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Identifying sustainable retrofit challenges of historical Buildings: A systematic review

Chamara Panakaduwa *, Paul Coates, Mustapha Munir

The University of Salford, 43 Crescent, Salford M5 4WT, United Kingdom

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ABSTRACT

The UK is reported to have approximately 400,000 historical buildings as listed buildings and buildings in conservation sites. Due to the historical value of these buildings, the level of changes possible to these buildings is limited. However, the government's vision for sustainability requires retrofitting existing buildings to minimise emissions as historical buildings contribute around 5% of total UK emissions. The study finds the specific challenges of retrofitting historical buildings by systematically reviewing 52 articles. Three databases were selected, namely ProQuest, webofsciences and Scopus. Challenges of historical building retrofit were identified, generalized, and thematically presented for better comprehension. The main challenge of retrofitting historical buildings is balancing historical values with energy efficiency. As these two objectives are mutually exclusive most of the time, when one is achieved, the other has to be compromised. Further, the complexity of retrofit works and unclear building characteristics were other challenges. There is a total of nine challenges identified. The study concludes that historical building retrofit needs better attention to address the identified challenges. Technological solutions, subsidies to the owners, supply chain development and collaborative stakeholder engagement models can be helpful in this regard.

1. 1. Introduction

1.1. Rationale

The UK has a rich architectural heritage, and many buildings across the country are designated as buildings with historical value. These buildings are deemed to be of special architectural or historical interest and are therefore afforded legal protection by the government. This means that any changes or alterations to the building must be approved by the relevant authority to ensure that the building's character and historical significance are preserved [1,2].

There are approximately 400,000 listed buildings in the UK, and they can be found in both urban and rural areas. These buildings are protected under the Planning (Listed Buildings and Conservation Areas) Act 1990. The listing of buildings with historical value started with the First Ancient Monuments Protection Act (1882), with a schedule of 50 prehistorical monuments [1]. The preservation of listed buildings is essential to maintain the country's cultural heritage and identity. These buildings tell the story of history, and their preservation is crucial for future generations to appreciate and understand the country's past. Additionally, listed buildings can attract tourism, providing economic benefits to local communities [3].

Decarbonisation of the building stock is essential for the UK to achieve its net-zero targets by 2050. The building sector accounts for approximately 35 % – 40 % of the country's carbon emissions, making it one of the largest contributors to climate change [4]. Therefore, reducing the carbon footprint of buildings is crucial to meet the net-zero target. Much of the carbon emissions from buildings come from the energy used for heating, cooling, and lighting. To achieve net-zero emissions by 2050, the UK will need to drastically reduce carbon emissions from buildings. Retrofitting existing buildings with energy-efficient technologies can help to achieve this goal. Retrofitting can involve measures such as improving insulation, replacing windows, upgrading heating and cooling systems, and installing renewable energy sources [5,6].

Retrofitting historical buildings in the UK can be challenging due to a variety of reasons. Many historical buildings were constructed using materials and techniques that are no longer in use or readily available. In some cases, it is difficult to ascertain the existing condition of the property. This can make it more complex to retrofit the building without

* Corresponding author.
E-mail address: c.s.panakaduwagamage@edu.salford.ac.uk (C. Panakaduwa).

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compromising its historical integrity [7]. The layout and design of historical buildings can make retrofitting more challenging. Many historical buildings have unique features that may be difficult to retrofit with modern energy-efficient technologies [8]. For example, the use of thick walls, small windows, and low ceilings in historical buildings may not allow for the installation of modern insulation or heating systems without significant alterations.

Planning and regulatory requirements can also pose challenges for retrofitting historical buildings. The legal protections afforded to listed buildings mean that any changes to the building must be approved by the relevant authorities to ensure that the building's character and historical significance are preserved. This can add time and costs to retrofitting works, as additional approvals may be required [9,10]. Finally, the cost of retrofitting historical buildings can also be a significant barrier. Many historical buildings are privately owned, and owners may not have the financial resources to fund the necessary retrofitting works. Retrofitting historical buildings can also be more expensive than retrofitting modern buildings due to the specialist materials and expertise required [11] Fig. 1.

The total emissions of the UK is reported to be 450 $MtCO_2e$ by 2022 [12]. The buildings' share of the same is reported 28 % [13]. 21.2 % of the buildings in the UK were built before 1919 and reported to have a significant historical interest [4]. When the UK housing stock is concerned, 20.6 % of the total houses are reported to have been built before 1919 [14]. Although the exact percentage of contribution to national emissions from the historical building stock is unclear, it is estimated that the historical buildings contribute approximately 5 % of the total emissions, which is around 7.7 $MtCO_2e$ per year [15].

RIBA (2021) emphasises that demolish and renew model is no longer. Demolishing and rebuilding create waste, consume virgin resources and contribute to embodied carbon [16]. RICS (2020) points out that the retrofitting of historical buildings is not straightforward. Urbanisation and natural events push historical buildings to be altered drastically. The solutions need to be smart as well as robust [17]. A study which analysed 69 historical building retrofit case studies has achieved an average 70 % energy consumption reduction while preserving the heritage values. Although there are challenges, heritage building retrofit is not impossible [18].

