Journal of Building Engineering 60 (2022) 105168

Contents lists available at ScienceDirect

Journal of Building Engineering

journal homepage: www.elsevier.com/locate/jobe

Understanding the impediments to sustainable structural retrofit of existing buildings in the UK

Jamiu A. Dauda *, Saheed O. Ajayi

School of Built Environment, Engineering and Computing, Leeds Beckett University, Leeds, UK

ARTICLE INFO

Keywords:
Critical barriers
Exploratory factor analysis
Infrastructural stocks
Likert scale
Reliability analysis
Structural Retrofitting old buildings
Sustainability

ABSTRACT

Structural retrofit of existing buildings for reuse remained one of the key steps toward decarbonisation of the existing housing stocks in the UK. This implies that any structural retrofitting procedure should aim at sustainability by ensuring net reduction in energy use with minimum cost, environmental and social impact. However, several factors impede the attainment of sustainable structural retrofit programs. In this study, quantitative data collection and exploratory factor analysis were used to investigate the factors that impede achieving sustainability in structural retrofitting of existing buildings. The study conducted a review of pertinent literature to draw up a list of potential impediments to sustainable structural retrofit. The lists were used to form Likert scale questionnaire that was administered to 126 professionals within the built environment sector in the UK. The data collected were subjected to reliability analysis and exploratory factor analysis using the SPSS IBM Statistics v24. The analysis revealed that there are four groups of barriers that impede sustainability in structural retrofitting of existing buildings. These are (i) cultural barriers involving factors that are characterised by human behaviour and interest; (ii) economic barriers involving cost functions; (iii) technical knowledge barriers involving education & skills factors and (iv) regulatory barriers involving legislation and policies around retrofitting old buildings. The findings of this study contribute to the broader discussion of sustainability within the built environment by increasing awareness of the key barriers to overcome to promote sustainable structural retrofit of existing buildings.

1. Introduction

The recent 26th United Nations Climate Change Conference (COP26) pledges a special commitment toward urgent staving off dangerous climate change due to the continual increase in carbon emissions. This is in line with the earlier assertation that we are now in a panic time to respond to the looming climate crisis [1]. Meanwhile, it has been widely agreed that the only viable solution to halting the threat of the climate crisis is decarbonisation through the efficient use of resources [1]. One of the approaches toward decarbonisation is by reusing existing housing stocks which are enormous across Europe. The Buildings Performance Institute Europe (BPIE) proclaimed that over 25% of all building stocks in European cities were constructed before the 1950s [2]. In the UK for instance, the percentage of new builds is less than 1–2% of total building stock each year and about 70% of total existing building stocks will still be in use in 2050 [3]. The study [3], highlighted that the rates of repair, refurbishment and retrofit are between 2.9% and 5% of the total existing domestic building stocks and 2–8% for commercial building stocks within the UK. These statistics culled from the

* Corresponding author.
E-mail address: j.a.dauda@leedsbeckett.ac.uk (J.A. Dauda).

https://doi.org/10.1016/j.jobe.2022.105168
Received 25 June 2022; Received in revised form 14 August 2022; Accepted 20 August 2022
Available online 27 August 2022

study [3] sustained the fact that repair, refurbishment and retrofit of existing buildings and infrastructures will remain extremely significant over the next coming years.

The term retrofitting is quite different from repair and refurbishment or renovation which are commonly used terms when dealing with the preservation of existing buildings. Repairing building structures is about fixing damaged structures to good working conditions, this involves processes such as patching up defects, cracks, re-building non-structural elements within the building and redecorations [4]. Refurbishment, on the other hand, involves restoring the structural integrity of damaged structures to their original state, often used interchangeably with renovation [5,6]. This involves carrying out structural repairs such as adding reinforcing mesh and injecting epoxy into structural elements within the building [7]. Retrofitting is the process of strengthening or improving the structural or energy performance of existing buildings [5,8]. Meanwhile, this study focuses on structural retrofitting of existing buildings which is a process of making them more resistant to damages or structural failures [9]. The main difference between these terms is that repair, refurbishment, or renovation are carried out after damage had occurred on buildings while retrofit is an improvement to performance before damages. Also, repair does not improve the structural strength of the building but renovation and retrofit do.

In providing structural retrofit of existing buildings, issues such as preserving the cultural and historic value of existing buildings, minimising structural damages and improving the safety of old buildings create pressure on the various retrofit experts within the built environment [10]. This is corroborated by a study [11] that affirmed that most structural retrofits are driven by combinations of enhancing structural capacity to vulnerable structures and protecting heritages of existing buildings. Meanwhile, the additional requirement to make structural retrofitting of existing buildings meet the key sustainability criteria and still preserve their historical values makes structural retrofitting process extremely complex nowadays. These unique constraints are the motivation for developing many sustainable structural retrofit techniques for existing buildings. However, most available structural retrofit techniques for old buildings still make use of grout and epoxy injection, reinforced plaster, steel column and plate as external reinforcement, elastomeric spray, internal concrete skin, post-tensioning, composite materials such as fibre reinforced polymer (FRP) and confinement [9,12]. The common thing from most of these emerged structural retrofit techniques is the question around their sustainability because they used materials that required high fossil fuel for production and releases high carbon during production.

Consequent to the increasing campaign for sustainable design and retrofit to reduce the carbon footprint on the earth, this study will investigate the factors that hinder the development of sustainable structural retrofit techniques for existing buildings. The study will contribute to the broader discussion of sustainability within the built environment by increasing awareness of the key barriers to overcome in order to provide sustainable structural retrofit of existing buildings. This paper contains five different sections. Section 1 here presents the introduction. In section 2.1, the details of materials and methods adopted in achieving the study aims were discussed. Thereafter, sections 3 and 4 present the result discussion and the concluding remarks from the study respectively.

2. Material and methods

This study was carried out in three different key stages shown in Fig. 1. The first stage (section 2.1) is the data construction phase where a systematic review of relevant literature was conducted to identify the potential impediments to sustainability in structural retrofit of existing buildings. In the second stage (section 2.2), the potential barriers identified in the first stage were used to develop a questionnaire on five-point Likert scale for data collection. Finally, the third stage (section 2.3) details the data analysis procedure.

2.1. Stage I: data construction phase

An inference from an earlier study [13], has proved that the review of extant literature relevant to the issue in discussion is an efficient procedure for creating variables for measuring constructs of questionnaires. Therefore, this section presents a systematic review of pertinent literature to identify potential key barriers against sustainable structural retrofit of old buildings. The review process started with the search for relevant literature to review by conducting a keyword search in Scopus which has been described as the largest database of peer-reviewed literature [14].

The initial search with the keyword ''barrier to sustainable retrofitting'' is very generic and thus returned 156 documents, which was further refined to 78 with the addition of ''building'' as a compulsory inclusion criterion. Thereafter, another inclusion criterion ''structural'' was imposed which returned only 5 articles. This is an indication that the barriers to sustainable structural retrofit have not been widely researched. So, the criterion ''structural'' was removed and the 78 articles most of which focused on energy retrofitting were screened. After the initial screening, 37 articles which are experimental studies that do not discuss sustainability in detail were removed and 41 articles were retained for the detailed review presented in sections 2.1.1–2.1.4.

2.1.1. Overview of the concept of sustainable building retrofit from literature

The detailed review started with understanding the concept of sustainable structural retrofit which simply implies retrofitting old buildings with environmentally friendly materials that have high strength properties, are economical and can be easily sourced around the globe. These environmentally friendly materials are often classified as renewable or recyclable and sustainable materials. Sustainability in buildings demands buildings to last for as long as possible with the best minimum carbon generation or emission throughout their lifespan [15]. So, when dealing with the structural retrofit of old buildings, one of the priorities is also to ensure that the structural retrofit solution is efficient and sustainable as much as possible. Absolutely, this is a challenging situation that requires a great deal of understanding in order for the retrofitted buildings to attain the most beneficial solution both in terms of structural capacity and energy performance. The key drivers to attain these are definitely the material components and techniques used in the structural retrofitting process.

