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Towards Zero-Emission Refurbishment of Historic Buildings: A Literature Review

Arian Loli * and **Chiara Bertolin**

Department of Architecture and Technology, Norwegian University of Science and Technology, 7491 Trondheim, Norway; chiara.bertolin@ntnu.no

* Correspondence: arian.loli@ntnu.no; Tel.: +47-922-36-913

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Abstract: Nowadays, restoration interventions that aim for minimum environmental impact are conceived for recent buildings. Greenhouse gas emissions are reduced using criteria met within a life-cycle analysis, while energy saving is achieved with cost-effective retrofitting actions that secure higher benefits in terms of comfort. However, conservation, restoration and retrofitting interventions in historic buildings do not have the same objectives as in modern buildings. Additional requirements have to be followed, such as the use of materials compatible with the original and the preservation of authenticity to ensure historic, artistic, cultural and social values over time. The paper presents a systematic review—at the intersection between environmental sustainability and conservation—of the state of the art of current methodological approaches applied in the sustainable refurbishment of historic buildings. It identifies research gaps in the field and highlights the paradox seen in the Scandinavian countries that are models in applying environmentally sustainable policies but still poor in integrating preservation issues.

Keywords: historic buildings; environmental sustainability; conservation; literature review; method; maintenance; refurbishment; Scandinavian countries

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1. Introduction

the renovation potential of buildings in the European Union (EU) is huge. Up to 110 million buildings could be in need of renovation [1] as 35% of the EU's buildings are over 50 years old and, in Europe, there is a slow replacement rate [2].

In the existing built environment, a historic building (HB) is a single manifestation of immovable tangible cultural heritage that does not necessarily have to be a heritage-designated building [3,4]. The historic buildings (HBs) that are not listed or fully protected by countries' legislation may have a significant cultural value in identifying the form of cities, and play a significant role in providing a sense of identity to the community. However, existing materials, building structures and envelope design may limit the choice of interventions to be applied, while the restraints in thermal-performance upgrades may limit their cost-effectiveness. This means that, if compared to recent buildings, these interventions are more demanding in terms of maintenance and adaptation and more challenging in energy-saving during the operational stage.

Nowadays, the preservation of historic buildings is at risk, not only due to natural weathering of their materials but also by the convenience of rebuilding instead of restoring or of developing renovation methods tailored to modern buildings. The topic has recently gained a lot of attention, including the first achievements of planning and executing preservation, protection, maintenance and restoration of immovable cultural heritage in a standardised way [3].

in recent years, several databases (e.g., the Odyssee database used by the European Environment Agency (EEA) [5]), assessment methods (e.g., Building Sustainability Assessment (BSA) [6]) and modelling and evaluations tools (e.g., the SURE Indicator Tool [7]) applicable to different stages of the refurbishment process have been created.

in addition, different sustainability certification systems to assess building performance have been developed. The most important at European level are:

- BREEAM (Building Research Establishment Environmental Assessment Methodology), leading in the EU market (80% of all the EU-certified sustainable buildings) but mostly used in the United Kingdom, where it was created in 1990 [8];
- LEED (Leadership in Energy and Environmental Design) developed in the USA in 1998 [9];
- HQE (High-Quality Environmental) developed in France in 1992 [10];
- Miljobyggnad (environmental buildings) created in Sweden in 2005 [11]; and
- the DGNB (German Sustainable Building Council) system developed in Germany in 2007 [12].

These tools apply a rating method to compare different options in new, converted or renovated buildings; for example, to assess the improvements in energy and materials before and after refurbishment. However, their scoring methods are actually not applicable for the conservation of HBs, as they are not designed to highly rate: (i) the multi-value of immovable cultural heritage; (ii) the significant embodied energy savings within this building stock; and (iii) the energy performance targets achievable through refurbishment.

Decisions on conservation, restoration and retrofitting interventions in HBs need to take into account not only the aspects mentioned in the above paragraph but also a broader range of benefits counting for historic, artistic, cultural and social values or the preservation of authenticity and use of materials compatible with the originals. In such a case, reversible techniques are preferable because, if proven to be inefficient or of low durability over time, they can be replaced without damaging the original material or decreasing artistic and historical value. However, reversible techniques (i.e., maintenance and preservation actions) do not always solve existing restoration problems that require higher levels of interventions of the irreversible type.

Is it possible to save HBs by implementing sustainable-refurbishment actions? What are the existing methods used by heritage scientists, environmental engineers and, generally, decision-makers to plan correct and effective sustainable interventions? Are the two main research communities working on these objectives? What are the gaps in knowledge?

This paper puts into the sustainability specialist and conservators' debate the potential conflict between the need to meet environmental targets—particularly greenhouse gas emissions, e.g., the objective of a 20% energy-saving target by 2020 [13]—and to retain cultural heritage values and resources (Section 1—Introduction). The aim is to clarify such issues through a systematic literature review (Section 2—Methodology). The results indicate a need for knowing, characterizing and summarizing the existing methodological approaches on cultural heritage safeguarding and CO_2-savings potentialities linked to refurbishment (Section 3—Results). Finally, the paper in Section 4 (Discussion and Conclusions) identifies the gaps in the methodological approach that must be addressed in the future. It also highlights the current situation created in the Scandinavian countries that are meritorious, and a model in applying sustainable policies that are nonetheless poor when it comes to integrating preservation issues.