As the UK has committed to achieving net zero by 2050, it is important to reduce the emissions from the building stock to the maximum level possible. Accordingly, historical buildings also play a main role. It is important to identify the challenges of retrofitting historical buildings in the UK. Aligning existing and innovative solutions to face these challenges can help drive retrofit at a scale. Accordingly, policymakers, construction professionals or other stakeholders can make use of the findings to optimize retrofit strategies in the historical building sector. By considering the same, this study expects to systematically review the existing literature to summarise the challenges of historical building retrofit. The study brings in novelty by generalising the body of knowledge, where the existing literature on historical building retrofit has focused on different areas of the subject.

1.2. Aim of the research

The study expects to identify the challenges of retrofitting buildings with historical value in the United Kingdom.

2. Methods

2.1. Nature of the literature

2.1.1. Eligibility criteria

The study mainly focused on journal articles which are published in the English language. Further, the articles are peer-reviewed. Ten years was selected as the date range for article selection. This allowed to select a good mix of articles during the recent past with adequate quality Table 1.

Table 1
Eligibility criteria.

	Criteria	Eligibility threshold
1	Type of document	Articles only
2	Publication stage	Final stage only
3	Source type	Journal articles only
4	Language	English only
5	Journal type	Peer reviewed only
6	Period	Published from 31.12.2013 to 31.12.2023

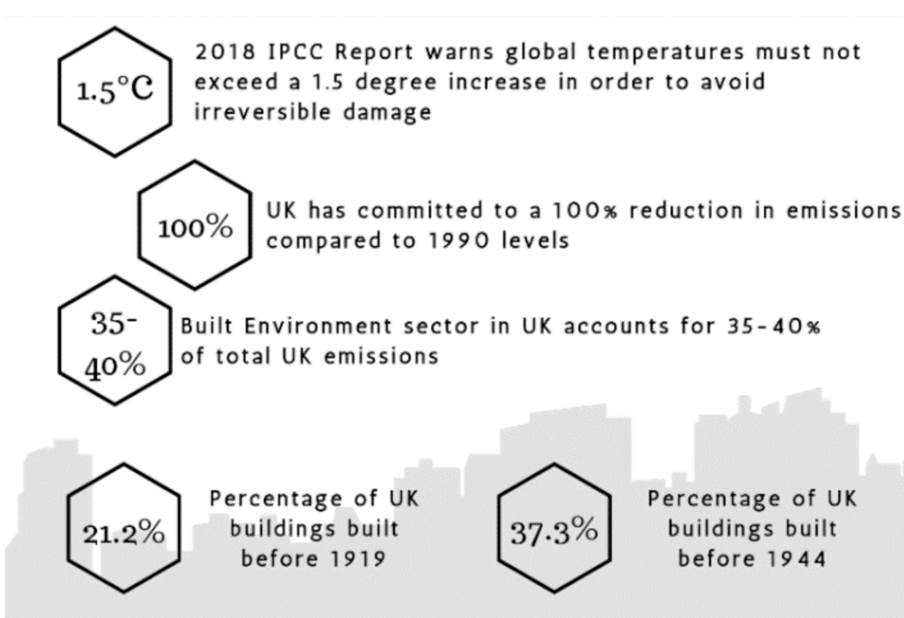

Fig. 1. Emissions from the building stock [4].

2.1.2. Information sources and search strategy

The databases Scopus, Webofscience and proquest were searched for the relevant literature on 17.01.2024. The keywords related to (retrofit, refurbish, renovate) and (historic, listed, heritage) and buildings and challenges were used Table 2.

2.1.3. Selection and data collection processes

The search was carried out by specifying the above keywords and search string on 17.01.2024. 304 citations including abstracts were downloaded in RIS format and they were then uploaded to Rayyan web tool. After deduplication, 99 records were removed, and 205 records were screened for eligibility by perusing the abstract. Automation was not used for screening. A further 148 articles were removed as they were not relevant. A total of 57 articles were shortlisted for full-text review. One article was not downloaded, and 56 articles were reviewed for the full text. 4 articles were removed as they did not meet the purpose. A final 52 articles were selected for the analysis.

As the purpose of the study was to identify retrofit challenges in heritage buildings, all the articles were analysed for such factors. No automation tools were used. However, Rayyan tool was used for data management. All possible challenges of retrofitting heritage buildings were collected from each article. Further, the country of the study, year published, research method, research area, population and building type were noted (where applicable).

3. Results

3.1. Study selection

Fig. 2.

3.2. Study characteristics

Table 3.

3.3. Result of individual studies / Results of synthesis

In the following table, the main challenges of retrofitting historical buildings were synthesized and presented with their respective references. There are nine themes of key challenges identified with the study. Table 4.

As far as the key challenges of retrofitting historical buildings are concerned, the top challenge is identified as balancing heritage values with energy efficiency. When it comes to retrofitting historical buildings, these two priorities are key considerations where an equilibrium should be sought. This challenge has been agreed by the majority of the articles as a key challenge. The second most cited challenge is the complexity of retrofit works and building characteristics. The literature agrees that both retrofits, as well as building characteristics, are more complex in historical buildings compared with modern buildings. For example, there are several areas to look at when retrofitting historical buildings. E.g., Planning permissions, special materials, specialised skilled labour, uncommon construction techniques, etc.