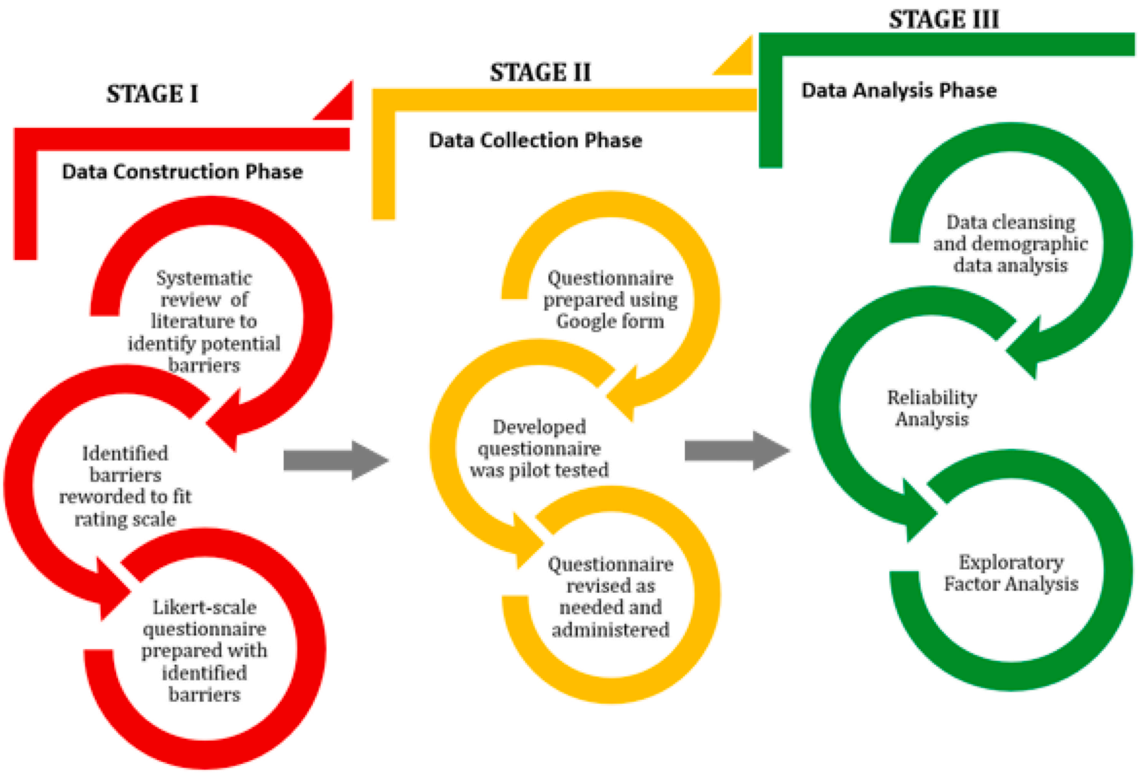

Fig. 1. Overview of research methodology.

Currently, there are several guidelines that help in planning structural retrofit of existing buildings, however, there is also a significant level of conflict on many issues such as how sustainable the solution will be [3]. Meanwhile, in order to understand the sustainability of a particular structural retrofit solution, the material components and techniques need to be evaluated against the three cores of sustainability. Hence, the subsequent sections 2.1.2-2.1.4 present abridge review of these cores i.e., the economy, environment, and social impact of the applied structural retrofit solution. The review also delves into the identification of some potential barriers to each core of sustainability and develops a conceptual framework of these barriers that need to be addressed if any structural retrofit solutions are to be regarded as sustainable.

2.1.2. Economical concept of sustainable building retrofit

Affordability is one of the primary goals of sustainability [16] and reusing existing buildings will improve the affordability of housing to low-income earners [17]. The acceptability criteria for low-cost retrofitting of existing buildings should account for the cost of running the retrofitted building [18]. This means that the economic sustainability of building retrofit is not only about the low initial cost but a moderate running cost of the retrofitted building. Retrofitting existing buildings reduces the amount of money spent on the decommissioning of old buildings and thus significantly put reusing existing buildings as a driver for a sustainable future in the built environment. However, while considering the economic viability of structural retrofit options for existing buildings, the safety and functionality of the implemented retrofit techniques should not be compromised. This is in line with the assertion that engineering design and operation should not be basically made solely on cost but with safety at the forefront because safety cannot be compromised in construction and other engineering operations [19]. So, sustainable structural retrofit is not about providing the cheapest retrofit option but providing the most economical solutions that meet the desired upgrade for the existing building to meet the needs of the owners. However, many factors impede the attainment of economic sustainability in structural retrofit.

The main impediment to the economic viability of structural retrofit is the high cost of materials that are involved in making the techniques sustainable [19]. In most cases, composite materials such as epoxy and fibre reinforced polymer (FRP) mostly based on carbon, glass, and aramid fibre offers promising structural retrofitting possibilities for existing buildings [20,21]. They present several well-known advantages that meet the requirements of sustainability goals; socially and environmentally [20]. This is because composite materials have quite higher strength and stiffness to thickness ratio. Composites have then arisen to be one of the most promising construction materials for the structural retrofit of existing structures [22]. However, some of the drawbacks of the composite applications are the relatively high cost of the material, the technical requirement for the installation, and limited knowledge about the ageing properties of the materials. This thus impacts the propagation of sustainable structural retrofit techniques. The other material commonly used in absence of the sustainable composites is the use of concrete overlay which is relatively cheaper but has high carbon embodiment. Concrete is the second largest consumed material apart from water and the major constituent of concrete is the Portland cement which is produced through the high release of carbon dioxide [23,24]. Therefore, reusing concrete structures or retrofitting structures with materials such as low carbon or near-zero carbon concrete will definitely reduce the amount of Portland cement consumption and thus subsequently reduce the carbon footprint which is an indication of increased environmental protection (sustainability).

In addition, earlier studies ([25–27]submitted that insufficient public funding, and lack of incentive from government and decision-makers also significantly hindered economic sustainability in structural retrofit. In addition, the high inflation rate of construction materials and other factors of production were key barriers to attaining economic sustainability in the affordable structural retrofit of existing buildings [28]. It has also been suggested that the challenge of finding the right balance between the initial cost of the retrofit and the cost of running the retrofitted housing is a great concern for sustainable structural retrofit of residential housing [29].

2.1.3. Environmental concept of sustainable building retrofit

Reusing existing structures will contribute immensely towards reducing the carbon footprint and thereby can be regarded as one of the key drivers to achieving environmental sustainability. According to the United Nations (UN) World Commission on Environment and Development, the act of providing engineering solutions that ensure significant protection of available natural resources and ecosystems in the immediate and future time is described as environmental sustainability [30]. Numerous researchers and experts such as [31–33] have consistently argued that environmental sustainability is the most important pillar of the three pillars of sustainability. They argued that if the issue of environmental sustainability is not well addressed in constructing a new system or retrofitting old systems, then the solution cannot be regarded as sustainable. Their evaluation is greatly dependent on the fact that the other pillars of sustainability depend on the wider system they live on, which is the environment [33]. In the case of structural retrofitting of old buildings, the motive is to use materials and systems that are environmentally friendly and can be easily sourced around the area to avoid a long transportation effect which might also affect the sustainability of the system. This has been consistently argued by Refs. [11,16], their works concluded that the transportation effect of materials should be accounted for when deciding whether the material is sustainable or not. In fact, the Institution of Civil Engineer code of conduct [34], supported by a more recent study [35], presents a strong argument that a complete life cycle analysis (i.e. planning, designing, construction, commissioning and decommissioning) of the system and materials should be evaluated to establish the true sustainability index of any proposed retrofit technique.

This macro-objective of ensuring environmental sustainable structural retrofit technique can be achieved by adopting various green technologies, sustainable materials as well as renewable energy and resources [36–38]. Some of the key performance indicators to gauge environmental sustainability in buildings are energy efficiency, water efficiency, effective utilisation of resources, reliability and durability, efficient waste management, comfortable and healthy indoor environment, and reduction of carbon footprint [39,40].

Meanwhile, in measuring these indicators, it has been established that the unavailability of certain retrofit materials in some geographical locations leading to longer commuting of materials impedes their environmental performance [11,16]. Factors such as zoning restrictions on land and housing, lack of awareness of the consequence of some human activities, higher population density, technological difficulties, limited interdisciplinary knowledge transfer, and external pressures in adopting certain structural retrofit techniques that are not suitable for some environmental conditions are also some of the factors mitigating against having an environmentally sustainable structural retrofit technique [23,41,42].

2.1.4. Social concept of sustainable building retrofit

Besides the evident housing and infrastructure values, most old buildings are historical and thus were part of the cities' heritages and as such constitute significant social, cultural, historical and architectural importance to the cities [43]. Hence one of the key priorities of retrofitting old buildings, most especially historical and listed buildings is to preserve their aesthetics and appearance to keep the social sustainability of the buildings. As deduced from the UN Global compact, social sustainability in building retrofit is about identifying and managing the impacts of the proposed retrofit both positive and negative on people and society at large [44]. Structural retrofit has always faced many challenges such as aesthetic or historical impact, reduction of functional space and disruption of occupancy usage [29]. So, social sustainability in the context of structural retrofitting old buildings will mean how best to minimise the impact of the retrofit on the way of life of the occupants [45]. So, the minimum disruption caused to their lives and the maximum benefit they derived from the retrofit define how socially sustainable the solution is [46,47].