2. Methodology

in research studies, there is a variety of methods that can be applied during a literature review and the choice of the appropriate one is a delicate process because the use of different methods in the same field may appear to have contradictory outcomes [14]. The topic of "sustainable refurbishment of historic buildings" involves different research communities and asks for a review of large bodies of information from different fields. For this reason, the systematic literature review method was selected and applied at the junction between the environmental sustainability and the heritage sectors, as this method guarantees a proper mapping of different areas of knowledge and of relevant research gaps and uncertainties and highlights research needs properly [15].

2.1. Selection of Publications

Identification and counting of existing research publications in the field of sustainable refurbishment of historic buildings was done using the online Elsevier database, Scopus. This platform was selected because it is the world's largest abstract and citation database of peer-reviewed literature i.e., scientific journals, books and conference proceedings, with over 22,000 titles from more than 5000 international publishers [16]. The interests of the two main research communities involved, sustainability and refurbishment specialists, drove the choice of the two initial sets of keywords in the search, using one set for each community. The first set was created to identify the publications related to sustainable methodologies applied to historic buildings by using the keywords "sustainab*" AND "method*" AND "histor* build*"; while the second research results related to interventions aiming at the preservation of historic buildings by using the keywords "preserv*" AND "interven*" AND "histor* build*". The two sets have in common only the category of analysed buildings, i.e., historic buildings, while they differ for the rest. The keywords were written keeping the root of the word and adding the asterisk symbol (*) after it to include all the grammar forms of the word. As the research topic is quite new, the search was performed for scientific publications from the year 2000 until the present day (search performed in September 2017). The search results gave a total number of 274 publications, of which 118 documents resulted from the first set of keywords (sustainability field) and 156 documents from the second set (preservation field). After a first scan, the total number was reduced to 246, removing 9 documents not written in English, 9 duplicate documents, and 10 lecturers' notes or conference proceedings' books. This final list was subject to a document analysis both in term of general characteristics, contents, gaps and needs. The list of the publications considered for the review is provided in the supplementary file.

2.2. Analysis of Publications

the first level in the analysis, i.e., the general characteristics for each document, was retrieved by reading the abstract aiming to identify the following information:

- geographical area;
- type of publication;
- year of publication;
- discipline of the research.

the classification of the documents regarding their discipline served as an input for the second level of analysis i.e., the content characteristics. Within this level, the documents were grouped using the scheme in Figure 1. They were categorised according to the intervention-driving factor i.e., sustainability or the measures to improve the performance of the building. When one document was judged to belong to more than one category, it was assigned to the most relevant field by the authors. From these two main driving factors (orange colour—Figure 1), more precise categories of contents were recognized (green colour in Figure 1) and the classes of environmental (impact) and refurbishment (process), the focus of our paper, were selected for further review. This deep review was the third and last level of analysis, i.e., the content's characteristics. This consisted of full text readings of papers that were assigned to environmental and refurbishment green boxes (Figure 1), in order to understand the objectives and the authors' judgement and track future research needs. Specifically, research products focused on methodological approaches (blue cell—Figure 1) were the ultimate objective of this review as the base on which to build new and effective tools in planning the sustainable refurbishment interventions of HBs in Scandinavian countries.

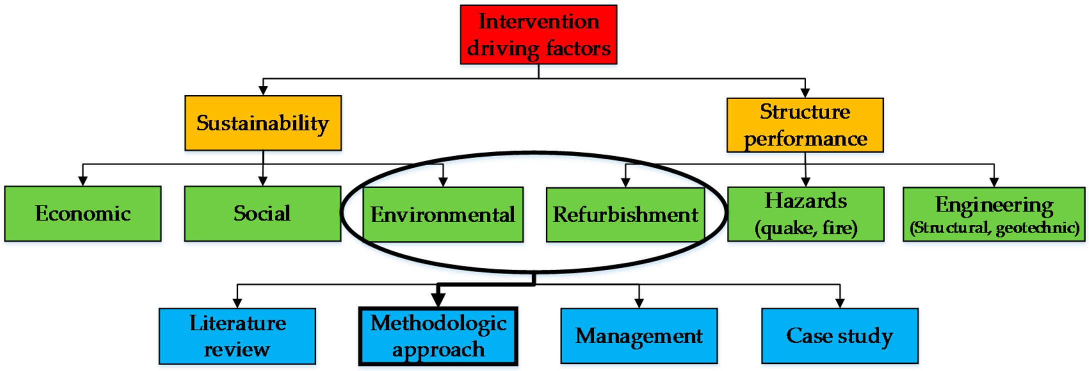


Figure 1. Flow diagram for the content review of the documents. Step 1 groups the documents according to the focus of publication (orange cells), step 2 categorizes them according the field of publication (green cells), and step 3 identifies the type of contribution (blue cells).