In addition to the above two key challenges, there are other challenges such as cost-effectiveness, unknown conditions of the buildings, information management, stakeholder collaboration, obtaining regulatory approvals and untended consequences of retrofit. For example, most of the older buildings have a breathable fabric. If the fabric was insulated using a non-breathable layer without a ventilation strategy, the building would not be comfortable and healthy to live in. Although the above table has summarised nine challenges, the number of challenges can be more. Further, the citations may not reflect the actual weight of the challenge. The following discussion section expects to further discuss the findings with reference to the literature.

Table 2
Search strings of the databases.

Database	Search string
Webofscience (137)	(TS=(historic* AND buildings OR listed AND buildings OR heritage AND buildings) AND TS=(retrofit* OR refurbish* OR renovat*) AND TS=(challenges)) AND (PY==("2023″ OR "2022″ OR "2021″ OR "2020″ OR "2019″ OR "2018″ OR "2017″ OR "2016″ OR "2015″ OR "2014″ OR "2013″) AND DT== ("ARTICLE") AND LA==("ENGLISH") AND DT== ("ARTICLE"))
Scopus (98)	(TITLE-ABS-KEY (retrofit* OR refurbish* OR renovat*) AND TITLE-ABS-KEY (historic* AND buildings OR listed AND buildings OR heritage AND buildings) AND TITLE-ABS-KEY (challenges)) AND PUBYEAR > 2013 AND PUBYEAR < 2023 AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (SRCTYPE, "j"))
ProQuest (69)	abstract(retrofit* OR Renovat* OR refurbish*) AND abstract (historic* OR heritage OR listed) AND abstract(challenges) AND abstract(buildings) Additional limits – Date: From 2013 to 2023

4. Discussion

4.1. Retrofit challenges

4.1.1. Balancing heritage values with energy efficiency

Retrofitting historical buildings requires a careful balance between preserving the building's cultural and historical values while improving energy efficiency. This can be achieved through a combination of compatible and reversible retrofit measures.

According to the study, the most prominent challenge of retrofitting historical buildings is managing the right equilibrium between the historical significance of the building and the energy efficiency level. As these two objectives are mutually exclusive most of the time, when one objective is achieved, the other has to be compromised. However, there can be innovative solutions where both objectives can be achieved together. E.g., Highly insulated uPVC windows with an antique look. Traditional solar panels will destroy the ancient appearance of a roof. Alternatively, a biogas unit can be a better option for onsite energy generation. Accordingly, not only innovative materials, but innovative thinking can also help to achieve both historical value and energy efficiency in historical building retrofit. By recognising the importance of using innovative methods, Brahmi et al. (2022) have recommended using integrated project delivery [IPD] with building information modelling [BIM] for historical building retrofits [7]. The IPD ensures collaboration among the project parties while the BIM supports the information management aspect. This has been endorsed by another research conducted in the UK. The researchers suggest a lack of communication and collaboration as the underlying reasons for this challenge [9].

Blagojevic and Tufegdzic (2016) argue that cultural heritage is a non-renewable resource. According to this point of view, preserving cultural heritage is a part of sustainable development [26]. As far as these two contradictory priorities are concerned, the literature recommends optimisation of the benefits for decision-making by tactically and strategically managing both the heritage values and energy efficiencies [42,52,60]. Another case study conducted in Spain has shown the real-life potential of managing both heritage values and energy efficiency at the same time. A residential building has been retrofitted with an air source heat pump, insulation, mechanical ventilation with heat recovery and a renewable energy system as a case study [44]. Another case study conducted in Spain has also shown that sustainable interventions to a historical building can result in cost savings and emission reductions at the same time in terms of life cycle analysis. Importantly, the historical interests were preserved [62]. There is another case study which had proven successful in preserving historical interests while retrofitting with a seismic upgrade to a historical property in Italy [64]. Another