Socially sustainable building retrofit solutions should fulfil the users' requirements and improve their life [13,48,49]. In addition, the impact on the immediate local culture and aesthetic values should also be integrated into the retrofit design [50]. However, some barriers could impede the social sustainability attainment in the structural retrofit of existing buildings. These barriers could be lack of personal engagement which hampers community contribution in providing the solution, insufficient skilled labour to implement certain retrofit solutions, health and safety concerns of the community, and poor management and maintenance culture [45,47,48].

Finally, as clearly explained above, there are three key factors in deciding the sustainability of any structural retrofit technique. The preference of the situation determines which of the pillars should be prioritised. Although [31,33], strongly argued that environmental sustainability should not be compromised for the economy or social sustainability. This is best explained using the quality triangle showing the interaction between the cores of sustainability (see Fig. 2). The indication from this interaction is that a sustainable system can only be created when all the sustainability factors are properly balanced. An environmentally and economically sustainable structural retrofit solution is regarded as a viable retrofit solution but unbearable with the possibility of social unrest due to the lack of integration of social implications on the retrofitted building [51]. Also, when the environmental and social factors were properly considered in providing the retrofit solution, a retrofitted building that is livable is created but with a very high-cost implication (unequitable). Meanwhile, a combination of economically and socially sustainable retrofit solutions might be considered equitable,

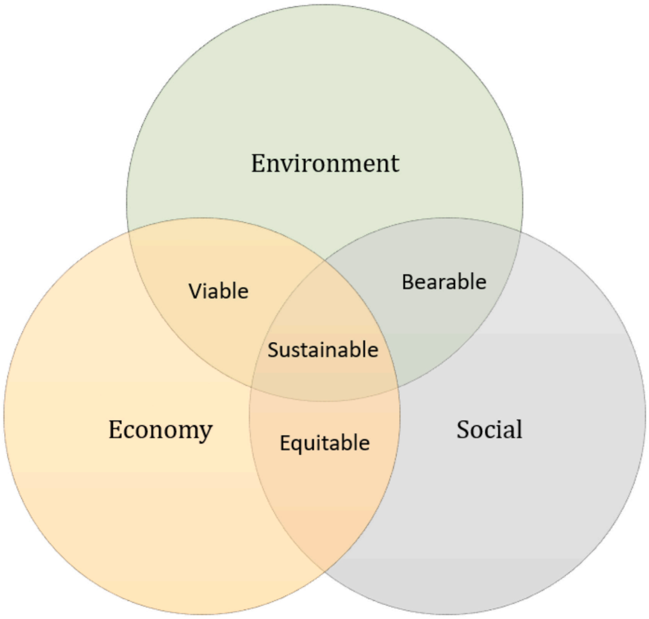

Fig. 2. Interaction of sustainability factors.

but the solution degrades the environment. Therefore, finding the right balance between these three factors is the challenge faced by retrofit experts because many impediments hinder these sustainability factors.

The literature review conducted identified some of these impediments and a conceptual framework showing the relationship among them was developed (see Fig. 3). The framework shows that the impediments were interrelated with one another and do not exist in isolation as indicated by the double-sided arrow in Fig. 3. Most of these impediments emanated from earlier studies that are mainly focused on energy retrofit in existing buildings. As such, the study draws up 21 lists of potential barriers to sustainability that are deemed relevant to structural retrofit in Table 1 and put that into the questionnaire as detailed in section 2.2.

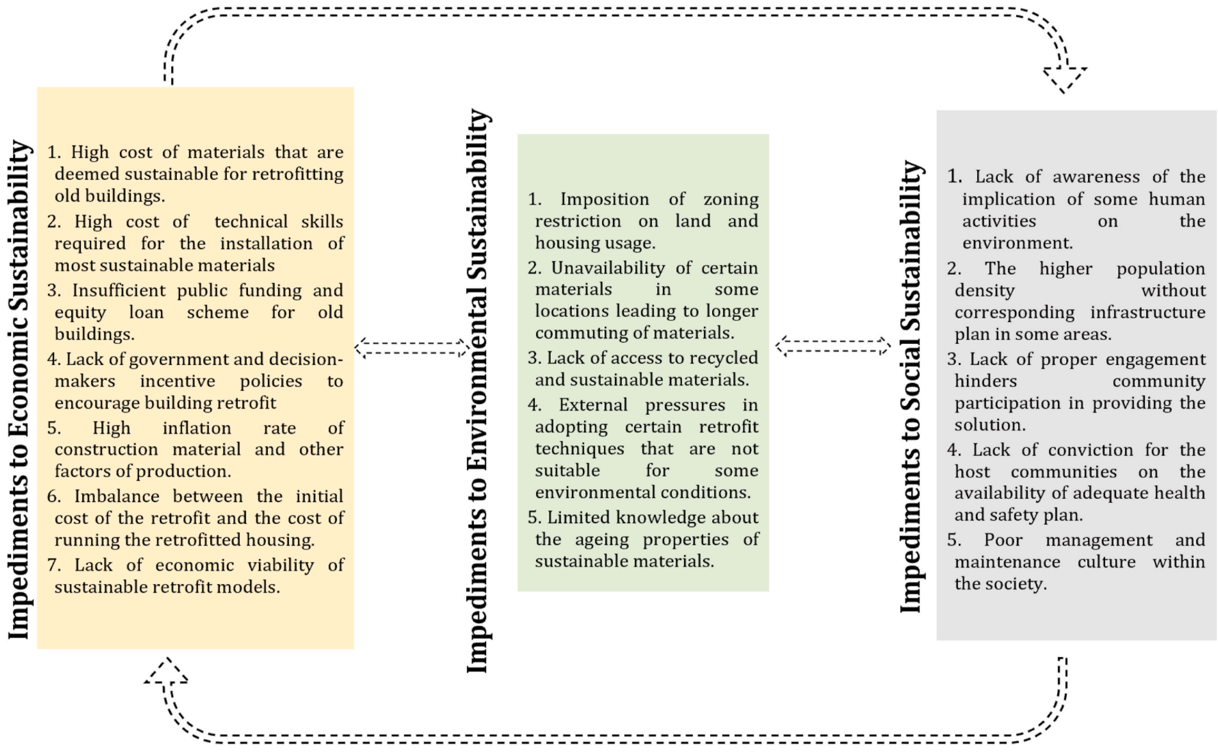

Fig. 3. Conceptual framework on impediments to sustainable structural retrofit.

Table 1
Potential barriers to sustainable structural retrofit of buildings.

Barrier	References
Relatively high cost of materials that are deemed sustainable for retrofitting old buildings.	[19,22]
Cost implication of the high technical skills required for the installation of most sustainable materials	[29,48]
Limited knowledge about the ageing properties of sustainable materials.	[20,23]
Insufficient public funding and equity loan scheme for old buildings.	[25,26]
Lack of government and decision-makers incentive policies to encourage building retrofit	[52]
High inflation rate of construction material and other factors of production.	[26,52]
Imbalance between the initial cost of the retrofit and the cost of running the retrofitted housing.	[25,29]
Imposition of zoning restriction on land and housing usage.	[36,48]
Unavailability of certain materials in some geographical locations leading to longer commuting of materials.	[11,38]
Lack of awareness of the implication of some human activities on the environment.	[37,38]
The higher population density without corresponding infrastructure plan in some areas.	[40]
Lack of adequate documentation of proven sustainable retrofit technologies for old buildings.	[25,29]
External pressures in adopting certain retrofit techniques that are not suitable for some environmental conditions.	[53]
Lack of proper engagement hinders community participation in providing the solution.	[36,47]
Lack of economic viability of sustainable retrofit models.	[37,40]
Lack of conviction for the host communities on the availability of adequate health and safety plan.	[10,23]
Poor management and maintenance culture within the society.	[15,17]
Lack of access to recycled and sustainable materials.	[11]
Lack of proper understanding of the performance of old buildings.	[29,37]
Lack of connection between good research, standards, and practice which will inform sustainable retrofit framework.	[29,48]

2.2. Stage II: data collection phase

In the second stage, the preliminary lists drawn up in Table 1 were used to form the questionnaire for the purpose of data collection. The questionnaire was in form of a five-point Likert scale starting from a score of 1–5 for strongly disagreed, disagreed, neutral, agreed and strongly agreed respectively. The questionnaire consists of twenty-six questions, with questions 1–4 measuring the demographic data of the respondents, and question 5 assessing how the respondent is keen on ensuring sustainability in any of their structural retrofit projects. The remaining questions, 6–26 directly measure the extent to which the respondents agreed to some potential barrier to sustainable structural retrofit. The developed questionnaire was first piloted through networks of personal contact among academics and professionals practising in the built environment sector in the UK. Piloting the questionnaire allowed for rephrasing some questions to remove some ambiguities and subsequently improve the participants' understanding [54].