3. Results

3.1. General Characteristics

3.1.1. Geography of Publications

the geographical distribution of the documents is defined taking into account the continent and the country of the first author's affiliation. By screening of the entire list it can be seen that 79% (n = 193) of the documents are published by researchers from the European continent, 10% of the documents (n = 25) are published in Asia, and each of the other continents has produced less than 5%. This result reflects the efforts and the financial availability that the European Commission is investing in Framework Programme (FP) for Research and Technological Development in order to develop innovative and effective ways to preserve its cultural heritage. In fact, over the last few decades, the largest EU-funded research initiatives such as the Noah's Ark [17], Climate for Culture [18], EFFESUS [19], 3EnCult [20] and MOVE [21] projects, have demonstrated valuable methodological approaches in the cultural heritage (CH) protection field.

It is interesting to examine the results within Europe. Almost half of the relevant European literature (45%) is published in Italy (n = 86), followed by United Kingdom with 11% (n = 22), Spain and Turkey with 6% (n = 11), Czech Republic with 5% (n = 10), and other countries with less than 10 publications. Regarding northern Europe, the number of publications is very low, with two documents published in the Scandinavian countries (both of them part of the European project EFFESUS [19]) and two documents published from researchers affiliated with the Baltic countries. The results show that the topic is still unexploited and more research should be conducted for the green refurbishment of historic buildings in northern Europe. The geographical distribution is given in Table 1.

Table 1. Distribution of the publications by continent within the two main research communities involved, i.e., the sustainability and conservation specialists.

Continent	"Sustainab"	"Preserv"	Total	Percentage
Europe	84	109	193	79%
Asia	20	5	25	10%
North America	5	7	12	5%
South America	1	8	9	4%
Australia	1	3	4	1%
Africa	1	2	3	1%
Total	113	134	246	100%

3.1.2. Type of Publication

the search has shown that documents were written in all forms of scientific literature, with the journal article being the most found genre (128 documents (52%)). As journal articles are expected to have top-level quality due to rigorous peer-review processes before publication and a larger impact in the research community, they received most attention during the literature-review process. The percentage of publications related to conferences is also considerable with 43% (n = 109) of the documents categorised as conference papers. The other types of publications such as books or book chapters account for less than 5%.

3.1.3. Year of Publication

the sustainable refurbishment of historic buildings is a multi-disciplinary topic that has received a lot of attention among researchers in recent years. In fact, while the number of publications within this field was quite low (n = 2) in 2000, over the last few years that has increased significantly, reaching a maximum in 2015 with 38 publications followed in 2016 with 35. Figure 2 shows the number and the categories of publications per year.

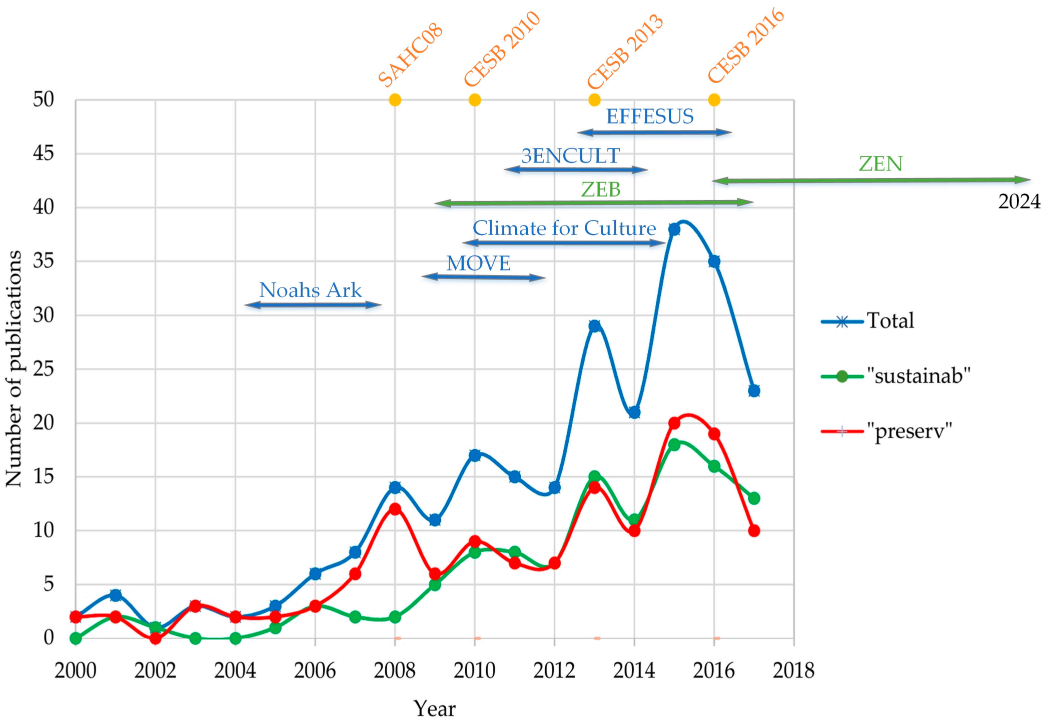


Figure 2. Distribution of documents by year of publication with indication of some major projects and conferences in the field that have influenced the growth of interest in this research topic. The Norwegian research centres for Zero-Emission Building (ZEB) and on Zero-Emission Neighbourhoods in Smart Cities (FME ZEN) are also highlighted.

