important trend: while the ‘how-to’ (methodology and application) is well-documented, there is a lack of theoretical-reflective studies guiding future research toward a more critical debate on conservation doctrines.

Cross-Analysis: Geographic Origin vs. Type of Study

To further illustrate the research trends, Figure 6 shows a cross-analysis between the geographic origin and the type of contribution.

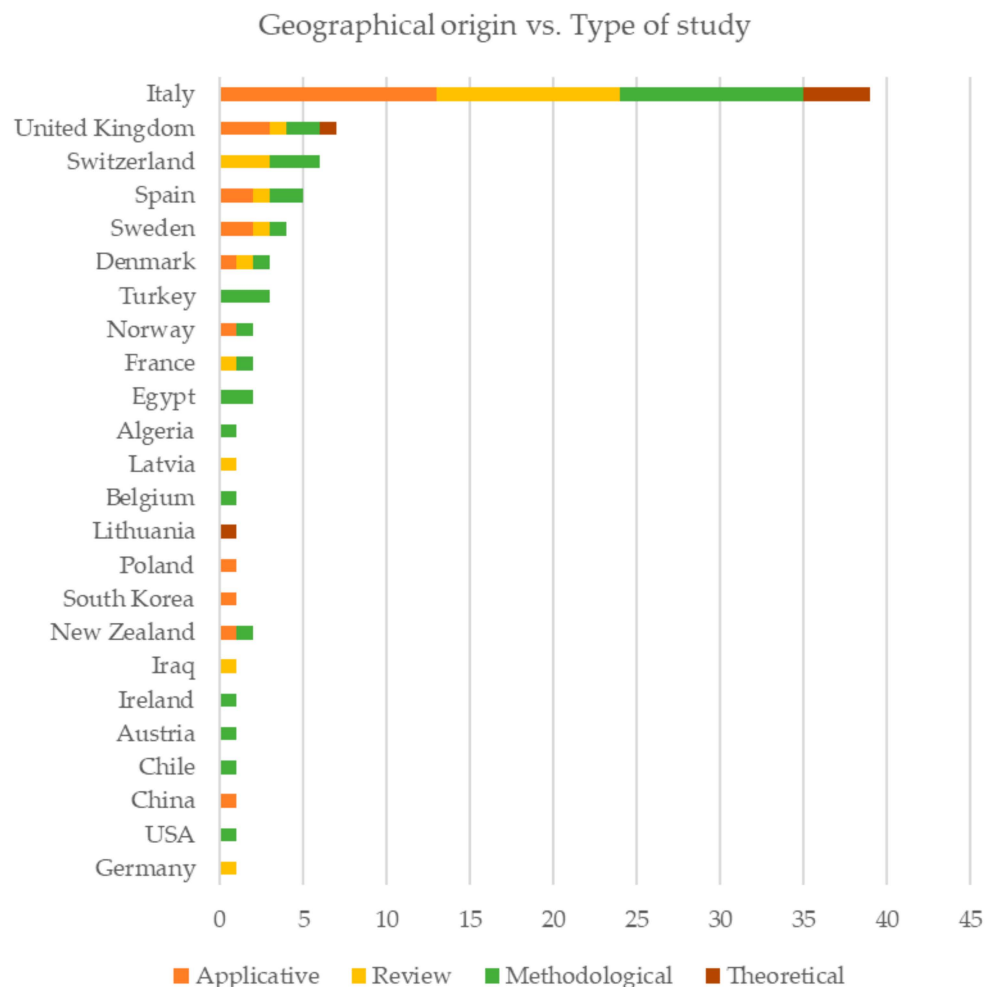


Figure 6. Cross-analysis: geographic origin vs. type of study. Source(s): Authors’ work.

Italian research exhibits a balanced multidisciplinary approach, leading in Applicative studies (13), while simultaneously contributing with Review (11) and Methodological (11) papers.

However, it is important to note that the findings for countries with a limited number of contributions must be interpreted with caution. These data points may be subject to selection bias and do not necessarily represent a national research trend, but rather isolated experimental cases.

In contrast, more robust trends can be observed in countries with a higher number of studies. Switzerland and Turkey show an orientation toward Methodological and Review studies, suggesting a focus on procedural standardization. Spain and the United Kingdom maintain a balance between practical application and methodology.

3.3. Evaluation Criteria Distribution

Figure 7 shows the distribution of the most used criteria for assessing the compatibility between energy efficiency measures and asset value in historic buildings. Based on the

findings of the review, these criteria have been organized into three main categories: aesthetic, technological, and energy-related.