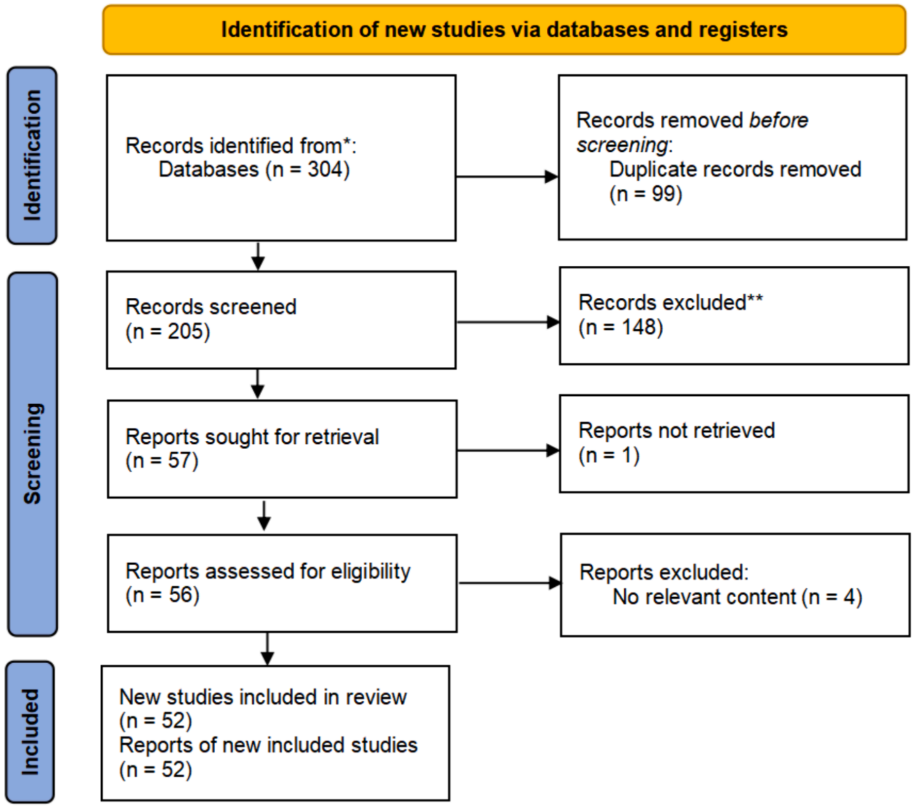

Fig. 2. Study selection.

study conducted in China states the potential of using Solar PV systems to help balance the priorities [66].

However, it is not an easy task to manage both the building performance and preserve historical interests when retrofitting buildings. While acknowledging the possibility of balancing both heritage values and energy efficiency, Piderit et al. (2019) state that there is a judgemental call to what extent to value the heritage interests [67]. In some cases, there are clear issues of balance between energy efficiency and heritage values. Sometimes, the influence is not only on the heritage values, but on the building health and occupants' health with a broader environmental impact [68]. In brief, the retrofit stakeholder should focus on the preservation of heritage values as well as achieving energy efficiency targets, as none of them can be compromised.

4.1.2. *Complexity of retrofit works and building characteristics*

Retrofitting historical buildings can be highly complex due to the building's unique characteristics and the need to balance heritage values with energy efficiency. Hard-to-treat building characteristics make retrofit more complex. Further, every building is different from one to another.

Using expertise knowledge can be a good focus. The life cycle approach and use of technology will help in retrofitting a complex old building. Lessons can be learned by looking at already retrofitted similar old buildings [42]. In terms of technology, building information modelling has been recommended as a better tool to manage the complexities of historical building retrofits [58]. This can be coupled with a building renovation passport to make the process more standardized and future-proof [10]. These historical buildings can be significant in terms of architectural and aesthetic values as well as cultural significance. When it comes to retrofit, it is important to consider all these aspects while making the process more complicated [61]. Most of the older buildings were not designed and constructed according to a particular standard. In this case, applying retrofit measures can be difficult. The retrofit strategy will be different from one to another [8]. Although the general retrofit measures can be similar, heritage buildings pose contrasting differences from one another. In this case, the professionals will have to develop tailor-made retrofit strategies for every building separately. A study conducted in China has found that poor construction techniques can harm the potential performance. For example, even if a poor-performing window is replaced with a high-performing one, the expected performance may not be realised if the window was installed poorly [69].

Barreca et al. (2022) highlight the importance of incentives to keep historical values. Due to the complex nature of the measures and potential higher costs due to these complexities, people may rush to achieve energy efficiency without focusing on the heritage values. The researchers believe incentives will motivate the people rather than regulations [55]. It is important to note that better planning, communication and standardisation are required to manage the complexities of retrofitting the traditional building stock [25]. In general, sixteen research articles have recognised the additional complexities in historical building retrofit. Further, it was recommended that the use of innovative technologies and adhering to more standard practices will make the historical housing retrofit better.

4.1.3. *Cost-effectiveness and economic viability*

Retrofitting historical buildings can be costly and may not be attractive from an economic point of view. The cost-effectiveness and economic viability of retrofit measures must be carefully considered to ensure the long-term sustainability of the building.

Additional requirements and complexities in historical building retrofit can increase the retrofit cost considerably. This can reduce the economic viability. However, the historical value of the building may help promoters to earn additional money by way of tourism. The higher valuations due to the historical significance can also be a positive financial motivation. A considerable amount of old buildings are now converted into attractions, due to their cultural values [70]. Prados et al. (2023) argue that the sustainability measures applied to historical

Table 3
Characteristics of the selected studies.