the graph highlights an increased number of publications in 2008 with regard to the set of search keywords related to interventions (i.e., "preserv*" AND "interven*" AND "histor* build*"). From the data analysis, the increase this year mainly came from publications related to the International Conference on Structural Analysis of Historic Construction (SAHC08). In addition, regarding sustainability issues, the number of publications reflects three fruitful series of conferences—the Central Europe towards Sustainable Building (CESB) event held in Prague, Czech Republic in 2010, 2013 and 2016. The 2015–2016 maximum in the number of publications is not a result of a separate event but rather the effect of the EU framework programme FP7—environment. This EU framework, over a 6-year period (2007–2013), produced a general increase in consciousness of environmental technologies to be used in CH protection and necessary knowledge that resulted in a rise in the number of publications a few years later. Publications in 2017 are counted until early September, the date when the search was concluded.

3.2. Content Characteristics

3.2.1. Field of Publication

the sustainable refurbishment of historic buildings has embraced researchers from different fields and disciplines. The grouping of documents according to their field of publication is reported in Figure 3. In about 34% (n = 84) of the listed documents (see supplementary file), the main driver of the publication is the refurbishment process, from maintenance (preservation, conservation) i.e., low-level interventions to renovation and/or restoration i.e., high-level interventions. Within this group of documents (primary driver: refurbishment), 55% (n = 47) of the publications focus on energy efficiency and the energy retrofit of historic buildings as part of the global effort to reduce energy consumption [13,20]. a wide variety of passive and active interventions were used to achieve such energy goals, e.g., passive interventions directed to the building envelopes, insulation of roofs and walls, introduction of high-performance windows, and active measures directed at energy-saving improvements linked to equipment maintenance, system controls, change in lighting, and heating, ventilation and air-conditioning (HVAC) systems. Ten documents (i.e., 12% within this driving factor) are, instead, related to the revitalization/reuse of abandoned buildings or their change of use.

the second large sub-group (Figure 3—yellow colours) of listed publications has sustainability issues as its main driver (n = 62, i.e., 25%) in accordance with the three main pillars of sustainability: environmental (n = 30, i.e., 12%), social (n = 23, i.e., 9%) and economic (n = 9, i.e., 4%). Although this sub-group is strictly connected with the first, this division was undertaken to maintain the focus of the paper, i.e., to analyse the union and intersection between the physical process of the intervention (sub-group 1 i.e., refurbishment) and the impact of the intervention (sub-group 2 i.e., sustainability). The environmentally sustainable-related documents mainly emphasise the reduction of greenhouse-gas emissions in the construction sector as part of worldwide action towards a decarbonised society [22]. Research in this sector is also devoted to the assessment of the impact of climate change on historic buildings, following the general increased awareness related to the topic and the call for action by the EU community in this field [17,18]. In the review, 15 documents (6%) that treat climate change-related research were identified.

the third large sub-group (i.e., Engineering in Figure 3) includes research contributions dealing with the integrity of the structure and its ability to resist natural ageing and decay. This category of publications has predominantly an engineering and technical character and includes several disciplines, such as structural engineering, geological and geotechnical issues, material sciences, and computer technologies. The number of publications listed in this category is comparable with those regarding sustainability (n = 62, i.e., 25%). The result points to two aspects:

1. Conservation and, above all, restoration interventions are conducted when HBs are in a situation of "emergency" i.e., when the risk of partial or complete loss of the building is high due to instability, leaning, rising damp, damage of building materials through moisture, corrosion, salt crystallization, etc.;
2. the value of an HB is often perceived by stakeholders, owners and users as intimately connected with the use and technical performance of the building itself [23].

the last sub-group (i.e., Hazard in Figure 3) refers to publications that intend to preserve tangible CH under natural hazards and catastrophic events (38 publications, i.e., 16% in total). Among those, 33 publications discuss the integrity of historic buildings during and/or after earthquakes. This result reflects the location of the majority of case studies in the Mediterranean Basin, which has a high risk of seismic activity. Although there is a diversity of publications concerning this topic, the majority of them discuss the strengthening interventions before the hazardous event, e.g., base isolation, fibre polymers and other non-invasive techniques with the help of computer simulations and laboratory testing. Only a few of them (3) are focused on post-disaster interventions and efforts to restore as much as possible of the initial buildings. In the list, there are also research documents that aim at the stability of buildings during other hazardous events such as fire (2), erosion (1), floods (1) or wind (1).