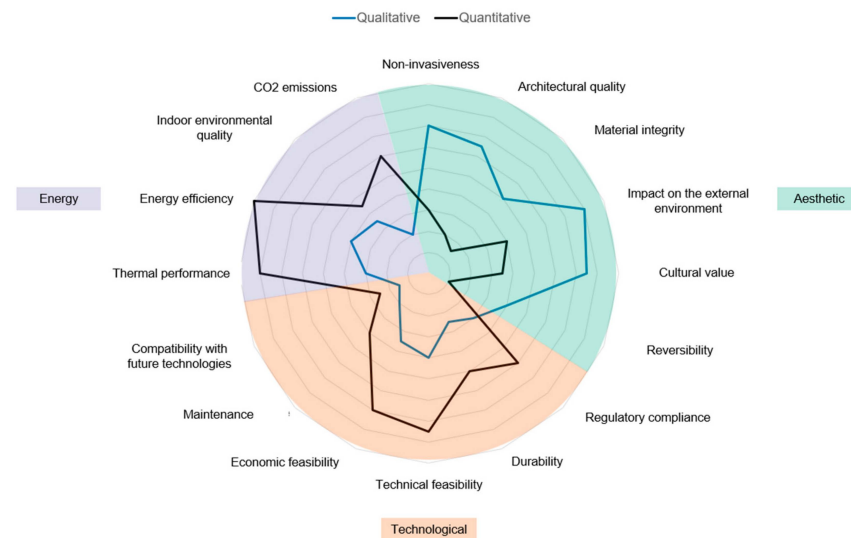


Figure 7. Distribution of evaluation criteria for energy efficiency measures in historic buildings. Source(s): Authors' work.

The analysis highlights a distinction between qualitative and quantitative studies. This distinction relates to how each study evaluates these criteria, not to the nature of the criteria themselves. The same criterion is assessed either numerically or through descriptive judgement depending on the authors' methodological approach.

In quantitative contributions, technological and energy criteria are more frequently used, such as technical feasibility, regulatory compliance, economic feasibility, and parameters related to energy efficiency and thermal performance.

In qualitative studies, on the other hand, aesthetic criteria prevail, such as cultural value and the non-invasiveness of the intervention, followed by architectural quality and reversibility.

3.4. Answering Research Questions

The analysis made it possible to answer the research questions that were initially formulated (see Table 3). The following discussion section further discusses the findings with reference to the literature.

Table 3. Answers to research questions: summary of main findings.

Research Question		Answers
(a)	What are the issues encountered in energy efficiency measures in historic buildings?	Lack of shared guidelines/protocols; limited availability of economic resources, partly due to the need for in-depth technical studies; focus on aesthetic acceptability, which can limit the levels of energy efficiency that can be achieved.
(b)	What methodologies have been developed to address the energy retrofitting of historic buildings?	Multi-criteria methodologies and mathematical models for comparing different intervention solutions; energy simulations for assessing consumption reduction; methods to support the decision-making process.
(c)	What technological solutions are preferred in energy efficiency measures for historic buildings?	Non-invasive interventions, such as internal insulation solutions; integrated solar technologies, especially BIPV systems. It is noted a lack of a clear definition of "compatibility," which makes assessments dependent on context.
(d)	What are the most common criteria for assessing the compatibility of interventions in historic buildings?	Aesthetic criteria. Technological criteria. Energy criteria.

4. Discussion

All studies included in the review were analyzed and contributed to the results. Some references [8–28] are not explicitly cited in the following discussion, as they appear only in the Appendix A tables.

4.1. Thematic Analysis

4.1.1. Balancing Efficiency and Conservation

The literature widely recognizes the central importance of the problem of combining energy efficiency with the protection of historical and architectural value. This conflict is rooted in traditional conservation principles, such as those of the Venice Charter (1964). Since these principles prioritize the preservation of the visual setting and of the relationships of volumes and colors (Art. 6), they inherently limit the use of standard energy solutions.

The analyzed studies reflect this struggle in different ways. Some contributions are practical and based on case study applications [1,29–36]. To respect the conservation limits, these studies show compatible and minimally invasive interventions that still lead to improved performance, with reductions in energy consumption, improved energy class, and closer alignment with nZEB building standards.

Other studies, on the other hand, offer more theoretical reflections. For example, Ginks [37] analyzes current approaches in the United Kingdom to retrofitting historic buildings, noting significant variation at the national level. Study [2], on the other hand, reflects on the economic importance of asset management systems, such as the implementation of RECs, which can contribute to energy efficiency through funds derived from the REC itself.

Several studies use state-of-the-art reviews to highlight critical issues arising from this balance [38–40]. These contributions highlight some difficulties related to the costs of interventions, technical complexities, lack of technical training, and poor collaboration between the parties involved. Study [41] points out that there are more regulatory difficulties in Italy: procedures are often unclear, which slows down processes.

4.1.2. Decision-Making Processes and Methodologies

The analysis shows a wide variety of methodological approaches, with attempts to construct shared models to support the retrofitting of historic buildings. The first category of studies proposes general frameworks [1,34,42–50]. These methods allow different retrofit options to be compared using energy, aesthetic, and technological parameters.