Thereafter, the questionnaire was administered to the willing participant electronically through an online survey platform by sharing the links to questions to professional groups via email, LinkedIn, Web and even WhatsApp. The sampling technique used in the study is referred to as convenient/opportunity samplings which allows any willing participant to answer the questionnaire.

In total, 126 respondents participated in the survey, which is considered suitable as a sample size of more than 30 is appropriate for most research [55]. Fig. 4 presents the overall distribution of the respondents. 92% of the respondents have participated in more than six different structural retrofit projects, which is an indication that the respondents provided informed answers to the questionnaires which might improve the reliability of the data collected.

2.3. Stage III: data analysis phase

The data collected were subjected to quantitative data analysis using the reliability analysis presents in section 2.3.1 and exploratory factor analysis in section 2.3.2.

2.3.1. Reliability analysis

SPSS IBM Statistics version 24 was used to carry out a reliability analysis of the collected data to assess their integrity and identify if there is any factor not significantly contributing to the overall reliability of the data collected. Thereafter, the identified factors not contributing to the reliability of the data are deemed not suitable for further analysis and were deleted from the data before subjecting it to the exploratory factor analysis (see section 2.3.2). The reliability analysis informs of Cronbach Alpha coefficient is extremely important especially when the Likert scale is used on questionnaires such as the one adopted in this study [56]. This analysis helps in determining the internal consistency and credibility of the data collected [56,57]. The value of the Cronbach Alpha coefficient ranges from 0 to 1, with a value above 0.7 indicating a satisfactory level of consistency within the data and a value above 0.8 representing a high level of internal consistency [57].

The reliability analysis performed in this study using the SPSS IBM Statistics version 24 returns a Cronbach Alpha coefficient of 0.939, this represents an excellent level of reliability and internal consistency among the data collected. According to a similar analysis presented by Refs. [54,58], a further analysis termed Cronbach Alpha coefficient if item deleted was conducted to guarantee that all the items on the questionnaire were significantly contributing to the internal consistency and stability of the data. This implies that any item that returns a Cronbach Alpha coefficient above 0.939 is deemed not reliable and as such deleted from the list of the variables. Referring to Table 2, BAR 1 & BAR 18 with Cronbach's Alpha if Item Deleted value of 0.941 & 0.940 respectively were deleted and the remaining variables were declared suitable and subsequently used in exploratory factor analysis.

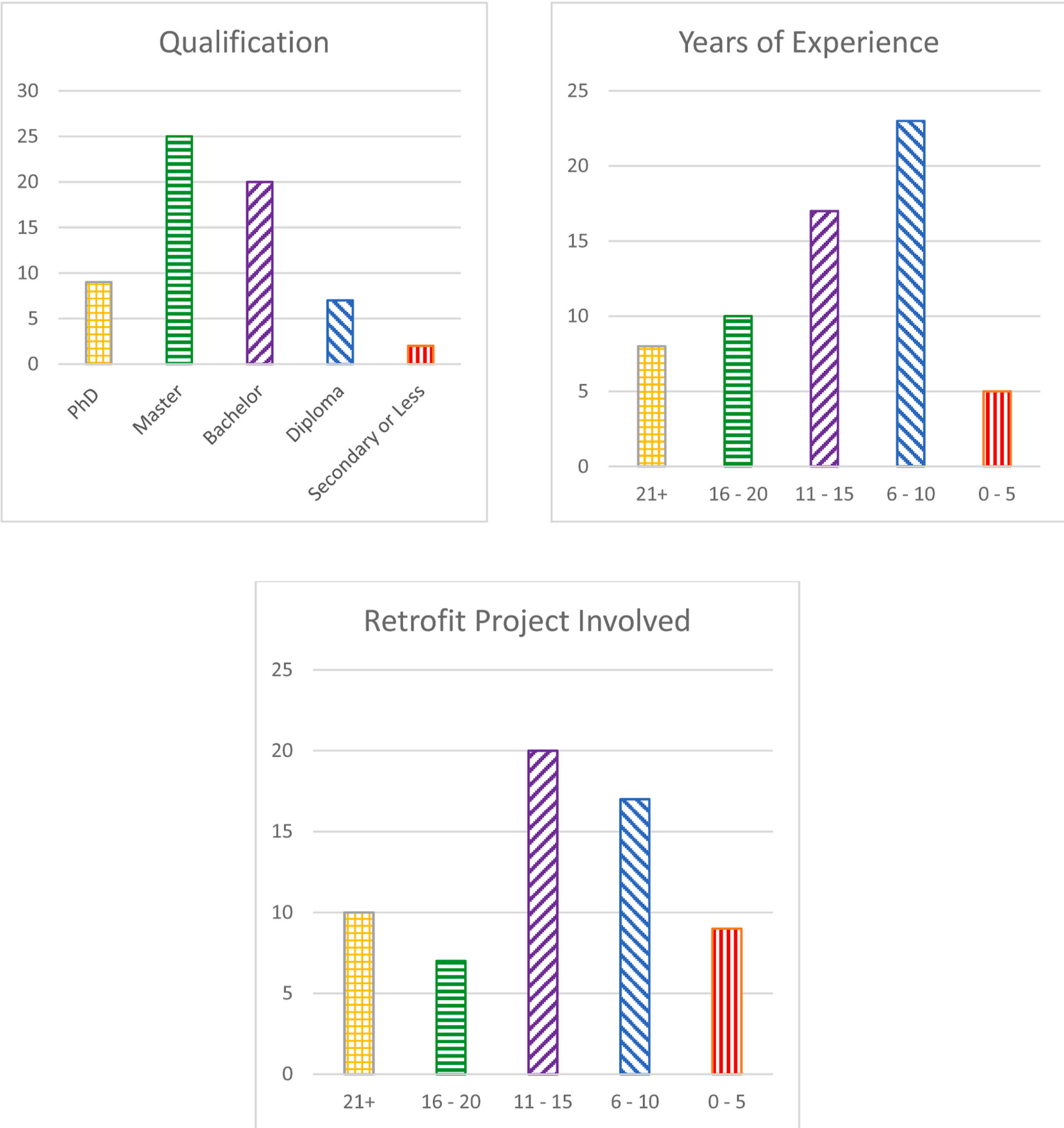

Fig. 4. Overview of the respondents.

2.3.2. *Exploratory factor analysis*

In this study, the exploratory factor analysis (EFA) was used to identify the inherent relationships between measured variables of 21 identified barriers to sustainable structural retrofit of buildings. It is basically used to distinguish a set of latent constructs underlying a series of measured variables listed in the questionnaire administered. The factor analysis was carried out in three distinct steps identified by Ref. [56] as the suitability of data test, factor extraction and factor rotation.

In the first step, the suitability of the data collected was established using Kaiser-Meyer-Olkin (KMO) and Bartlett's test of sphericity. The Kaiser-Meyer-Olkin measures the adequacy of the sampling using the guideline from Refs. [56,59] which states that for data sampling to be adequate, the KMO value must be greater than 0.5. Meanwhile, the Bartlett's test of sphericity compares an observed correlation matrix to the identity matrix and checks for certain redundancy between the variables that can be summarised with a few factors [59]. Specifically, the SPSS IBM documentation [60] recommends a Small Bartlett's test of sphericity values (less than 0.05) for factor analysis to be useful on data. In this study, the analysis returns a KMO value of 0.86 and Bartlett's test of sphericity value of 5.78E-245, both values are within their respective allowable limit and thus establishing that the data are suitable for factor analysis. In line with the earlier study [54], a quick assessment of the anti-imaging matrix was carried out to identify any variables with a diagonal value less than 0.5 and remove such as recommended [56]. In this study, all variables have anti-imaging values above 0.5 and thus certifying that the data collected are fit for further analysis.

Table 2
Reliability statistics.

