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Analyzing the Critical Impediments to Retrofitting Historic Buildings to Achieve Net Zero Emissions

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Abstract:

Aim: The aim of this study is to introduce the critical impediments to historic building retrofitting that can be specifically tailored and applied to managing historic building protection while also achieving net zero emissions and improving the sustainability of the buildings.

Background: Despite the various calls advocating for the sustainable retrofitting of historic buildings to reduce carbon emissions and enhance energy efficiency, the extent of possible alterations that can be made to historic buildings is restricted because of their historical, architectural, and cultural significance, which is one of the many critical impediments of retrofitting historic buildings. While there are existing studies that focus on identifying some of the impediments to retrofitting historic buildings, most of these studies did not systematically examine the interrelationships among these impediments. An effective retrofit of historic structures can be greatly influenced by having a proper understanding of how various impediments interrelate with one another.

Objective: The objective of this study is to identify, analyze, and prioritize the critical impediments to historic building retrofitting to improve their sustainability and attain net zero emissions.

Methods: The data for the study was gathered using a systematic review of related literature and expert-based survey, while the results were analyzed using the interpretive structural modelling (ISM) technique.

Results: Based on the study findings, the top-ranking impediments that have the greatest impact on other impediments and are crucial in projects for retrofitting historic buildings are “high costs of retrofit projects,” “poor stakeholders' engagement and coordinated efforts,” and “disparity between the buildings' energy efficiency levels & historical significance.”

Conclusion: The study reported in this paper fills an existing gap in the literature, which also offers useful insights into a crucial area of managing historic building conservation and enhancing energy performance. The major managerial implication of this research is the need for strategic planning and decision-making. Policymakers and heritage conservation practitioners should carefully consider the study findings to create a comprehensive strategy that successfully addresses the critical impediments that have been identified. Thus, future research can investigate how historical authenticity and values can be preserved while enhancing energy efficiency and cutting emissions through the integration of sustainable retrofitting approaches with preservation initiatives.

Keywords: Energy efficiency, Historic buildings, Impediments, Net zero emissions, Retrofit, Sustainability.

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1. INTRODUCTION

A net zero building is one that generates an equivalent amount of energy to what it consumes throughout a year or compensates for any emissions by buying carbon offsets or renewable energy certificates [1]. This can be achieved by using renewable sources such as geothermal heat pumps, solar panels and wind turbines and, most importantly, through bettering the energy efficiency of the building's envelope and systems [2]. There are several benefits to buildings with net zero characteristics, including lower operating costs, increased occupant comfort and well-being, and improved building value and resilience [3]. In general, historic buildings are often viewed as inconsistent with achieving net zero goals due to their age, design and cultural importance [4]. Nonetheless, retrofitting historic buildings can have various advantages, such as preserving the embodied energy and materials of the existing system and enabling innovation and creativity to thrive in these spaces while conserving a community's architecture and culture [5]. Moreover, historic buildings could often realize significant energy savings *via* cost-effective and minimally-disruptive measures, for example; insulation, air sealing, lighting upgrades, and heating, ventilation, and air conditioning (HVAC) improvements [6].

Historic buildings are essential when it comes to achieving net zero. It is common knowledge that enhancing energy efficiency and preserving the historical, architectural as well as cultural significance of such buildings are mutually beneficial objectives [7]. Retrofitting historic buildings properly represents a key element towards attaining net zero. In fact, increasing the energy efficiency of historical buildings is necessary for their long-term preservation, enhancing their value as desirable places to live while retaining them as valuable cultural assets. Historic buildings face unique difficulties while balancing between safeguarding cultural heritage and meeting future sustainability needs [8].

As the global community progresses towards achieving net zero emissions, these cherished landmarks encounter a delicate equilibrium between environmental responsibility and the safeguarding of their historical authenticity [6]. Historic buildings were not originally constructed with the considerations of modern technologies and practices, which makes the task of reducing their carbon footprint a complex endeavor. Thus, the way towards a net zero future necessitates reducing carbon footprint within the built environment [1]. In many buildings, the major source of carbon emissions occurs during energy consumption in the form of heating, cooling and lighting. Greenhouse gas emissions released from buildings must be significantly reduced to make it possible to achieve net zero. This can be achieved through retrofitting historic buildings with energy efficient technologies. Such works may include techniques such as better insulation methods, changing windows, enhancing HVAC systems and using renewable sources of power [9]. Through retrofitting, historic buildings can become functional spaces that are compatible with today's requirements by retrofitting them. This in turn gives a chance for economic revitalization, creating opportunities for businesses, tourism and community development, hence local empowerment and the perpetuation of indigenous economic cultures [5].

Recognizing the impediments associated with retrofitting historic buildings is crucial. Bringing both cutting-edge and established technologies to address these impediments can support large-scale retrofitting of historic buildings. Consequently, the results of this study can be utilized by construction experts and policymakers to enhance retrofit approaches in the conservation of historic buildings. Thus, this paper aims to comprehensively determine, analyze, and prioritize the impediments associated with retrofitting historic buildings. By broadening the body of knowledge, the study adds uniqueness to the field of historical building retrofit. Previous research has concentrated on distinct aspects of the topic. While the existing literature generally paid more attention to different aspects of cultural heritage conservation, the findings of this paper broaden the body of knowledge by adding uniqueness to the field of historical building retrofit to help achieve net zero emissions.

2. BACKGROUND - LITERATURE REVIEW

Historic buildings, possibly due to their unique influence on people around the world, are assets worthy of protection because of their historical, cultural, social, architectural, and economic significance [10]. In contrast to new construction, they are often considered more sustainable, adding an aesthetic value as expressed by the notion of timelessness and appreciation of value. When they are compared to new buildings with the same functionality levels, their energy performance is often poorer, and their structural elements tend to be categorically different [1]. These buildings have been designed according to construction principles and materials different from those employed today, where the environmental concerns and potential end-of-life impact were non-existent. This particular nature distinguishes the retrofitting of historical buildings from that of their modern counterparts [5].