No	Ref.	Journal	Year	Research area	Research design	Population	Building type
1	[19]	Journal of Architectural Conservation	2013	Renovation	Case study	UK	Mixed
2	[20]	International Journal of Sustainable Development and Planning	2014	Energy efficiency	Case study	UK	Public
3	[21]	Journal of Green Building	2014	Rehabilitation	Case study	USA	Public
4	[22]	Energy and Buildings	2014	Retrofit	Case study	Baltic region	Industrial
5	[23]	Energy and Buildings	2015	Retrofit	Simulation	Italy	Mixed
6	[24]	The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences	2015	Retrofit	Case study	Taiwan	Mixed
7	[25]	Frontiers of Architectural Research	2015	Energy efficiency	Triangulation	UK	Religious
8	[26]	Energy and Buildings	2016	Adaptation	Case study	Serbia	Industrial
9	[27]	Journal of Cultural Heritage	2016	Energy efficiency	Case study	Italy	Educational
10	[28]	IOP Conference Series. Materials Science and Engineering	2017	Retrofit	Case study	Malaysia	Entertainment
11	[29]	Journal of Cultural Heritage	2018	Refurbishment	Modelling	Norway	Mixed
12	[30]	Heritage	2018	Retrofit	Case study	Egypt	Hotel
13	[31]	Historic Environment: Policy and Practice	2019	Energy efficiency	Survey	Norway and Sweden	Residential
14	[32]	IOP Conference Series. Materials Science and Engineering	2019	Energy efficiency	Case study	Portugese	Residential
15	[33]	Sustainability (Switzerland)	2019	Energy efficiency	Case study	Spain	Religious
16	[34]	IOP Conference Series. Materials Science and Engineering	2019	Refurbishment	Case study	Norway	Residential
17	[35]	Applied Sciences (Switzerland)	2019	Refurbishment	Modelling	Spain	Educational
18	[36]	IOP Conference Series. Materials Science and Engineering	2019	Retrofit	Literature review	Poland	Mixed
19	[9]	International Journal of Building Pathology and Adaptation	2019	Retrofit	Survey	UK and Italy	Mixed
20	[37]	Climate	2019	Sustainability	Interviews	Italy	Cultural
21	[38]	Journal of Physics: Conference Series	2019	Retrofit	Case study	Belgium	Residential
22	[39]	Journal of Sustainable Development of Energy, Water and Environment Systems	2020	Retrofit	Literature review	Italy	Cultural
23	[40]	Atmosphere	2020	Retrofit	Literature review	UK and Turkey	Farmhouse
24	[41]	International Journal of Building Pathology and Adaptation	2020	Sustainability	Interviews	UK	Religious
25	[42]	Energy and Buildings	2020	Retrofit	Interviews	General	Cultural
26	[43]	International Journal of Building Pathology and Adaptation	2020	Retrofit	Mixed methods	UK	Residential
27	[44]	Energy and Buildings	2021	Decarbonisation	Simulation	Spain	Residential
28	[45]	IOP Conference Series. Earth and Environmental Science	2021	Retrofit	Literature review	General	Mixed
29	[46]	ASHRAE Transactions	2021	Energy efficiency	Case study	USA	Residential
30	[47]	Heritage	2021	Retrofit	Mixed methods	New Zealand	Mixed
31	[48]	International Journal of Architectural Heritage	2021	Retrofit	Literature review	Portugal	Mixed
32	[49]	IOP Conference Series. Earth and Environmental Science	2021	Retrofit	Modelling	General	Mixed
33	[50]	Heritage	2021	Retrofit	Case study	Denmark	Mixed
34	[51]	Energy and Buildings	2021	Retrofit	Modelling	Serbia	Mixed
35	[52]	Sustainability	2021	Energy efficiency	Case study	Portugal	Mixed
36	[53]	Energy Policy	2021	Renovation	Literature review	Spain	Mixed
37	[10]	Sustainability	2021	Sustainability	Case study	UK	Residential
38	[54]	Journal of Architectural Conservation	2021	Decarbonisation	Simulation	UK	Mixed
39	[11]	Sustainability	2021	Retrofit	Case study	Portugal	educational
40	[55]	Sustainability	2022	Retrofit	Modelling	Italy	Mixed
41	[7]	Construction Management and Economics	2022	Renovation	Mixed methods	USA Canada	Mixed
42	[56]	Applied Sciences-BASEL	2022	Energy efficiency	Literature review	Mexico	Residential
43	[57]	IEEE Transactions on Industry Applications	2022	Renovation	Case study	Italy	Educational
44	[8]	Energies	2022	Retrofit	Literature review	General	Mixed
45	[58]	The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences	2022	Refurbishment	Modelling	Italy	Cultural
46	[59]	Sustainable Energy Technologies and Assessments	2022	Renovation	Case study	Italy	Mixed
47	[60]	Energy	2023	Retrofit	Case study	Poland	Cultural
48	[61]	Earth and Environmental Science	2023	Energy efficiency	Case study	Greece	Mixed
49	[62]	Buildings	2023	Retrofit	Case study	Spain	Mixed
50	[63]	Buildings	2023	Retrofit	Case study	Croatia	Residential
51	[64]	Environmental Science and Pollution Research	2023	Retrofit	Modelling	Italy	Mixed
52	[65]	Energies	2023	Energy efficiency	Case study	Poland	Residential

Table 4
Key themes of historical building retrofit challenges.

Item	Challenge	Reference	
1	Balancing heritage values with energy efficiency	[7,9,19,21,25,26,29,31–33,35,37,39–44,47–49,52,54,56,57,60–64]	30
2	Complexity of retrofit works and building characteristics	[8,10,24,25,30,31,38,47,48,51,53,55,58,60,61,65]	16
3	Cost-effectiveness and economic viability	[9,11,23,28,33–35,40,46,62]	10
4	Lack of technical knowledge and access to suitable solutions	[11,36,40,43,45,50,60]	7
5	Uncertainty and unknown conditions of buildings	[8,9,21,38,59,63]	6
6	Acquiring and Integration of different information	[24,31,38,59,60,64]	6
7	Stakeholder commitment and collaboration	[11,21,25,31,64,65]	6
8	Difficulties in obtaining regulatory approvals	[9,10,33,34,62]	5
9	Unintended consequences of retrofit intervention	[9,20,28]	3

buildings are economically profitable from a lifecycle perspective [62]. Although most heritage property retrofits can be expensive, there are case studies which had shown cheaper but effective [46]. Another study suggests that the cost can be a barrier as well as a motivator. When people find the perceived cost is low and perceived energy efficiency benefits high, this can be a positive factor. However, it is important to keep in mind the rebound effects which can devastate the sustainable benefits of retrofit [9].