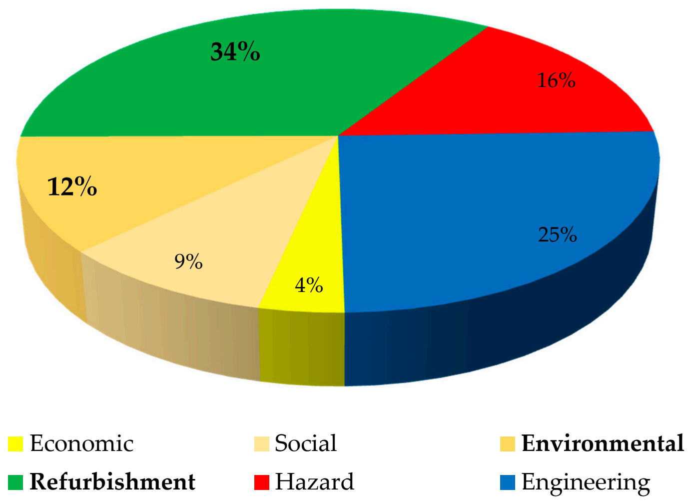


Figure 3. Distribution of the documents by field of publication i.e., content characteristics.

3.2.2. Type of Contribution

Research outcomes dealing with refurbishment processes and the environmental sustainability pillar were identified with respect to four types of contributions, and are reported in Figure 4.

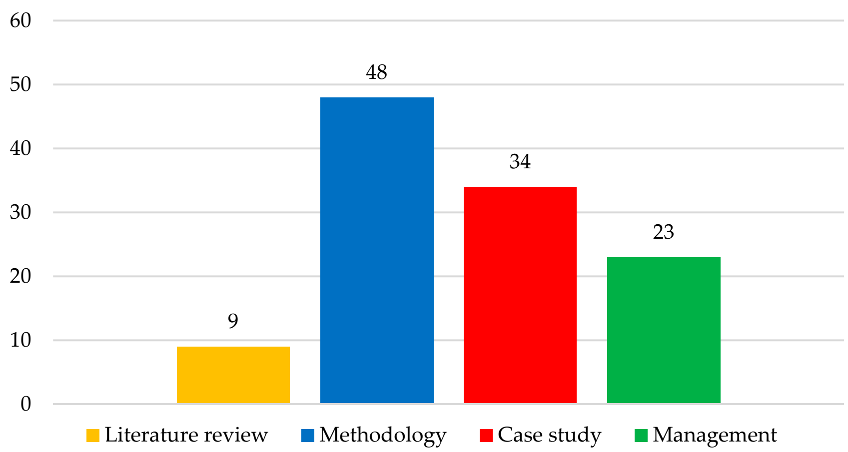


Figure 4. Distribution of the environmental and refurbishment documents by type of publication.

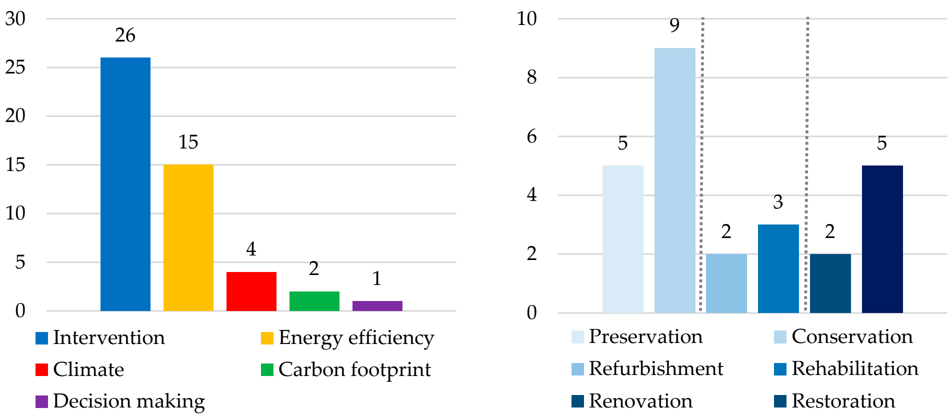
the literature review is the less-used approach when working with sustainable interventions in heritage buildings (i.e., the smallest category, with nine listed documents). At this point, it is quite common to present research results as descriptions of the methodological approaches to be applied during restorations (the largest category with 48 documents). It is also common (n = 34) to use the analysis of data and information gathered on specific case studies, eventually supported by computer simulation, to suggest generalized conservation and/or energy-retrofitting actions on similar buildings in comparable geographical conditions.

Finally, the last type of contribution is mostly focused on the management process, including communication methods and channels used to involve different types of stakeholders (n = 23). This proves the importance, both in the heritage and sustainable sector, of keeping decision makers, owners, and local communities involved in HB conservation projects. Concern about the social aspect from the beginning may positively influence the planning of the interventions (i.e., maintenance, preservation, and refurbishment/restoration), as well as guarantee the long-lasting and effective application of advice coming from the research community.