Other studies develop specific methodologies designed for specific conditions or building types: Abd Elgawad [51] deals with the choice of compatible materials; Etxepare [52] focuses on buildings with ornate facades, Frattolillo [3] on historic prisons, Galbiati [53] on modern buildings, ref. [54,55] on the integration of photovoltaics, Rieser [56] on ventilation systems, Seddiki [57] on masonry buildings and Trachte [58] on pre-war buildings.

In several cases, however, methods useful for decision-making are developed. A bottom-up approach that encourages stakeholder participation is proposed in [59], while a system for evaluating the construction techniques of historic buildings to be used as a reference for future interventions is developed in [60].

4.1.3. Evaluation Criteria

The definition of evaluation criteria emerges as one of the most complex aspects in the studies analyzed. The criteria identified in the literature can be divided into three broad categories: aesthetic, technological, and energy-related. Several authors point out that technical compatibility alone is not sufficient in protected contexts. Study [29] emphasizes that factors such as visibility and reversibility are considered fundamental for the acceptability of interventions. Similarly, Okutan [61] shows that there is no direct correlation

between visual acceptability and energy efficiency, opening the possibility of finding a balance between conservation and efficiency while confirming that there is no natural synergy between savings and acceptability.

One of the main issues concerns the objective assessment of aesthetic criteria, which is why several studies attempt to introduce quantitative metrics. A scoring system based on pre-filled forms to facilitate comparison is proposed in [42]. A weighting matrix that allows a relative value to be assigned to the different elements of a historic building and, consequently, to evaluate retrofit options is developed in [48]. A quantitative method for measuring the application of guidelines by assigning a score to best practices is defined in [62].

Alongside these approaches, some authors maintain a qualitative assessment. For example, Trachte [58] attributes greater or lesser importance to the preservation of various parts of the building without resorting to numerical systems.

4.1.4. Strategies and Technologies for Compatible Interventions

Several studies focus on solutions considered most compatible with historical heritage. In general, the literature shows a preference for minimally invasive interventions, in line with the importance attributed to aesthetic criteria. For example, Bianco [63] analyzes the use of thermal insulating plaster, while Seddiki [57] identifies the insulation of secondary facades and the replacement of windows and doors as the most suitable solutions.

However, the largest part of the studies concerns solar technologies, particularly the integration of panels through BIPV systems. Studies [4,64] explore the use of colored or semi-transparent modules designed to reduce visual impact. Other works focus exclusively on photovoltaics: a framework for assessing risks and benefits is proposed in [54]; shared criteria derived from a comparison of different guidelines are defined in [46]; photovoltaics combined with digital tools are studied in [65]; the hBESST methodology, which integrates panels considering their cultural value, is developed in [55]; and a quantitative method for assessing visual impact is proposed in [66].

The topic of solar technologies is also addressed on a larger scale through Renewable Energy Communities (RECs). Studies [5,67] investigate their role in supporting the regeneration of historic centers through plants located outside the historic center and connected via the REC. Other studies explore different alternatives: Franco [68] proposes a REC with plants installed directly on UNESCO sites using building roofs, while Manni [69] analyzes the use of RECs for the redevelopment of Ina Casa neighborhoods. In these cases, the focus shifts from the individual building to the urban and social scale. Studies [70–72] further explore how RECs can be integrated into urban planning frameworks.

4.2. Limitations Found in the Analyzed Studies

The following limitations emerge from the studies analyzed:

1. Limited availability of long-term data: many studies do not include post-intervention monitoring.
2. Reduced comparability between case studies due to the use of very different methodologies.
3. Limited case studies, often based on a single building or specific types.
4. Unbalanced analyses, either toward energy aspects or toward conservation.
5. Uneven geographical coverage, with a strong concentration in Europe and especially in Italy.

4.3. Recommendations

Based on the analyzed literature, several recommendations are proposed to enhance energy retrofitting in historic buildings. It is necessary to act on multiple levels to improve a process that is currently often fragmented.

First, intervention is required at the regulatory and doctrinal levels. Current legislation and international restoration documents often limit retrofitting efforts either through restrictive stances or by failing to provide feasible solutions. Therefore, the development of shared guidelines is essential to prevent experts from treating every project as an isolated experiment. While universal solutions are impossible due to the unique nature of heritage buildings, we recommend the creation of regional or local guidelines, which can better reflect specific territorial features. This requires close collaboration between public administrations and heritage authorities to establish clearer criteria and practical definitions for ‘compatibility’ and ‘reversibility.’ Such a framework would provide more consistent and predictable paths for project approval.

Furthermore, this strategy must be supported by technological and professional integration. At the project level, the adoption of Heritage Building Information Modeling (HBIM) is fundamental for managing the amount of site-specific data and information of historic structures. Simultaneously, it is necessary to address the significant skills gap within the sector through professional education on both traditional materials and the continuous development of new technologies. To support this, dedicated funding should be implemented for both training and the interventions themselves, which often require substantial investment.