According to the literature findings, energy retrofit may or may not achieve energy savings. The operation of the buildings differs considerably from one to another [8,61]. For example, one occupant may prefer to set the thermostat at 18 °C while another may wish to set it at 24 °C. This will deeply affect the energy bills. In addition, the difference between the electricity and natural gas prices also affects the cost-effectiveness of a retrofit. Currently, electricity is three times more expensive than gas in the UK [71]. As far as the cost-effectiveness of retrofit is concerned, the literature recommends the installation of solar PV systems, which will set off the electricity consumption [66]. However, there are other challenges involved with the heritage values that need to be addressed in historical housing retrofit. For example, solar panels should not be visible to the front of the house due to regulations. In this situation, installing solar PV panels may not be possible in every building.

4.1.4. Lack of technical knowledge and access to suitable solutions

There may be a lack of knowledge and access to suitable retrofit solutions for historical buildings. More research and development of retrofit solutions specifically for historical buildings are needed.

Many researchers have talked about the importance of using technology to overcome specific barriers to historical building retrofit [7,58,59]. However, access to such solutions and the availability of the skilled labour force have been identified as critical challenges [4,19]. According to McGinley et al. (2020), most of the contractors involved in housing retrofit are small and medium enterprises. They always fight with the limited technical and human resources to complete the projects [72]. In this case, although the industry has the right technology, the required skills and affordability are problems to make the best use of modern technology [73]. For example, Aerogel has been identified as a better insulation material for historical buildings as it will cause the lowest damage to the appearance of the building fabric [74]. Further, Aerogel windows are proven to keep the aesthetics of buildings while giving the highest level of insulation [75]. On the contrary, these technologies are highly expensive. Fewer people have the expertise to work with these technologies.

Considering the industry sources of information, it is difficult to find skilled people who have the right expertise to work with the unique architectural features of historical buildings. For example, these buildings may have been rendered with traditional lime plaster. If the rendering is retrofitted, this needs to be done with the same lime plaster. Unlike cement plaster, lime plaster takes months to settle. If the cement plaster is used, that can lead to condensation as well as accumulating moisture within the wall [76]. Unfortunately, there is a critically limited number of skilled people who work with lime plastering in the UK.

4.1.5. Uncertainty and unknown conditions of buildings

The uncertainty and unknown conditions of the building and site make retrofitting a complex process. Due to this reason, careful planning, detailed analysis, and innovative techniques are required to identify the existing situation of historical buildings.

In a case study conducted in Croatia, the researchers stated that it was highly difficult for them to assess the building for refurbishment purposes. As the building was two centuries older, there was no proper documentation. They conducted several tests to identify the existing condition and materials of the property [63]. The difficulty in assessing and understanding the existing conditions of heritage buildings has been stated in some other case studies conducted in the USA, Sweden and Italy [8,21,59]. In the case of Italy, that was a large-scale retrofit project, which involved a number of buildings in a particular area. The researchers have used a software-driven approach and collected as much as possible digital data for the preliminary analysis [59]. This approach has made the process more efficient. However, as the buildings and their characteristics are highly diverse, most of the case studies have proven that there is no one-size-fits-all solution for heritage building retrofits [8,59].

In any retrofit project, identifying the existing condition of the property is a prerequisite. Usually, the condition report issued by a chartered building surveyor serves the purpose to a greater extent [77]. For the purpose of retrofit decision-making, there are other destructive and non-destructive techniques such as thermographic surveys, air tightness tests, coheating tests, etc. Although these tests are available in the industry, identifying the exact condition is not that simple in historical buildings [16]. These buildings have been changed over centuries, removing parts and adding parts, changing details and renovating.

4.1.6. Acquiring and integration of different information

Acquiring and integrating different information, including architectural, historical, technical, and energy efficiency data, is crucial for successful retrofitting. This has been identified as a challenge, particularly in historical building retrofit.

This problem can be noted not only in historical buildings, but also in other buildings. Building information modelling [BIM] can be a good idea for this purpose [24,58,78]. Considering the problem today, such a BIM model will be more valuable in future. As discussed earlier, the inability to assess the existing conditions of a building is a challenge. If the BIM is used for information management today, that will help to mitigate the same challenge in future. The non-machine-readable formats of the existing information are a challenge to integrate data for retrofit decision-making purposes. Researchers have developed digital tools to overcome these challenges [59]. The one-stop shop solution has been recommended by the literature to overcome this challenge of information acquisition and integration. In the one-stop shop retrofit model, the client is given a single interface to coordinate with the other parties. Apart from the client, all the stakeholders can be collaborated through this model [72,79]. The concept can be more valuable in heritage building retrofit due to added complexity.

4.1.7. Stakeholder commitment and collaboration

Retrofitting historical buildings requires the commitment and collaboration of all parties involved, including building owners, regulatory bodies, architects, and contractors.

As far as stakeholder collaboration is concerned, the literature recommends the use of building information modelling [24,58,78] and stakeholder engagement models such as the one-stop shop retrofit model [72,79]. The previous challenge was about information integration and the same tools can be applied to stakeholder collaboration as well. However, when it comes to stakeholder commitment, this is a new topic. The historical buildings have unique characteristics which make the retrofit process complicated, expensive, time-consuming and difficult [8,45,50]. The literature suggests that the stakeholders should be committed to facing these barriers for retrofitting buildings for energy efficiency while preserving historical significance. However, one of the challenges is that the stakeholders do not commit themselves to face these challenges.