Barrier ID	Barriers	Cronbach's Alpha[a]	Cronbach's Alpha if Item Deleted
BAR 1[b]	High consideration for ensuring environmental, economic, and social sustainability in any construction project.	0.247	0.941
BAR 2	Relatively high cost of materials that are deemed sustainable for retrofitting old buildings.	0.742	0.935
BAR 3	Cost implication of the high technical skills required for the installation of most sustainable materials.	0.664	0.936
BAR 4	Lack of government and decision-makers incentive policies to encourage building retrofit.	0.635	0.937
BAR 5	Lack of adequate documentation of proven sustainable retrofit technologies for old buildings.	0.707	0.935
BAR 6	Lack of connection between good research, standards, and practice which will inform sustainable retrofit frameworks.	0.676	0.936
BAR 7	The high inflation rate of construction materials and other factors of production.	0.601	0.937
BAR 8	The imbalance between the initial cost of the retrofit and the cost of running the retrofitted housing.	0.676	0.936
BAR 9	Imposition of zoning restriction on land and housing usage.	0.664	0.936
BAR 10	Unavailability of certain materials in some geographical locations leading to longer commuting of materials.	0.755	0.935
BAR 11	Lack of awareness of the implication of some human activities on the environment.	0.603	0.937
BAR 12	The higher population density is without corresponding infrastructure plans in some areas.	0.622	0.937
BAR 13	Lack of proper engagement which hinders community participation in providing solutions.	0.716	0.935
BAR 14	Insufficient public funding and equity loan scheme for old buildings.	0.582	0.938
BAR 15	Lack of economic viability of sustainable retrofit models.	0.699	0.936
BAR 16	Limited knowledge about the ageing properties of sustainable materials.	0.712	0.936
BAR 17	Lack of conviction for the host communities on the availability of adequate health and safety plan.	0.736	0.935
BAR18[b]	Poor management and maintenance culture within the society.	0.443	0.940
BAR 19	Lack of access to recycled and sustainable materials.	0.650	0.936
BAR 20	Lack of proper understanding of the performance of old buildings	0.625	0.937
BAR 21	External pressures in adopting certain retrofit techniques that are not suitable for some environmental conditions	0.508	0.938

[a] Cronbach alpha is 0.939.
[b] Item excluded from further analysis.

Thereafter, the factor extraction analysis using the Principal Component Analysis (PCA) was carried out to find similar patterns in data and use a common theme to suitably represent the factors in the same group. The PCA requires a minimum value of 1 for the Eigen Value of each group [56] and the analysis in this study extracted four different groups with their respective Eigenvalues greater than 1 (See Table 3). Thereafter, a factor rotation using the Equamax with Kaiser Normalization method in the PCA was carried out to generate the rotated component matrix. It is not uncommon to have factors loaded in more than one group, so it is recommended to delete such factors and remove them from further analysis [60,61]. Variable 10 (unavailability of certain materials in some geographical locations leading to longer commuting of materials*)* was loaded under groups 1 and 4 and was deleted from further analysis. Fig. 5 shows the overall scree plot of all factors with their eigenvalues and % of variance to demonstrate how much variation each PC captures from the data. The figure shows that the first four factors capture the most variation which is in conformation to an ideal PCA scree plot.

Table 3 present the complete result of the factor analysis (extraction and rotation) with the values of the factor loading, eigenvalue and percentage of variance for each group. The four groups were construed and categorised based on the inherent theme common in all factors within each group. Using the value of eigenvalue and percentage of variance as an indication of the order of importance of each component, GRP1: Cultural Barrier is the most important component followed by GRP 2: Economic Barrier. In third place is GRP 3: Technical Knowledge Barrier while GRP 4: Regulatory Barrier is the least. Most importantly, the extracted total variance is 69.995%, which is greater than the 60% threshold suggested as the rule of thumb [62]. Therefore, the analysis presented here is valid and the results of the analysis can be considered valid and reliable. As such, a complete discussion of the results is presented in the subsequent section 3.

3. Discussion of result

Once the suitability of the data and reliability of the analysis results were confirmed, the finding of the study was discussed based on the main objective of this research which is to identify the barriers that hinder the development of sustainable structural retrofit techniques for old buildings. There are 21 factors analysed in the questionnaire, but the results of the exploratory factor analysis after extraction and rotation substantiated 18 of them and grouped them into four different categories (see Fig. 6) which are used for the discussion as follows.

3.1. Cultural barriers to sustainable building retrofit

This study identified cultural barriers as the main impediment to sustainability in structural retrofitting of old buildings with the component having the highest percentage of variance (18.223%). The component comprises four different factors as listed in Table 3.

Table 3
Exploratory factor analysis.

	Extracted and Rotated Components	Factor Loading	Eigen Value	% of Variance
Group -1	**Cultural Barriers**		**3.462**	**18.223**
BAR 11	Lack of awareness of the implication of some human activities on the environment.	0.632		
BAR 12	The higher population density is without corresponding infrastructure plans in some areas.	0.823		
BAR 13	Lack of proper engagement which hinders community participation in providing the solution.	0.774		
BAR 17	Lack of conviction for the host communities on the availability of adequate health and safety plan.	0.609		
Group-2	**Economic Barriers**		**3.367**	**17.722**
BAR 2	Relatively high cost of materials that are deemed sustainable for retrofitting old buildings.	0.630		
BAR 3	Cost implication of the high technical skills required for the installation of most sustainable materials.	0.613		
BAR 7	The high inflation rate of construction materials and other factors of production.	0.760		
BAR 8	The imbalance between the initial cost of the retrofit and the cost of running the retrofitted housing.	0.617		
BAR 14	Insufficient public funding and equity loan scheme for old buildings.	0.576		
BAR 15	Lack of economic viability of sustainable retrofit models	0.510		
Group - 3	**Technical Knowledge Barriers**		**3.263**	**17.174**
BAR 16	Limited knowledge about the ageing properties of sustainable materials.	0.573		
BAR 19	Lack of access to recycled and sustainable materials.	0.760		
BAR 20	Lack of proper understanding of the performance of old buildings.	0.708		
BAR 21	External pressures in adopting certain retrofit techniques that are not suitable for some environmental conditions.	0.831		
Group - 4	**Regulatory Barriers**		**3.131**	**16.480**
BAR 4	Lack of government and decision-makers incentive policies to encourage building retrofit.	0.854		
BAR 5	Lack of adequate documentation of proven sustainable retrofit technologies for old buildings.	0.513		
BAR 6	Lack of connection between good research, standards, and practice which will inform sustainable retrofit frameworks.	0.588		
BAR 9	Imposition of zoning restriction on land and housing usage.	0.731		

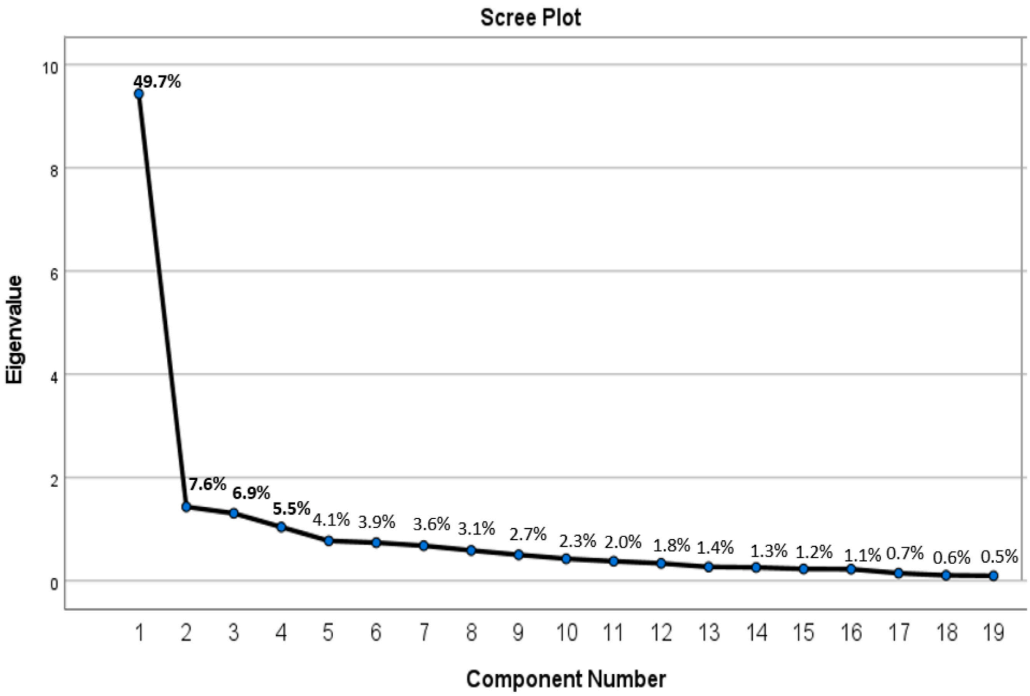

Fig. 5. PCA Result showing Scree Plot of Eigenvalues of Covariance.

The factors group was named cultural barriers because all the factors that made up the group were based on human behaviour, interaction, perception, interest, awareness, and individual way of life.