Finally, energy retrofitting should be integrated into broader urban-scale strategies. Initiatives such as Renewable Energy Communities (RECs) are particularly valuable, as they allow for clean energy production without necessarily altering the building fabric, while simultaneously addressing fuel poverty, indoor comfort, and the overall economic sustainability of heritage conservation.

4.4. Limitations of the Review Process and Implications for Future Research

This review has some methodological limitations. All study selection and data extraction were performed by a single reviewer, which may introduce subjective bias. Additionally, only three databases were searched, and the synthesis was qualitative, limiting the ability to perform statistical comparisons between interventions.

Another limit is the lack of empirical validation; since this study analyzes existing literature, the identified challenges may not reflect the full spectrum of difficulties encountered in practice. Similarly, the criteria identified in the literature have not always been tested for their actual effectiveness in evaluating interventions.

Future studies could explore the most used criteria, test them on real cases, and verify their effectiveness through post-intervention monitoring. Further research could focus on heritage management policies and tools to support the protection of historic buildings and promote compatible energy interventions.

5. Conclusions

This study sought to identify the relationship between energy efficiency and heritage conservation by focusing on four main areas: the common issues, the most used strategies and technologies, and the criteria used to assess intervention compatibility. Based on the analysis of the literature, specific conclusions can be drawn.

First, there is a fragmented state of the art: there are no shared guidelines, criteria, or methods. A significant part of the literature is dedicated to the development of multi-criteria frameworks, mathematical models, and scoring systems, with the aim of comparing

different solutions and supporting the decision-making of the retrofit process. However, the analysis reveals that many studies are based on specific case studies that limit the possibility of generalizing the results, and few studies include long-term monitoring of the interventions.

A key finding is the growing focus on innovative solutions, both technological, such as low-visual-impact BIPV systems, and social, such as Renewable Energy Communities. While this interest is linked to European climate policies, this study concludes that analyses are often biased toward either energy or conservation aspects. The current “case-by-case” approach, while necessary for historic monuments, often leads to bureaucratic delays and high costs. Therefore, it is recommended a transition toward regional methodological protocols and the adoption of HBIM to manage the complexity of data.

In this sense, it is concluded that there is a need for increased technical training. This is essential to keep pace with ongoing research on new technologies and to ensure that interventions are not only energy-efficient but also technically compatible and respectful of the building’s authenticity.

In conclusion, retrofitting should not be seen as a choice between energy performance and conservation. The literature suggests that, even with existing technology, balance is possible. However, this requires a change in strategy: moving from isolated experiments to integrated urban policies.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/doi/s1>, Table S1: PRISMA 2020 checklist; Table S2: PRISMA 2020 Abstract checklist. Reference [73] is cited in the Supplementary Materials.

Author Contributions: Conceptualization, P.F. and M.G.; validation, P.F. and M.G.; formal analysis, I.D.N.; investigation, I.D.N.; data curation, I.D.N.; writing—original draft preparation, I.D.N.; writing—review and editing, I.D.N., P.F. and M.G.; visualization, I.D.N.; supervision, P.F. and M.G.; project administration, P.F. All authors have read and agreed to the published version of the manuscript.

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Abbreviations

The following abbreviations are used in this manuscript:

BIPV	Building-Integrated Photovoltaics
nZEB	Near Zero Energy Buildings
REC	Renewable Energy Community

Appendix A

Table A1. Publications concerning methodological contributions.