3.2.3. Methodological Contributions

Documents presenting methodological approaches (48 papers, marked with italic in the supplementary file) to apply during refurbishment processes were further screened to pinpoint achievements and gaps in the field (Figure 5a). The first document in this category was published in 2008. This shows how research into developing a methodological approach is still in its early phase and has recently gained increasing interest. About 54% of these documents (n = 26) describe methodological approaches that deal with intervention processes, while 31% of them (n = 15) focus on energy-retrofit measures and energy-efficiency evaluation after the refurbishment process (e.g., [24–27]). Four publications (8%) present conservation methods that take into account the effects of future climate-change scenarios [28,29] and the evaluation of microclimate conditions [30,31] in the building. Finally, two documents primarily focus on the carbon footprint calculation after intervention [32,33], and one publication discusses the methodology in the decision making process [34].

the 26 documents that describe a methodological approach in maintenance and refurbishment were further categorised according to the levels of intervention (Figure 5b). Three categories were used: low (preservation and conservation), middle (refurbishment and rehabilitation), and high (renovation and restoration). The actions of the first category refer to maintenance interventions, while the middle- and high-level interventions are performed during deeper adaptation processes. From the analysis, 14 documents (54%) describe methods referred to a low level of interventions i.e., preservation (e.g., [35,36]) and conservation (e.g., [37,38]) using the rule of minimum intervention and as much as possible non-destructive techniques. Five publications (19%) have as a primary driver mid-level interventions (i.e., refurbishment, rehabilitation) (e.g., [39–41]) while seven documents (27%) present methodological approaches applied to deeper interventions and the full restoration of decayed or abandoned buildings (e.g., [42–45]).



(**a**) (**b**)

Figure 5. Findings from the systematic literature review: (**a**) categorisation of the documents presenting methodological approaches by primary driver; (**b**) categorisation of the documents describing a methodologic approach in maintenance and refurbishment by level of intervention.

A further analysis was made regarding the type of methodological approach used to achieve the sustainable refurbishment of historic buildings. The results underline a huge variety of approaches used in the field in recent years. The most common approach was the multi-criteria assessment method that was applied in buildings for both energy-efficiency improvement [46] and for interventions [35,44,47]. Decision-makers, using this assessment, have the ability to rank different interventions in order to select the most effective and appropriate actions. Criteria eventually in conflict—that create awareness about conservative interventions—can be also identified. Particular methodological approaches were: maturity matrix assessment [48], multi-attribute value theory (MAVT) [42], methodology for energy-efficient building refurbishment (MEEBR) [25], the functionality index [39], or other methods that require the use of computer simulation or numerical methods. This diversity and heterogeneity of tools shows the importance of using cross-disciplinary, multi-criteria, multi-index, multi-level procedures to develop an effective method/tool able to plan and assess different levels of sustainable interventions depending on the conservation needs, type of building, and climate conditions.

3.2.4. Further Findings

Further analyses of the data gathered from the listed papers allowed the type of building and level of applied interventions to be determined, as well as the building materials subject to alterations. For example, no method was identified that can tailor sustainable interventions on buildings' façades, although in HBs the front walls are often representatives of much of the aesthetic and architectural value and constantly exposed to climate and anthropic-induced decay. The majority of the methods (60%, i.e., $n = 29$) (e.g., [44,47]) were applied to single (as a whole) buildings while the rest (40%, i.e., $n = 19$) to interventions at district level (e.g., [34,49]) (see Figure 6a). Regarding the occupancy of the building, about 33% focus on residential buildings ($n = 16$, e.g., [48,50]), 17% on religious buildings ($n = 8$, e.g., [45,51]), 10% on educational buildings ($n = 5$, e.g., [24,25]), 8% on museums ($n = 4$, e.g., [31,32,46]) etc. (see Figure 6b).