The United Nations Educational, Scientific and Cultural Organization (UNESCO) report [63] argued that culture must be at the centre of our development strategies for achieving sustainability because cultures frame people's relationships with others in their society and the world around them, including the natural environment. The result of this study sustained the UNESCO arguments with

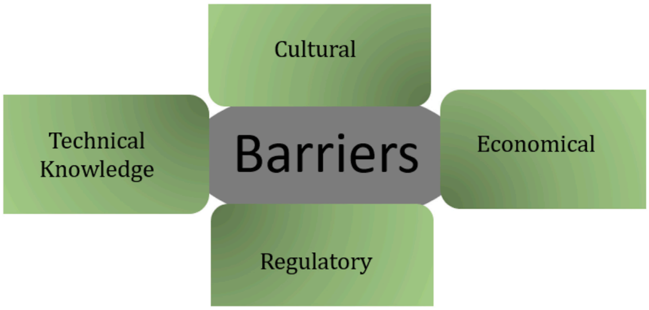

Fig. 6. Categories of barriers to sustainable structural retrofit of old buildings.

lack of awareness of the implication of some human activities on the environment strongly identified as one of the key cultural barriers to achieving sustainability in structural retrofitting of old buildings. The most relevant example of this in structural retrofit is the constant use of concrete materials in retrofitting old buildings without accounting for its implication. Concrete has been identified as the second most consumed substance on earth after water, growing by 2.5% annually and its major constituent is cement which production involves the burning of fossil fuels that account for about 5% of global CO2 emissions [64] and [73].

In addition, the continuous increase of the population density in the urban area leads to the demolition of many old buildings to erect many modern facilities to meet the demand of the growing population. The demolition of old buildings if not properly handled can generate harmful resource extraction and excessive waste materials that impact negative the sustainability of the environment [54]. Where the existing building is been considered for refurbishment, this study also revealed that lack of proper engagement with host communities hinders their participation in providing sustainable retrofit solutions. This also affects their confidence and raises concerns over their health and safety, thus affecting the usage of the building after the retrofit work. It is thus essential that when planning any structural retrofit project, the promotion of cultural vitality of the host communities must be given a high consideration as much as the technology and the economical consideration. The minimum disruption caused to lives during retrofitting and the maximum benefit they derived after the retrofit define how socially sustainable the solution is [46,47]. The finding of this study corroborated the submission of the International Federation of Arts Councils and Culture Agencies (IFACA) which states that the inclusion of culture within sustainable development agendas was a central focus for the promotion of sustainability within the built environment [65].

3.2. Economical barriers to sustainable building retrofit

The second category of major barriers that emanated from this study has six factors with a percentage of variance value of 17.722%. This component was described as economical barrier because the component's six factors have a common theme pointing towards the cost of materials, labour, inflation rate and the overall economic implication of the retrofit process. Even though the earlier study [19], argued that economic sustainability in building retrofit does not mean the cheapest retrofit solution, this study reiterated the economic bias of people in providing building retrofit. As such, the study revealed that the high initial cost of sustainable materials and the corresponding cost of engaging high skilled technical experts will impact the adoption of most sustainable materials and techniques in structural retrofitting of old buildings. This finding is in line with the earlier study [66] that declared that the short-term costs of sustainable retrofit are too high to justify their application in a highly competitive market. Meanwhile, it has been clearly established that the major economic benefits of sustainable retrofit of buildings are majorly reduced operation and utility costs, reduced maintenance costs, and an overall improvement in the buildings' performance and efficiency [67,68]. This creates an imbalance between the high initial cost of the retrofit and the low cost of running the retrofitted housing. This often drives the decision of investors to prioritise having cheap initial costs rather than the overall economic sustainability which comes with the low operating cost.

Another major economic barrier facing the sustainable structural retrofit of old buildings is the unavailability of public funding and equity loan schemes for old buildings from the government which essentially impede the economic viability of sustainable retrofit models. For instance, in the UK, the government have an equity loan scheme in form of help to buy. This help to buy is an equity loan from the government to potential homebuyers and it is around 20%–40% of the cost of a newly built home depending on the location within the UK [69]. This equity loan is interest-free for the first five years, and it is only available for newly built homes which impacts the market for retrofitted old buildings. As a result, property developers are not willing to invest so much in old houses and thus target the acceptable standard for the retrofitting scheme instead of prioritising sustainability. In addition, the fear of higher investment costs for sustainable structural retrofit of old buildings and the risks of unforeseen costs compared to traditional newly buildings are often addressed as barriers to sustainable structural retrofit [70].

3.3. Technical barriers to sustainable building retrofit

Lack of adequate technical knowledge in dealing with old buildings is another obstacle that is hampering the attainment of sustainability in the structural retrofitting of old buildings. The component has 17.174% value in percentage of variance and integrates four different factors. This component revealed that inadequate knowledge of sources and properties of sustainable materials, insufficient understanding of the structural behaviour of old buildings and adoption of certain retrofit techniques without proper knowledge and skills to implement such complex solutions imperilled the attainment of sustainability in the structural retrofit solution. The starting point of any structural retrofit project is to understand the building in terms of both existing conditions and performance during use [71]. This means a detailed consideration of the current structural performance and the subsequent future responses due to the intended retrofit application is a key part of retrofitting process. However, if the technical knowledge and skills to do this are lacking, it will be difficult to implement a balance retrofit solution that will encompass all the key elements of sustainability.

The outcome of this study buttressed the earlier submission [71] which implied that lack of professional knowledge has been recognised as a great challenge in the implementation of sustainable structural retrofit solutions within the built environment. This particular point was also raised in the report [72] submitted to the UK Department for Business, Energy and Industrial Strategy. The key submission from Ref. [72] is that structural retrofit works in social housing are being hampered by limited knowledge about some materials to achieve sustainable housing retrofit either by the housing provider or their suppliers. In addition, the development of sustainable building retrofit requires the active and integrated engagement of all stakeholders which will allow everyone to contribute to the solution. Therefore, to overcome the technical knowledge barriers identified in this study and other previous related studies, there is a need to develop an education & skills programme for the entire property and construction supply chain about all aspects of sustainable refurbishment and retrofit market [71].

3.4. Regulatory barriers to sustainable building retrofit

Regulations are mainly put in place by certain approved authorities to either promote or discourage certain actions. In terms of structural retrofitting of old buildings, this study identified the lack of some incentive policies to encourage old building retrofit from the government and decision-makers as the main regulatory barrier that impacted the realisation of sustainability in structural retrofit of old buildings. This is interrelated with the economic barriers such as the provision of help to buy schemes for new buildings in the UK [69] which impacted negatively on dealing with old buildings. This component also has four factors with a percentage of variance value of 16.480%.

While this study generally suggests that regulatory barriers are not the leading barrier to sustainable structural retrofitting of old buildings with the least value of percentage of variance, the responses definitely indicate that enabling regulatory frameworks and policies will encourage potential homeowners to consider investing in the sustainability of old buildings. To this effect, Carbon action 2050 White papers from the chartered institute of building [71] recommend key action points around the revision of the Building Regulations to encourage sustainable structural retrofit and introduce more rigorous requirements for works to existing buildings and introduce the Code for Sustainable Homes for refurbishment and retrofitting work.

4. Conclusion

This paper presents a study to investigate the barriers that impede achieving sustainability in structural retrofitting of old buildings. The study adopted a mixed method of data collection involving a critical review of pertinent literature and administration of a questionnaire that was responded to by 126 professionals within the built environment sector in the UK. The main mode of data collection is electronic through an online survey platform and sharing the links to questions to professional groups via email, LinkedIn, Web and even WhatApps which make it possible to collect data from different locations around the UK. The collected data were subjected to reliability analysis and exploratory factor analysis using the SPSS IBM Statistics version 24.

The findings of this study substantiated that 18 out of the pre-identified 21 significant impediments hinder the attainment of sustainability in structural retrofitting of old buildings. Through the exploratory factor analysis, the results after the extraction and rotation of the factors produced four different components which are named based on the common theme that emerged from each component. Cultural barriers involving factors that are characterised by human behaviour, interaction, perception, interest, awareness, and individual way of life is revealed to be the most significant barrier with the highest value of percentage of variance (18.233%). This is then closely followed by economic barriers with a 17.722% value of percentage of variance. The third barrier identified in this study is the technical knowledge barrier with a 17.174% percentage of variance. This component established that there is need for proper development of education & skills programs in every phase of refurbishment and retrofitting. In the last category, i.e regulatory barrier with 16.480% percentage of variance are factors that showed that the absence of encouraging regulatory frameworks and policies to promote interest in old buildings impacted sustainable structural retrofit of old buildings. The key finding from this study is that there is no wide margin in terms of which barrier has the most damning impact because all four categories are within 10% variation.

However, it is important to point out that the main limitation of this study is the relatively small sample size, which can affect the results and the interpretation deduced from the study results. Therefore, this study recommends a future study where much more sample sizes can be collected and possibly grouped into two categories of data from developing and developed countries. This could reveal much insight into the specific barriers to sustainable structural retrofit of old buildings in developing and developed countries. Besides, with a relatively larger sample size, other parametric analyses could be employed to explore the relationship between these barriers. Also, questionnaires should also be administered to homeowners, property investors and possibly housing authorities to understand the issue from their perspective. This is because the sample collected in this study were from only professionals and experts within the built environment sector in the UK.