No	Authors	Aim of the Study	Results
1	Abd Elgawad et al. (2025) [51]	Develop a mathematical model to identify best materials for adaptive reuse interventions in historic buildings	Algorithm that balances heritage conservation (through criteria) and energy efficiency
2	Berg & Donarelli (2019) [59]	Present a bottom-up method to support the retrofiting of historic multi-residential buildings	Emphasizes the importance of presenting the pros and cons of alternatives based on various criteria for better choice
3	Çalışkan & Dişli (2025) [60]	Develop a scoring method to evaluate historic buildings in terms of energy efficiency, to be used as a basis for retrofiting	Demonstrates that passive solutions in historic buildings ensure energy efficiency. Demonstrates that these characteristics can be adapted to contemporary projects
4	Castaldo et al. (2017) [9]	Propose a retrofit approach that combines the principles of GBC certification with innovative systems for the retrofiting of historic buildings.	Improvement in terms of energy consumption and certification score achieved
5	Castilla (2023) [10]	Evaluate and optimize the internal microclimate of historic cellars to ensure the preservation of their original function and provide a replicable method for other industrial heritage buildings.	The proposed methodology allows for the evaluation and management of the internal microclimate for conservation and sustainable reuse
6	De Medici (2021) [12]	Identify criteria for integrating photovoltaic systems into pre-industrial buildings, with a focus on protecting cultural heritage	Divides criteria into compatibility and acceptability; develops hypotheses for classifying buildings based on their state of conservation
7	De Santoli (2014) [13]	Define guidelines for improving the energy efficiency of historic buildings while respecting their cultural value.	The paper presents a clear framework for retrofit actions
8	Galbiati et al. (2021) [53]	Propose a comparative method for energy interventions on modern heritage buildings	The MERMA methodology applied to the Olivetti building allows for a 55% reduction in energy consumption while preserving its historical architectural elements
9	Garzulino (2020) [42]	Propose a multi-criteria method for comparing energy improvement techniques on historic buildings	Organization of a system useful for the easy description and objective evaluation of possible interventions
10	Ismaeel & Gouda Mohamed (2023) [43]	Develop a decision-making model to guide the eco-rehabilitation and adaptive reuse of historic buildings	The model identifies three main parameters (efficient use of materials, indoor environmental quality, and energy efficiency) and allows actions to be prioritized based on the specific context
11	López et al. (2021) [54]	Creating a risk-benefit analysis framework for solar installation solutions in heritage contexts	Technical compatibility is not the main obstacle, while visual impact, reversibility, and heritage protection represent the main challenges for solar installations.
12	López et al. (2021) [17]	Identifying a methodology for integrating BIPV into buildings of architectural and historical interest, assessing compatibility and energy parameters	Proposing a methodological approach for BIPV in heritage contexts. Critical factors identified: visibility, reversibility, technical and regulatory compatibility with historical contexts.
13	López-Zambrano et al. (2019) [45]	Develop a system to evaluate and select energy renovation interventions compatible with the constraints of protecting Cultural Heritage	Highlighted that simple technical feasibility does not guarantee acceptability in protected contexts
14	Piderit et al. (2019) [47]	Creating a methodology that reconciles energy needs and heritage protection in vulnerable contexts, identifying building elements to be restored	The system allows interventions compatible with the level of protection of the asset to be identified and evaluated in terms of energy performance. It demonstrates that it is possible to improve energy efficiency while respecting historical and artistic value
15	Rieser et al. (2021) [56]	Creating a clear method for selecting and designing efficient ventilation systems in historic buildings	The methodology allows us to determine which parts of the building can be redeveloped without losing value, exploiting construction defects as opportunities to improve energy efficiency
16	Roberti et al. (2017) [48]	Proposing a method for evaluating retrofits of historic buildings by quantitatively comparing three aspects: compatibility with conservation, energy savings, and comfort	The proposed approach allows for reliable preselection of ventilation solutions compatible with historic buildings, integrating the EN 16883 standard with the HiBERTool decision tree
17	Rosa (2020) [55]	Develop a method for integrating photovoltaic panels into historic buildings without affecting their cultural value	It identifies a set of optimal retrofits, showing that it is possible to reduce consumption by about four times while maintaining high comfort without compromising the heritage too much
18	Ruggeri et al. (2020) [49]	Developing a decision support system for planning energy retrofits on historic buildings using a quantitative ‘restoration score’	The results show that the hBESST approach allows for energy-efficient designs that respect heritage, minimizing visual impact
			The system identified the optimal retrofit that reduces consumption and costs, improves indoor comfort, and preserves historical value

Table A1. *Cont.*

No	Authors	Aim of the Study	Results
19	Seddiki et al. (2016) [57]	Developing a method to determine the most relevant criteria and best solutions for the energy renovation of heritage masonry buildings	The method made it possible to obtain a complete ranking of renovation solutions, identifying external roof insulation, insulation of secondary facades and courtyards, and replacement of windows and doors as the best interventions
20	Trachte & Stiernon (2024) [58]	Developing decision-making tools to support the planning of energy renovation interventions in pre-war historic buildings	The project developed a reflective process, decision-making tools, and recommendation sheets, facilitating the choice of energy interventions
21	Ulu & Durmus Arsan (2020) [50]	Develop an integrated approach to identify effective large-scale energy retrofit solutions in historic urban fabrics, respecting the historical and architectural value of buildings	The approach allows for quick decisions without in-depth checks and can be adapted to other Mediterranean historical contexts
22	Xu et al. (2017) [66]	Develop a quantitative method to assess the visual impact of solar panels on buildings	The salience method made it possible to accurately measure the visual impact of different BIPV designs, clearly distinguishing which design generates impact

Table A2. Publications concerning applicative contributions.