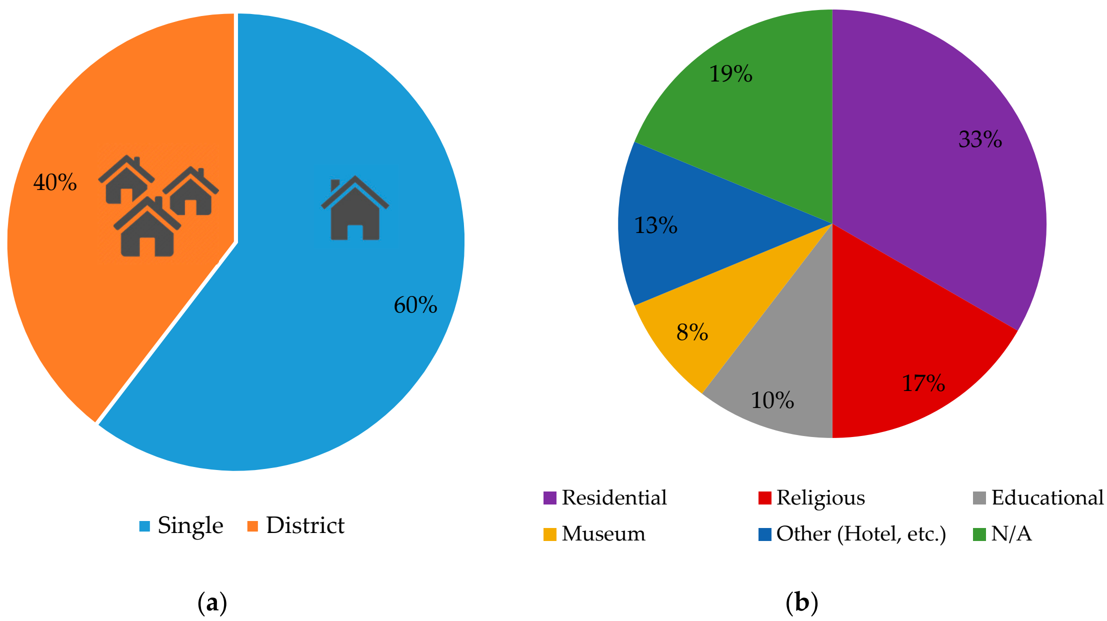


Figure 6. Findings from the systematic literature review: (**a**) categorisation of the scale of intervention at building (blue) or district level (orange); (**b**) categorisation of the building by its function.

It is interesting also to analyse the type of the materials that constitute the building subject to intervention. More than 40% (i.e., $n = 19$) are brick buildings that require interventions to improve mortar and plaster conditions and to reduce energy consumption through the addition of insulation.

Sixteen documents (i.e., 33%) focus on the refurbishment of stone buildings with interventions directed towards thermal insulation of the walls and application of chemical agents against moisture, while less than 10% (i.e., $n = 3$) of documents propose suggestions for the refurbishment of timber buildings. The findings are summarised in Table 2, with some examples of the most common interventions performed.

Table 2. Categorisation of publications by primary building constructive material, number of related publications, and most common performed interventions.

Material	Number	Level of Intervention		
		Low	Middle	High
Stone	16	Re-opening blocked wall doorways and removal of false ceilings to enhance authenticity	Treatment with chemicals to inhibit plant growth and fungal infestation	Enhancement of window airtightness and thermal resistance; thermal insulation of ground floor and roof; internal thermal-insulating plaster
Masonry	19	Maintenance and minimal brick substitution with compatible material	Repairing the roof with thermal insulation and waterproofing slabs	Insulation of the roof and floors; superposition of certified frame windows to the existing ones
Wood	3	Monitoring campaign to assess the state of preservation	Replacement using original technique	-
Concrete	1	-	-	Change of windows; envelope insulation addition; heat-recovery intervention; new ventilated facade
Not Applicable (N/A)	9			

4. Discussion and Conclusions

This review offers insights into the state of knowledge on sustainable refurbishment of HBs and reports how these topics are being explored globally. Its ultimate aim is to influence scholars belonging to the two communities of experts on sustainability and conservation of cultural heritage by further increasing science-based knowledge within the field and influencing decision-making in safeguarding heritage in a society that demands better energy management. This systematic review shows that such topics were incorporated in research agendas since 2006, demonstrating growing interest with an increasing production of research papers. However, current research is geographically limited to Europe and still has some significant gaps in knowledge, as recognized and analysed in the following sub-section.

4.1. Knowledge Gap and Research Needs

First, almost all the published methodological approaches evaluate the actual performance of the buildings and suggest the application of interventions to improve their energy performance and related environmental impact. Environmental sustainable improvements are always assessed during the operational phase i.e., after the conclusion of interventions. No methods are proposed to assess the environmental impact of the refurbishment process itself.

This identified gap is driving our future work on the assessment of the environmental footprint of different refurbishment scenarios by developing a methodological tool that will respect conservation principles i.e., the adoption of minimal technical interventions (avoiding unnecessary replacement of historic fabric), compatibility, and reversibility. The refurbishment scenarios, while ensuring the best preservation, have the potential to become a powerful tool in optimizing the re-use of original materials, planning the time of intervention, and reducing its cost. In fact, they can be developed to take advantage of embodied energy, to recognize areas most vulnerable to climate-induced decay, and to focus interventions on minimum waste production, and thereby on the whole to increase a building's lifetime.

Second, all the published methods for refurbishment processes are fragmentary with a focus on different stages or procedures and based on the partial needs of different stakeholders. In our perspective, there is a call for a multi-disciplinary, inclusive method able to confront and link different issues that can help stakeholders in:

- revealing and improving the protection of the historic, cultural, and socio-economic value of the building;
- identifying levels of intervention from monitoring results on the state of conservation and on structural health;
- reducing costs of building management without trying to compromise on the comfort for occupants;
- applying preparedness measures for HB in order to face slow cumulative and/or immediate drastic hazards;
- selecting new materials for interventions based on types and properties compatible with already existing materials;
- using a life-cycle assessment (LCA) approach to find optimal combinations that maximize the reuse of materials and their lifetimes, thus reducing the carbon footprint of interventions.

Such inclusive and effective sustainable-refurbishment processes can take place given the close cooperation of professionals from different fields such as urban planners, architects, engineers, heritage scientists, conservation specialists, buildings owners, and decision-makers involved in heritage management. From the perspective of planning a long-term building management strategy, its use provides benefits for both the conservation of HBs and the reduction of environmental impact.

Due to the complexity of the field, the methodology will first be applied to regions with similar climatic conditions and to historic buildings with similar architectural attributes. Later, it will be further developed into a tool to be applied in different built environments and places.