Albeit this limitation, this study still contributes to significant issues on attaining sustainability targets within the built environment by increasing awareness on current practices and concerns about attaining sustainable structural retrofitting in building projects. The study outcomes cover the main impediments to sustainable structural retrofit of old buildings by highlighting both well-publicised and also lesser-known issues that have not been the subject of widespread coverage. In practical terms, this study highlights the key barriers to overcome to promote sustainable cities and communities which is goal 11 of the Sustainable Development Goals of the United Nation.

Author statement

Jamiu A. Dauda: Conceptualization, Methodology, Investigation, Analysis, Writing - Original draft preparation.
Saheed O. Ajayi: Analysis, Writing- Reviewing and Editing.

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

No data was used for the research described in the article.

References

[1] R. Pierrehumbert, There is no Plan B for dealing with the climate crisis, Bull. At. Sci. 75 (2019) 1–7, https://doi.org/10.1080/00963402.2019.1654255.
[2] BPIE, Europe's Buildings under the Microscope, Buildings Performance Institute Europe, 2011. http://www.bpie.eu/publication/europes-buildings-under-the-microscope/.
[3] M. Eames & Dixon Tim, S. Lannon, M. Hunt, C. De Laurentis, S. Marvin, M. Hodson, P. Guthrie, M.C. Georgiadou, Retrofit 2050: Critical Challenges for Urban Transitions Retrofit 2050: Critical Challenges for Urban Transitions Authors, 2014, pp. 1–14.
[4] V. Hasik, E. Escott, R. Bates, S. Carlisle, B. Faircloth, M.M. Bilec, Comparative whole-building life cycle assessment of renovation and new construction, Build. Environ. 161 (2019) 106218, https://doi.org/10.1016/j.buildenv.2019.106218.
[5] O. Iuorio, J.A. Dauda, P.B. Lourenço, Experimental evaluation of out-of-plane strength of masonry walls retrofitted with oriented strand board, Construct. Build. Mater. 269 (2021) 121358, https://doi.org/10.1016/j.conbuildmat.2020.121358.
[6] A. Kamari, P.H. Kirkegaard, C.P. Leslie Schultz, PARADIS - a process integrating tool for rapid generation and evaluation of holistic renovation scenarios, J. Build. Eng. 34 (2021) 101944, https://doi.org/10.1016/j.jobe.2020.101944.
[7] International association for earthquake engineering (IAEE), repair, restoration and strengthening of buildings, in: Guidel. Earthq. Resist. Non, -Engineered Constr., 2015.
[8] L. D'Angelo, M. Hajdukiewicz, F. Seri, M.M. Keane, A novel BIM-based process workflow for building retrofit, J. Build. Eng. 50 (2022) 104163, https://doi.org/10.1016/j.jobe.2022.104163.
[9] J.A. Dauda, Numerical and Experimental Investigation of Unreinforced Masonry Wall Retrofitted with Timber Panels, University of Leeds, UK, 2020.
[10] Z. Ma, P. Cooper, D. Daly, L. Ledo, Existing building retrofits: Methodology and state-of-the-art, Energy Build. 55 (2012) 889–902, https://doi.org/10.1016/j.enbuild.2012.08.018.
[11] O. Iuorio, J.A. Dauda, Retrofitting masonry walls against out-of-plane loading with timber based panels, Appl. Sci. 11 (2021) 5443, https://doi.org/10.3390/app11125443.
[12] M.A. Elgawady, P. Lestuzzi, A review of conventional seismic retrofitting techniques for URM, 13th Int. Brick Block Mason. Conf. (2004) 1–10.
[13] Q. He, S.T. Ng, M.U. Hossain, G.L. Augenbroe, A data-driven approach for sustainable building retrofit—a case study of different climate zones in China, Sustainability 12 (2020) 4726, https://doi.org/10.3390/su12114726.
[14] A. Saad, S.O. Ajayi, H.A. Alaka, Trends in BIM-based plugins development for construction activities : a Trends in BIM-based plugins development for construction activities : a systematic review, Int. J. Constr. Manag. (2022) 1–13 https://doi.org/10.1080/15623599.2022.2093815, 0.
[15] A. Tahon, A. Elyamany, Sustainability Concept and Knowledge Analysis in Construction Industry, 2017, pp. 307–315.
[16] A.P.C. Chan, M.A. Adabre, Bridging the gap between sustainable housing and affordable housing: the required critical success criteria (CSC), Build, Environ. Times 151 (2019) 112–125, https://doi.org/10.1016/j.buildenv.2019.01.029.
[17] J. Schuetz, To Improve Housing Affordability, We Need Better Alignment of Zoning, Taxes, and Subsidies, 2020. https://www.brookings.edu/policy2020/bigideas/to-improve-housing-affordability-we-need-better-alignment-of-zoning-taxes-and-subsidies/.
[18] X. Gan, J. Zuo, P. Wu, J. Wang, R. Chang, T. Wen, How affordable housing becomes more sustainable? A stakeholder study, J. Clean. Prod. 162 (2017) 427–437, https://doi.org/10.1016/j.jclepro.2017.06.048.
[19] I. van de Poel, Z. Robaey, Safe-by-Design: from safety to responsibility, Nanoethics 11 (2017) 297–306, https://doi.org/10.1007/s11569-017-0301-x.
[20] M. Corradi, A.I. Osofero, A. Borri, G. Castori, Strengthening of Historic Masonry Structures with Composite Materials, 2015, pp. 257–292, https://doi.org/10.4018/978-1-4666-8286-3.ch008.
[21] N. Ismail, J.M. Ingham, In-plane and out-of-plane testing of unreinforced masonry walls strengthened using polymer textile reinforced mortar, Eng. Struct. 118 (2016) 167–177, https://doi.org/10.1016/j.engstruct.2016.03.041.
[22] D. Rajak, D. Pagar, P. Menezes, E. Linul, Fiber-reinforced polymer composites: manufacturing, properties, and applications, Polymers 11 (2019) 1667, https://doi.org/10.3390/polym11101667.
[23] A. Myhr, F. Røyne, A.S. Brandtsegg, C. Bjerkseter, H. Throne-Holst, A. Borch, A. Wentzel, A. Røyne, Towards a low CO2 emission building material employing bacterial metabolism (2/2): prospects for global warming potential reduction in the concrete industry, PLoS One 14 (2019) e0208643, https://doi.org/10.1371/journal.pone.0208643.
[24] M. Valente, M. Sambucci, M. Chougan, S.H. Ghaffar, Reducing the emission of climate-altering substances in cementitious materials: a comparison between alkali-activated materials and Portland cement-based composites incorporating recycled tire rubber, J. Clean. Prod. 333 (2022) 130013, https://doi.org/10.1016/j.jclepro.2021.130013.
[25] X. Zhang, L. Shen, V.W.Y. Tam, W.W.Y. Lee, Barriers to implement extensive green roof systems: a Hong Kong study, Renew. Sustain. Energy Rev. 16 (2012) 314–319, https://doi.org/10.1016/j.rser.2011.07.157.
[26] P.E.D. Love, M. Niedzweicki, P.A. Bullen, D.J. Edwards, Achieving the green building council of Australia's world leadership rating in an office building in perth, J. Construct. Eng. Manag. 138 (2012) 652–660, https://doi.org/10.1061/(ASCE)CO.1943-7862.0000461.
[27] L. D'Angelo, M. Hajdukiewicz, F. Seri, M.M. Keane, A novel BIM-based process workflow for building retrofit, J. Build. Eng. 50 (2022) 104163, https://doi.org/10.1016/j.jobe.2022.104163.
[28] B.-G. Hwang, W.J. Ng, Project management knowledge and skills for green construction: overcoming challenges, Int. J. Proj. Manag. 31 (2013) 272–284, https://doi.org/10.1016/j.ijproman.2012.05.004.
[29] N. May, C. Rye, Responsible Retrofit of Traditional Buildings. A Report on Existing Research and Guidance with Recommendations, 2012, pp. 1–133.
[30] B.R. Keeble, The brundtland report: "our common future, Med. War 4 (1988) 17–25, https://doi.org/10.1080/07488008808408783.
[31] R. Goodland, H. Daly, Environmental sustainability: universal and non-negotiable, Ecol. Appl. 6 (1996) 1002–1017, https://doi.org/10.2307/2269583.
[32] United Nations, Balancing the Pillars: Eradicating Poverty, Protecting the Planet and Promoting Shared Prosperity, 2017, pp. 1–8. https://sustainabledevelopment.un.org/content/documents/15026T2030.pdf.