No	Authors	Aim of the Study	Results
1	Balocco & Colaianni (2018) [29]	Comparing retrofit solutions for the heating system of a historic school building	Improving heating systems through a regulated heating system is the most effective and least invasive intervention for historic school buildings; combining this with the building envelope can further increase energy efficiency
2	Basti et al. (2023) [67]	Investigating the role of RECs in the energy transition of inland areas and smaller historic centers, with an application to the case of Roseto Valfortore	RECs can promote urban and landscape regeneration and energy self-production when integrated with a multidisciplinary approach
3	Bhati et al. (2025) [8]	Identify energy transition issues in World Heritage sites	World Heritage status supports conservation goals but creates additional barriers to energy efficiency
4	Bianco et al. (2015) [63]	Analyzing thermal insulating plaster as a non-invasive technique	The new plaster reduces heat loss through walls (by approximately 20–40%) thanks to its superior insulating capacity compared to traditional plasters. It also indicates that the material has a low environmental impact, making it a promising solution
5	De Berardinis et al. (2014) [11]	Analyzing historic buildings in Abruzzo and proposing energy efficiency measures based on invasiveness	Demonstrates that, through a case-by-case approach, it is possible to improve the energy efficiency of historic buildings damaged by the 2009 earthquake by more than 50% by choosing solutions compatible with their specific characteristics
6	Di Rocco et al. (2024) [62]	Evaluate the effectiveness of the “BIPV meets History” guidelines in integrating photovoltaics into historic buildings, applying them to cases in the HiBERAtlas database	Three approaches identified (complete, indirect, and partial integration); aesthetics is the most decisive factor; some technological criteria are difficult to apply due to lack of data
7	Etxepare et al. (2020) [52]	Establish a protocol for the energy retrofitting of historic buildings with ornate facades	The energy retrofitting of historic buildings with ornate facades is possible through solutions such as improvements to systems and customized external insulation using BIM modeling
8	Fedorczak-Cisak et al. (2019) [30]	Defining and evaluating criteria for comparing different adaptive reuse solutions for historic buildings, using the example of the ‘Stara Polana’ building in Zakopane	Criteria were defined to evaluate the reuse of the building, considering material, immaterial, and socio-economic characteristics, and identifying possibilities and limitations for new functions
9	Fiore et al. (2016) [1]	Provide a methodology for improving the energy efficiency of historic buildings, balancing renovation work with the preservation of historical and architectural values	The case study of the Convent of the Holy Spirit shows that it is possible to increase energy performance thanks to new technologies without compromising the integrity of the monument
10	Franco & Mauri (2024) [31]	Demonstrate the possibility of reconciling energy efficiency measures aimed at nZEB standards with the conservation of historic buildings	It was possible to approach nZEB standards even in a listed building. Critical issues identified: interdisciplinary coordination, long timescales, costs, lack of specialized technical personnel
11	Franco (2018) [32]	Evaluate and propose criteria for the integration of solar technologies in rural buildings in the Cinque Terre UNESCO site, reconciling energy efficiency and cultural heritage protection	The study defined compatibility criteria considering size, shape, materials, inclination, and integration into the context

Table A2. *Cont.*

No	Authors	Aim of the Study	Results
12	Frattolillo et al. (2023) [3]	Providing a methodology for the redevelopment and sustainable reuse of historic prison buildings, integrating heritage conservation, energy efficiency, and environmental comfort	Diagnostic procedures and targeted interventions are defined on the building envelope, systems, and historic materials, with a multidisciplinary approach
13	Giannobile et al. (2024) [7]	Assessing the benefits of establishing a REC in a residential area in the Abruzzo hinterland	The REC allows for energy self-sufficiency of over 40%, reduces CO ₂ emissions, and protects the soil by using existing roofs, with significant economic and social benefits for the local community
14	Jerome et al. (2021) [33]	Analyzing the relationship between asset value recovery, environmental impact, and economic impact in the renovation of a pre-war building	Renovation with a facade recreated to resemble the original improved the thermal comfort and aesthetics of the building, albeit with an unfavorable economic return
15	Jiang et al. (2023) [44]	Develop a framework for the adaptive reuse of historic buildings and gardens	Adaptive reuse with PV improves heritage conservation, energy sustainability, and user well-being, reducing the risk of abandonment and preserving the historical memory of the gardens
16	Mazzarella (2015) [19]	Analyzing the energy and economic feasibility of retrofitting existing historic/residential buildings, considering regulatory and heritage restrictions	Significant energy savings can also be achieved in historic buildings, compatibly with conservation constraints, by optimizing the performance of the building envelope and systems
17	Minutoli (2021) [65]	Analyzing strategies and criteria for integrating photovoltaic systems into historic buildings using digital tools	The integration of photovoltaic systems into historic buildings is possible through innovative solutions; the use of digital tools facilitates objective assessments of technical and aesthetic compatibility
18	Murillo et al. (2023) [21]	Understanding how different stakeholders in Mexico City's historic center balance historical values, thermal comfort, and energy efficiency	There is a conflict between protecting historical value and energy efficiency, exacerbated by institutional constraints and a lack of resources. Including users and their values in the decision-making process is essential
19	Okutan et al. (2018) [61]	Comparing the acceptability of interventions on a historic building with energy savings	Public opinion through questionnaires with photographs. It is shown that greater savings do not necessarily equate to less acceptable measures
20	Onecha et al. (2021) [34]	Define a method that balances energy efficiency and the preservation of cultural values in a historic building, applying it to the case of the Can Armengol Palace	Internal insulation of the facades is the most effective strategy for reducing heating demand, but even with all possible interventions, the building cannot exceed energy class C without compromising its heritage
21	Paschoalin & Isaacs (2021) [22]	Exploring how to adapt international guidelines to the energy retrofitting of historic buildings in New Zealand	Retrofitting the entire building envelope significantly reduces energy, costs, and carbon emissions compared to isolated interventions; professionals are calling for national guidelines but fear risks to heritage and moisture problems
22	Pedersen et al. (2024) [35]	Investigating how to retrofit three historic Norwegian farmhouses for energy efficiency while respecting their architectural value	Targeted interventions can reduce energy demand by 55–75% while maintaining the cultural value of the buildings. Meeting modern standards is possible, but each building requires a case-by-case assessment
23	Rose & Thomsen (2021) [36]	Analyzing how to reduce energy consumption and improve indoor comfort in renovated historic buildings without compromising cultural value, using Danish case studies	Both projects achieved significant reductions in energy consumption (up to 77% for heating) and improvements in indoor comfort
24	Xu et al. (2025) [26]	Develop sustainable retrofit strategies for historic buildings to reduce energy consumption while preserving historical value	Customized retrofits reduced energy consumption by up to 37%, minimizing historical impact and initial costs
25	Yuk et al. (2023) [27]	Finding an optimal energy retrofit package for historic buildings that reduces energy consumption while preserving historical value	The application of glass wool between battens is the optimal method for the South Korean context, ensuring compatibility with historic roofs and energy savings