The UK standard framework for housing retrofit PAS 2035:2023 has addressed stakeholder engagement to a certain level [80]. The standard was proposed as a response to the Each home counts report in 2016. The purpose of the standard is to improve professionalism in the industry, assign responsibilities and avoid unintended consequences of retrofit [81]. The PAS 2035 has developed a risk pathway for historical buildings. If the property comes under the definition of a historical building under BS 7913, the retrofit has to be separately evaluated by a qualified assessor for traditional buildings [80]. The same process is applied to non-domestic buildings under PAS 2038:2021 [82].

4.1.8. Difficulties in obtaining regulatory approvals

In the historical building sector, the regulatory approvals required for the retrofit works are more complex and exhausting. They are likely to take more time and hassle due to the historical values that need to be preserved.

The current process of obtaining regulatory approvals is to design the retrofit intervention and make an application. This "ad-hoc" method of approvals takes longer times and hinders the progress of traditional building retrofit. Villarejo et al. (2021) suggest going for the building renovation passport method, where the traditional buildings are evaluated in bulk in advance to pre-approve permitted developments. This would make traditional housing retrofit processes more efficient [10]. Currently, the UK has added some of the retrofit measures into the permitted development category. For example, a heat pump can be installed without local authority approval as a permitted development subject to conditions [83]. However, these permitted developments cover a smaller scope. In order to expedite the historical building retrofit, a broader approach is required. On the other hand, it is important to have a mechanism to ensure that historical interests are not compromised.

Another study has looked into the policy issues in retrofitting traditional buildings in Norway. The planning regulations recommend demolishing old buildings while there are regulations to protect buildings with historical significance. However, there are no clear regulations on how to retrofit these protected buildings, and often owners of these properties find them as a burden [34]. By considering the above aspects, it is clear that there are clear challenges in terms of the regulatory approval process for traditional building retrofit. Further action is required to streamline these regulatory burdens from the retrofit process.

4.1.9. Unintended consequences of retrofit intervention

The application of modern technologies in retrofitting historical buildings may have unintended consequences on the building's historical and cultural values. These unintended consequences must be carefully considered during the retrofit process.

Rispoli and Organ (2018) have extensively discussed the unintended consequences of traditional housing retrofit. They have identified this as a critical challenge in retrofitting traditional buildings, compared with other retrofit projects [9]. Avoiding unintended consequences is not a new challenge to the retrofit industry. This has been talked about a lot in the literature, especially in terms of retrofitting residential houses [84]. Further, the introduction of PAS 2035 standard has the objective of avoiding unintended consequences in housing retrofit projects [81]. A case study has found that some of the assessment methodologies adopted by professionals in the retrofit industry are less accurate. These wrong predictions can lead to unexpected outcomes when the actual retrofit is carried out [33]. Further, prebound and rebound effects can also cause to have unpredictable results out of retrofit projects [85]. The prebound effect can be identified as residents consuming less energy than estimated, resulting in lower than expected performance after the retrofit. The rebound effect is when the residents start consuming higher levels of energy than estimated after retrofit, still not realising the expected energy reductions.

4.1.10. Other

Apart from the above challenges, there are a few other challenges noted. Absence of separate energy performance ratings for historical buildings, Inconvenience during the retrofit works, Embodied carbon emission of retrofit works, and non-reversible nature of retrofit measures. Most of these challenges are quite common during any kind of retrofit work. However, the requirement for a separate energy performance rating has been a topic of discussion for some time. Berg and Donarelli (2019) show that residents use the energy performance rating system to identify the potential retrofit measures for poor-performing buildings. However, the criteria for energy efficiency retrofit measures for historical buildings are different from usual residential dwellings. In this case, the residents can be misled due to the common energy efficiency recommendations in traditional buildings' energy performance certificates [31]. A separate energy performance rating system with special consideration for preserving heritage aspects can be used to fill this gap.

As the UK context is considered, the minimum energy efficiency requirements (MEES), renting, or selling a property trigger the requirement of an energy performance certificate (EPC). The energy performance certificate (EPC) legislation says that the listed buildings are exempt from having an EPC if the recommendations of the EPC will significantly alter the historical characteristics of the property. This statement is confusing and leads to become a chicken and egg situation. In order to see the recommendations, an EPC has to be issued. If the recommendations alter the historical characteristics significantly, there is no need for an EPC [86]. By taking this into consideration, a separate version of the EPC rating can be the solution. This EPC should generate property-specific recommendations, considering the historical characteristics.

4.2. Recommendations

The systematic literature review has identified a number of challenges in terms of retrofitting historical buildings. The following recommendations were made by considering these challenges and the literature recommendations. The important takeaway of the recommendations is that these historical properties pose significant unique factors and values which should be considered in determining the optimum mix of retrofit measures.