[33] B. Purvis, Y. Mao, D. Robinson, Three pillars of sustainability: in search of conceptual origins, Sustain. Sci. 14 (2019) 681–695, https://doi.org/10.1007/s11625-018-0627-5.
[34] Institution of Civil Engineer, ICE Code of Professional Conduct, 2017, pp. 379–397.
[35] O.O. Tokede, A. Roetzel, G. Ruge, A holistic life cycle sustainability evaluation of a building project, Sustain. Cities Soc. 73 (2021) 103107, https://doi.org/10.1016/j.scs.2021.103107.
[36] T.D. Mulligan, S. Mollaoğlu-Korkmaz, R. Cotner, A.D. Goldsberry, Public policy and impacts on adoption of sustainable built environments: learning from the construction industry playmakers, J. Green Build. 9 (2014) 182–202, https://doi.org/10.3992/1943-4618-9.2.182.
[37] A. Darko, A.P.C. Chan, E.E. Ameyaw, B.-J. He, A.O. Olanipekun, Examining issues influencing green building technologies adoption: the United States green building experts' perspectives, Energy Build. 144 (2017) 320–332, https://doi.org/10.1016/j.enbuild.2017.03.060.
[38] A.P.C. Chan, A. Darko, A.O. Olanipekun, E.E. Ameyaw, Critical barriers to green building technologies adoption in developing countries: the case of Ghana, J. Clean. Prod. 172 (2018) 1067–1079, https://doi.org/10.1016/j.jclepro.2017.10.235.
[39] N. Ross, P.A. Bowen, D. Lincoln, Sustainable housing for low-income communities: lessons for South Africa in local and other developing world cases, Construct. Manag. Econ. 28 (2010) 433–449, https://doi.org/10.1080/01446190903450079.
[40] L. Fuhry, W. Wells, Green goes mainstream in low-income housing, Planning 79 (2013) 31–35.
[41] J. Fořt, R. Černý, Limited interdisciplinary knowledge transfer as a missing link for sustainable building retrofits in the residential sector, J. Clean. Prod. 343 (2022), https://doi.org/10.1016/j.jclepro.2022.131079.
[42] D.-G.J. Opoku, J. Ayarkwa, K. Agyekum, Barriers to environmental sustainability of construction projects, Smart Sustain. Built Environ. 8 (2019) 292–306, https://doi.org/10.1108/SASBE-08-2018-0040.
[43] L.F. Ramos, P.B. Lourenço, Modeling and vulnerability of historical city centers in seismic areas: a case study in Lisbon, Eng. Struct. 26 (2004) 1295–1310, https://doi.org/10.1016/j.engstruct.2004.04.008.
[44] United Nations, Do Business in a Way that Benefit Society and Protect People, Soc. Sustain., 2018. https://www.unglobalcompact.org/what-is-gc/our-work/social. (Accessed 20 August 2021). accessed.
[45] A. Colantonio, T. Dixon, Social sustainability and sustainable communities: towards a conceptual framework, in: Urban Regen. Soc. Sustain., Wiley-Blackwell, Oxford, UK, 2011, pp. 18–36, https://doi.org/10.1002/9781444329445.ch2.
[46] M. Davidson, Social sustainability and the city, Geogr. Compass. 4 (2010) 872–880, https://doi.org/10.1111/j.1749-8198.2010.00339.x.
[47] N. Dempsey, G. Bramley, S. Power, C. Brown, The social dimension of sustainable development: defining urban social sustainability, Sustain. Dev. 19 (2011) 289–300, https://doi.org/10.1002/sd.417.
[48] N. Gritths, N. May, Responsible retrofit of traditional buildings, A Rep. Exist. Res. Guid. with Recomm. by STBA. (2012) 1–133. http://www.sdfoundation.org.uk/downloads/RESPONSIBLE-RETROFIT_FINAL_20_SEPT_2012.pdf.
[49] D. Fatourehchi, E. Zarghami, Social sustainability assessment framework for managing sustainable construction in residential buildings, J. Build. Eng. 32 (2020) 101761, https://doi.org/10.1016/j.jobe.2020.101761.
[50] J. Muazu, D. Oktay, Challenges and prospects for affordable and sustainable housing: the case of yola, Nigeria, Open House Int. 36 (2011) 97–118, https://doi.org/10.1108/OHI-03-2011-B0011.
[51] C.J. Clark, R.S. Gragg, Evaluation of initial environmental engineering sustainability course at a minority serving institution, Sustainability 4 (2011) 297–302, https://doi.org/10.1089/SUS.2011.9646.
[52] B.-G. Hwang, L. Zhu, J.S.H. Tan, Green business park project management: barriers and solutions for sustainable development, J. Clean. Prod. 153 (2017) 209–219, https://doi.org/10.1016/j.jclepro.2017.03.210.
[53] D.-G.J. Opoku, J. Ayarkwa, K. Agyekum, Barriers to environmental sustainability of construction projects, Smart Sustain. Built Environ. 8 (2019) 292–306, https://doi.org/10.1108/SASBE-08-2018-0040.
[54] S.O. Ajayi, L.O. Oyedele, M. Bilal, O.O. Akinade, H.A. Alaka, H.A. Owolabi, Critical management practices influencing on-site waste minimization in construction projects, Waste Manag. 59 (2017) 330–339, https://doi.org/10.1016/j.wasman.2016.10.040.
[55] R.V. Lenth, Some practical guidelines for effective sample size determination, Am. Statistician 55 (2001) 187–193, https://doi.org/10.1198/000313001317098149.
[56] A. Field, Discovering Statistics Using IBM SPSS Statistics, SAGE Publications, 2013.
[57] E. Cho, S. Kim, Cronbach's coefficient alpha: well known but poorly understood, Organ. Res. Methods 18 (2015) 207–230, https://doi.org/10.1177/1094428114555994.
[58] S.O. Ajayi, O.O. Adegbenro, H.A. Alaka, A.S. Oyegoke, P.A. Manu, Addressing behavioural safety concerns on Qatari Mega projects, J. Build. Eng. 41 (2021), https://doi.org/10.1016/j.jobe.2021.102398.
[59] B.G. Tabachnick, L.S. Fidell, Using Multivariate Statistics, seventh ed., Pearson, California, 2019.
[60] IBM Corp, IBM SPSS Statistics for Windows, Version 24.0, (n.d.).
[61] A. Ponnam, D. Sahoo, A. Sarkar, S.N. Mohapatra, An exploratory study of factors affecting credit card brand and category selection in India, J. Financ. Serv. Market. 19 (2014) 221–233, https://doi.org/10.1057/fsm.2014.17.
[62] J.F.H. Jr, W.C. Black, B.J. Babin, R.E. Anderson, W.C. Black, R.E. Anderson, Multivariate Data Analysis, 2018, https://doi.org/10.1002/9781119409137.ch4.
[63] UNESCO, Culture and Development The Future We Want, The Role of Culture, 2017 2017.
[64] C.R. Gagg, Cement and concrete as an engineering material: an historic appraisal and case study analysis, Eng. Fail. Anal. 40 (2014) 114–140, https://doi.org/10.1016/j.engfailanal.2014.02.004.
[65] IFACCA, Culture as Goal in the Post-2015 Development Agenda, 2013. https://ifacca.org/news/2013/10/24/culture-goal-post-2015-development-agenda/.
[66] D. William Dobson, A. Sourani, B. Sertyesilisik, A. Tunstall, Sustainable construction: analysis of its costs and benefits, Am. J. Civ. Eng. Architect. 1 (2013) 32–38, https://doi.org/10.12691/ajcea-1-2-2.
[67] D.J. Lowe, Economic'Challenge'of'Sustainable' Construction, 2003.
[68] M. Emma, S. Kieran, et al., An assessment of sustainable housing affordability using a multiple criteria decision-making method, Omega 41 (2013) 270–279.
[69] Hm Government, Help to Buy: Equity Loan, 2021. https://www.ownyourhome.gov.uk/scheme/help-to-buy-equity-loan/.
[70] N. May, N. Griffiths, Planning Responsible Retrofit of Traditional Buildings, Responsible Retrofit Ser, 2015. www.stbauk.org.
[71] J. Edwards, A. Townsend, Buildings under Refurbishment and Retrofit, Ciob, vols. 1–11, 2011. http://www.carbonaction2050.com/sites/carbonaction2050.com/files/document-attachment/Buildings under Refurb and Retrofit.pdf.
[72] J. Palmer, A. Poku-Awuah, A. Adams, S. Webb, What Are the Barriers to Retrofit in Social Housing? Report for the Department for Business, Energy and Industrial Strategy), 2018, p. 31.
[73] J.A. Dauda, S.A. Rahmon, I.A. Tijani, F. Mohammad, W.O. Okegbenro, Design optimisation of reinforced concrete pile foundation using generalised reduced gradient algorithm, Front. Eng. Built Environ. 2 (3) (2022) 133–153, https://doi.org/10.1108/FEBE-12-2021-0059.