Table A3. Publications concerning theoretical-reflective contributions.

No	Authors	Aim of the Study	Results
1	D'Andria (2022) [4]	Analyze the role of RECs in small towns, with particular attention to Italian villages, assessing their potential and critical issues in the relationship between energy transition and heritage protection	RECs can offer energy, social, and economic benefits, but in Italian historical contexts, there are critical issues related to landscape impact and heritage conservation. The literature indicates the need for integrated, low-visibility solutions on a territorial scale
2	Del Curto (2021) [6]	Analyze the impact of the 'Relaunch' Decree Law on the restoration and energy efficiency of historic buildings in marginal areas, assessing the relationship between heritage protection and sustainability	It demonstrates that the 'Relaunch' Decree Law represents an opportunity for energy transition, but requires attention to the limitations of energy certification and the enhancement of aspects such as comfort, habits, and behaviors

Table A3. *Cont.*

No	Authors	Aim of the Study	Results
3	Ginks & Painter (2017) [37]	Analyze current approaches in the UK regarding retrofitting historic buildings, particularly the replacement of traditional windows	There is considerable variation at the national level, leading to inconsistency in interventions
4	Grazuleviciute-Vileniske et al. (2020) [16]	Highlight the link between historic buildings, historic urban landscapes, and sustainable development to guide urban planning	Historic buildings can help the sustainable development of historic cities by improving the quality of the natural, social, cultural, built, and economic environments
5	Manni & Valzano (2022) [69]	Exploring the potential of RECs as a tool for regenerating post-war reconstruction buildings, particularly in the Ina Casa neighborhoods.	RECs can be an alternative to traditional efficiency measures, which are often invasive and standardized. The gap lies in the lack of methodologies for translating RECs into measures that are compatible with architectural value.
6	Sessa (2024) [2]	Propose the Renewable Energy Communities (RECs) model as heritage management entities.	Hypothesize scenarios in which RECs could manage or support the protection of historic buildings by reinvesting the economic benefits derived from energy self-consumption.

Table A4. Publications concerning review contributions.