Third, the research should be performed in a broader spatial context for monumental buildings, i.e., extending the method to the neighbourhood scale, as this would result in time and cost savings in adaptation processes. In a district perspective, it is more efficient and economical to categorise the buildings and give solutions for each category than to treat them one by one. Moreover, in towns and cities, buildings with no outstanding historic and architectural value by themselves may, taken as a whole, represent an important part of the country's heritage [52]. This wider-scale approach of increasing the number of buildings subject to refurbishment would enhance the achievement of ambitious energy-efficiency targets and would significantly improve the living conditions of the inhabitants. Furthermore, it would upgrade the image of the cities and the incomes through leisure and tourism.

4.2. the Scandinavian Paradox

Finally, this review pointed to the Scandinavian paradox. In Norway, more than 300,000 buildings from before 1900 have been identified, and about 6000 buildings are protected under the Cultural Heritage Act [53]. In Denmark, the number of protected buildings as of 2016 was about 7000 [54]; while in Sweden there are 1500 sites identified as protected (containing many more buildings) [55]. However, the number of papers published in international peer-reviewed journals from researchers affiliated to Scandinavian institutions was very low and they all resulted from the EFFESUS EU project. It was in the interest of the authors to underline the contribution obtained by Scandinavian countries in the results depicted by this literature review. This accentuates the need for future research work and broader dissemination strategies to develop a methodological approach that targets zero-emission refurbishment of historic buildings.

the major publications from the Norwegian governmental institutions that deal with the preservation of cultural heritage, such as the Norwegian Institute for Cultural Heritage Research (NIKU) [56] and the Directorate for Cultural Heritage (Riksantikvaren) [57], are transmitted as reports and, therefore, cannot be traced in a Scopus database search. Moreover, some of them are written in Norwegian, which makes them not easy accessible to researchers of other countries. However, the database search has indicated that even Scandinavian research bodies have devoted very little attention to new methods to effectively maintain and refurbish historic buildings through conservative actions and/or to develop environmental friendly, science-based tools to increase such practice. The existing publications are mainly national reports that, although they contain valuable results in the field [58], have limited dissemination potential due to the language and type of publication.

the literature review has shown that Norway is keeping to traditional established refurbishment and maintenance methods without asking for innovative, science-based approaches. Conservators and researchers in this field want to build further knowledge about maintenance and restoration, collect information on what has been done in the course of the last few years on the usage of traditional handicrafts, and develop "new" knowledge concerning the use of different traditional materials (e.g., results from the "Stave Church Preservation Programme" funded by Riksantikvaren over the 2001–2015 period [59]).

Research on such "new" knowledge concerning the use of traditional material is required in Scandinavia to preserve wooden historic buildings that have high maintenance demands. A detailed knowledge is required to understand the (i) properties of original, aged materials, restored materials and new/created composite materials (e.g., assembling new and aged materials); (ii) changes in building performances (e.g., air-exchange rates, thermal transmission) that include the aesthetic and physical impacts on the existing structure; and (iii) alterations in decay rates or duration of interventions.

An international research project that involves the Norwegian University of Science and Technology (NTNU), NIKU, Riksantikvaren, the Getty Conservation Institute, and the Polish Academy of Science, focuses on the preservation of Stave Churches in Norway and historic wooden buildings in the Scandinavian countries. In the next few years (2018–2021) this will answer some of the questions about the sustainable management of heritage buildings with a long-term perspective. [60]

On the other hand, Norway and the other Scandinavian countries are the most active countries aiming at zero emissions for new construction [61,62] or in developing energy-retrofitting measures for existing buildings, even at a large scale (e.g., district level) [19,63]. This means that:

- Sweden is one of the countries in the EU that, since 2005, has created an energy and sustainable certification scheme for commercial and residential buildings [11], while the large stock of residential buildings in Europe is not certified yet [64].
- in the Scandinavian countries, an increasing number of new constructions, residential or not, are targeted to be nearly zero-energy buildings before 2020 i.e., to balance any CO_2 emission caused by the use of electricity (or other energy carriers) during the building's operation with onsite generation of renewable energy [65].
- in Norway, projects involving dozens of public and industrial partners as well as a large number of pilot projects have been funded since 2009 with industry and governmental support to enable the transition to a low-carbon society. These research centres are: the Research Centre on Zero-Emission Buildings (ZEB) 2009–2017 [61] and the Research Centre on Zero-Emission Neighbourhoods in Smart Cities (FME ZEN) 2016–2024 [62].

the energy-efficiency renovation rate in Norway is at the maximum level compared with that in the 13 countries of the European Union where data are available. It reaches 2.5% a year, while in other countries it varies in a range from 0.5% to 2.0% a year [66–68], with a typical figure being 1% (about 250 million m^2) per year [69]. If retrofit actions are blindly applied to historic buildings without complete knowledge of the challenges involved, in a short time uncontrolled decay will increase the risk of losing valuable historic buildings and will require a huge economic effort to repair the damage caused.

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