The first recommendation is the importance of balancing energy efficiency and historical values. In some cases, the regulation may not strictly help to decide the equilibrium between these two constraints. Situation-specific priorities are to be considered by making a judgement call. Looking at the industry's best practices and stakeholder interests is also important. For example, the Chester Cathedral has used the roof valley to install solar PV units. The roof valley is not easily visible. This has helped to achieve renewable energy targets while avoiding the threats to historical values. The important point to note is that both the historical values and the energy efficiency challenges cannot be compromised. The historical values can be considered as another non-renewable resource. In the same way, it is not a possibility to achieve sustainability challenges without improving energy efficiency, unless there is a game-changing innovation. Accordingly, the priority is the balance between the historical value and energy efficiency.

The second recommendation is the use of technology. The use of building information modelling, integrated project delivery, and building renovation passports are some other tools that can be used to overcome most of the challenges in historical building retrofit. These tools can help to promote stakeholder collaboration, information sharing and determining integrated retrofit approaches. For example, building renovation passports can help reduce inefficiencies involved with a longer planning approval process. Apart from the above tools, the literature has recommended a number of innovative tools that could be used for better retrofit assessments, both for individual cases and large-scale projects. Importantly, even the existing level of technological advancements has proven the potential of preserving historical values and achieving energy efficiency at the same time according to this systematic literature review.

The literature also suggests the use of specific materials and products that can be useful to manage the heritage values during the retrofit, while achieving the performance targets. For example, Baeli (2013) has discussed the custom-made windows that imitate casement windows observed in historical buildings [87]. Further, innovative materials such as Aerogel can be used to provide thinner insulation and window glazing [74,75].

The third recommendation is to financially incentivise retrofitting historical buildings by way of grants, tax concessions, green finance or other suitable methods. Historical building retrofit is observed with increased costs to a massive level due to the use of specific construction techniques, materials and products. In this case, more government incentives and concessions are required to promote retrofit among the historical building owners, compared with the other building owners. This will improve the equality among the property owners, without letting them be financially discriminated.

The fourth recommendation is to level up the workforce with the knowledge of historical building retrofits. According to the literature, there is a considerable skills gap in building retrofits in the construction industry. This is more severe in the case of historical building retrofits. Both the industry and the academia shall work together to match this skills gap, while the government shall help with policy measures.

The fifth recommendation is to promote stakeholder collaboration as well as commitment. Stakeholder collaboration is required to remove the bottlenecks of the process. For example, the study has noted the challenge of obtaining regulatory approvals for historical building retrofits. The enthusiasm of the supply chain to manufacture specific products for the historical building sector is in question. The skills gap shows the lack of enthusiasm in the industry to come to the historical building retrofit industry. A proper collaboration is required to bring all of them together to face the challenges stronger. Not only that, a deeper stakeholder commitment is also important. If the building owners are not happy to go the extra mile to face these challenges and make the historical buildings better energy efficient, this will be a problem of commitment.

4.3. Limitations of the review process and implications for future research

The main limitation of the review process is the absence of empirical validation. The study was done by reviewing existing literature. Validating the findings with case studies or stakeholders in historical building retrofit is recommended. Although the challenges are ranked according to the number of citations, it does not justify that the highest citations mean the greatest challenge. However, the study will be still highly influential in terms of knowledge creation.

Considering the financial, historical, sentimental, and archaeological values of the historical buildings, there is a policy-making obligation to the government to protect them. On the other hand, the government is legally bound to achieve net zero emissions by 2050. Retrofitting historical buildings will not be a solo journey of the government. Accordingly, everybody has the responsibility of preserving these buildings for future generations while reducing carbon emissions. This research will contribute to the body of knowledge in this sense.

5. Conclusion

Retrofitting existing buildings is a greater challenge in the journey to net zero emissions. Due to the additional constraints observed in historical buildings, retrofitting these buildings will make this challenge tougher. There are more than 400,000 such buildings in the UK. The study expects to identify the specific challenges of retrofitting these historical buildings.

It was concluded that there are considerably higher challenges in retrofitting historical buildings. Compared with the retrofitting of a historical building with a building with non-historical significance, a historical building retrofit is required to keep the historical values intact. That means, the appearance of the building should not be changed. High cost, difficulties in finding materials, unknown building conditions, lack of expertise, complexity of the retrofit, difficulty in obtaining planning approvals, stakeholder management and unintended consequences are the other challenges. By considering the study findings, the following conclusions can be highlighted.

The historical value of a building cannot be compromised as it is a non-renewable resource. Due to the importance of achieving sustainability goals and the contribution of carbon emissions from the historical building stock, energy efficiency also cannot be compromised. The literature shows that even the existing technology is sufficient to overcome both of these challenges together. In this case, more incentives, stakeholder collaboration, stakeholder commitment and the development of a skilled workforce are timely requirements.

It can be argued to give an exception for historical buildings in terms of energy efficiency, by focusing on energy decarbonisation. For example, if the historical buildings can be heated with a subsidised electricity supply, the problem can be solved. However, retrofitting is not all about energy efficiency, it is integrated with other priorities such as structural renovation, aesthetic preservation, addressing fuel poverty, better health and comfort. Apart from the listed buildings and buildings in conservation areas, there are other buildings with historical interests. For example, around 1 in all 5 buildings has a historical interest in the UK. It is important to make the building stock better to make the lives better, in addition to the decarbonisation and heritage values.

CRediT authorship contribution statement

Chamara Panakaduwa: Writing – original draft, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Paul Coates:** Writing – review & editing, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Mustapha Munir:** Writing – review & editing, Supervision, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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