No	Authors	Aim of the Study	Results
1	Del Hierro López & Olivieri (2025) [38]	Analyze case studies of BIPV installations in order to increase their visibility as solutions	BIPV systems are mainly installed on the roofs of historic buildings in Europe, respecting historical values; Switzerland and Italy lead the way in adoption, while the main obstacles are cost, technical complexity, and lack of awareness
2	Durante et al. (2021) [14]	Examine the state of the art of technologies and criteria adopted for the integration of photovoltaic systems in heritage contexts, analyzing case studies	They highlight the variety of possible approaches and the differences related to the regulatory and cultural context
3	Franco & Casanova (2023) [68]	Map RECs in Italy and identify issues, especially in restricted areas. Propose an initial approach to a REC at a UNESCO site	Identify 21 public buildings for possible photovoltaic systems at a UNESCO site, assessing visibility and historical compatibility; map RECs in Italy and identify the main barriers to their dissemination
4	Galatioto et al. (2017) [15]	Analyze the state of the art and feasibility of energy retrofitting in Italian historic buildings	Significant energy saving potential, especially through interventions on the building envelope and systems, but with high variability linked to climate, building type, and regulatory constraints; significant difficulties in achieving nZEB requirements
5	Herrera-Avellanosa et al. (2024) [39]	Analyzing case studies of retrofits in historic buildings	Several challenges are identified in the renovation of historic buildings: restrictions, specific technical solutions, costs, relations with authorities, physical limitations of the building, knowledge gaps
6	Ladu & Milesi (2023) [5]	Analyzing regulatory frameworks in historic centers in Sardinia for the integration of renewable energy systems through RECs	Regulations focus more on the historic settlement, allowing for partial integration and encouraging the participation of historic centers in RECs through external systems
7	Lucchi (2022) [64]	Providing a useful framework for defining national and local policies that balance conservation and energy sustainability.	Identifies an updated set of criteria divided into aesthetic, technological, and energy integration
8	Lucchi et al. (2023) [46]	Define shared design criteria for the integration of solar technologies in historic buildings, creating a methodological framework based on the comparative analysis of international guidelines	Identifies recurring criteria, creates an international glossary of key terms, and proposes an innovative framework of guidelines
9	Lucchi et al. (2022) [41]	Comparing Italian and Swiss legislative frameworks for the integration of photovoltaic systems in protected areas	In Italy, legislation slows down the adoption of PV in protected areas, while in Switzerland clearer procedures favor its spread; in both cases, guidelines and technical training need to be updated
10	Lucchi et al. (2020) [18]	Investigating the integration of solar systems in historic buildings and sites, developing a conceptual framework and operational guidelines	BIPV/BIST allow for adequate integration in historic contexts; national and local guidelines provide clear criteria, but concrete examples of applications are lacking
11	Miran & Husein (2023) [20]	Analyzing adaptation interventions in historic buildings in the Citadel of Erbil and developing a conceptual model to guide future interventions	Most buildings have been restored or adapted for new uses, but almost none have undergone energy efficiency interventions or passive retrofits

Table A4. Cont.

No	Authors	Aim of the Study	Results
12	Panakaduwa et al. (2024) [40]	Review to identify challenges in retrofitting historic buildings	Greater challenges are identified compared to non-historic buildings. Technologies to balance energy efficiency with preserving historical value already exist; what is needed are greater incentives, collaboration between stakeholders, stakeholder commitment, and the development of a skilled workforce
13	Perret et al. (2025) [23]	Validate, through an extensive literature review, the conceptual model of the CALECHE HUB for the sustainable redevelopment of historic buildings	Approaches that combine adaptive reuse, cultural values, and sustainable technologies can combine conservation and energy retrofitting. More integration of new technologies, LCA, and updated regulatory frameworks are needed
14	Sacchetti et al. (2023) [24]	Analyze Italian cases of regeneration of small historic centers, highlighting how they can be integrated with energy efficiency strategies	Energy interventions are often limited to individual buildings, while integration with energy communities can promote larger-scale strategies
15	Santi & Laiola (2019) [25]	Analyze energy retrofit strategies for residential industrial villages in Friuli-Venezia Giulia and identify best practices and guidelines	Energy retrofit strategies that respect the historical and cultural value of industrial villages have been identified, highlighting the potential for regeneration of residential areas
16	Zagorskas et al. (2013) [28]	Analyze strategies for improving energy efficiency in historic buildings, with attention to the limitations imposed by conservation	In historic buildings, internal insulation improves energy efficiency only if integrated with mechanical ventilation; achieving modern standards is often impossible, and risks of humidity and mold must be avoided

Table A5. Publications relevant by abstracts but excluded due to lack of access to full text.

No	Authors	Title
1	Besen et al. (2020)	Energy and seismic retrofit of historic buildings in New Zealand: reflections on current policies and practice
2	Broström prof et al. (2014)	method to assess the potential for and consequences of energy retrofits in Swedish historic buildings
3	Conejos et al. (2016)	Governance of heritage buildings: Australian regulatory barriers to adaptive reuse
4	Crockford (2014)	Sustaining our heritage: the way forward for energy-efficient historic housing stock
5	De Berardinis & Rotilio (2009)	The promotion of energy efficiency of the building envelope in the rehabilitation process. Case study: a minor center in Abruzzo
6	Eriksson et al. (2020)	Balancing preservation and energy efficiency in building stocks
7	Herrera-avellanosa et al. (2020)	Deep renovation of historic buildings: the IEA-SHC task 59 path towards the lowest possible energy demand and co2 emissions
8	Posani et al. (2021)	Towards resilience and sustainability for historic buildings: a review of envelope retrofit possibilities and a discussion on hygric compatibility of thermal insulations
9	Rispoli & organ (2019)	The drivers and challenges of improving the energy efficiency performance of listed pre-1919 housing
10	Ulaş sariaydin (2025)	AHP multi-criteria decision-making model for selecting an energy renovation scenario for a historic building

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