Sustainable retrofitting of historic buildings refers to the modification of existing historic buildings to improve energy efficiency, reduce carbon emissions, and increasingly use materials from renewable sources in repair or replacement [11]. The sustainability balance can be significantly affected by the choice of materials and construction methods to upgrade the performance of the historic building [12]. In essence, retrofitting historic buildings eliminates the necessity for new developments and planning, as well as reduces street disruptions and construction waste. The waste and energy consumption associated with demolition and reconstruction can be substantial, whereas retrofitting historic buildings allows for a significant portion of the investments to be retained [13]. It makes sense to repurpose historic buildings irrespective of their historical status. Moreover, sustainable retrofitting of historic buildings is essential to restore them to their original state while meeting the needs of modern times in order to reduce the impact on global warming.

As pointed out [14], retrofitting projects for historical buildings possess a matrix of interconnected impediments that must be managed to be successful, ensuring the preservation of the integrity of historical buildings while offering additional housing opportunities. For instance, the financial feasibility of retrofitting projects is critical for the preservation of historic buildings. This is because the income resulting from the retrofitting project is unable to cover the costs and expenses of the investment. Without financial support from public and private organizations, there will be little chance for the retrofitting and rehabilitation of historic buildings [15]. The high initial cost of the retrofitting works is often perceived as a generic characteristic of investment in historic buildings and the preservation of these buildings is assumed to be a loss of profit [16].

Retrofitting historic buildings to improve their sustainability is often physically challenging on technical terms [17]. Historic buildings are usually considered an obstacle to the installation of new, state-of-the-art services such as heating, mechanical ventilation and air conditioning, elevators, among others, due to their historical features and architectural elements. Despite advancements in technology and specific systems for historic buildings, conservation experts still face difficult decisions, such as whether to install services externally or hide ductwork within the building, both of which can impact the building's historic character [11]. Although historic buildings are often perceived as consuming excessive energy and resources, the very features that contribute to a building's historical importance may also result in a higher level of energy efficiency compared to modern construction [8]. Prior to the availability of modern technologies and sustainable materials, historical buildings used for residency were designed with internal circulation patterns to allow for cross-ventilation and passive cooling methods [7]. The original materials used in these homes provide thermal mass that enhances energy performance. Additionally, the architectural design includes shades and overhangs that reduce energy consumption by shielding against high summer sun angles. Furthermore, historic buildings were constructed before the introduction of indoor plumbing, which has resulted in modern homes requiring water-wasting landscaping techniques [18].

Despite the various calls advocating for the sustainable retrofitting of historic buildings to reduce carbon emissions and enhance energy efficiency, the extent of possible alterations that can be made to these structures is restricted because of their historical, architectural, and cultural significance, which is one of the many critical impediments of retrofitting historic buildings [19-22]. While there are existing studies that focused on identifying some of the impediments of retrofitting historic buildings (Table **1**) [10, 12, 15, 16, 18-40], most of these studies did not systematically examine the interrelationships among these impediments. An effective retrofit of historic structures can be greatly influenced by having a proper understanding of how the various impediments interrelate with one another. As a result, the goal of this study is to identify, assess and prioritize these impediments and look into how they are related to one another. The expected findings could provide practitioners and policymakers with a solid foundation to build their knowledge of how to overcome these impediments and carry out historic building retrofitting projects effectively.

2.1. Methods for Retrieving Literature

A comprehensive desktop search was performed using the Scopus database to retrieve journal articles (peer-reviewed) that are empirically connected to this paper. For instance, conference papers, book reviews, and editorials were left out as [49] noted that these documents lack intense evaluation and are not well circulated amongst academics. Further [50], a study stated that peer-reviewed works that are the most significant, well-known, and reliable research studies are usually categorized as "verified knowledge." Thus, when compared to other reputable databases like Engineering Village, PubMed, and Web of Science, the Scopus database has been used extensively for reviewing related literature because of its vast record of published journal articles and relatively faster indexing process, which increases the likelihood of retrieving recent scientific publications related to the study [51].

The terms "heritage conservation," "cultural heritage," "historic buildings," "heritage building," "retrofit," "retrofit impediments," "historic building retrofitting," and "retrofitting heritage building" were specifically utilized during the literature search. Meanwhile, the search domain included the terms "keywords/abstract/title," while the "document type and language" was simply restricted to "articles and English language." Most importantly, the data range was set between 2010 and 2024 because of the prominence that energy efficiency in heritage buildings gained during that time among scholars and professionals in the field.

To find the most relevant articles, two sets of criteria were used. The initial criterion guarantees that the evaluation process limited the consideration of published journal papers that solely address the conservation of heritage buildings, energy efficiency in historic buildings, and the rehabilitation and refurbishing of historic structures. Also, another study [52] pointed out that the second requirement ensures that the publications must primarily rely on empirical reasons. A valid list of 28 journal articles was produced by applying these standards, and it is believed that this number is adequate to pinpoint a research deficit for this kind of study [53]. The details of the journal articles selected for the review are listed in Table **2**.

Table 1. Literature review on critical impediments to retrofitting historic buildings.

Impediments	Literature Sources
Appalling greenhouse gas emissions when executing retrofitting projects	[9, 19, 23-27]
Complexity in evaluating and characterizing the current state of the buildings	[18-21, 28]
Complication in collecting and synthesizing diverse data sources	[19, 23, 27-29]
Difficulty in securing required authorization from relevant authorities	[15, 20, 30-32,]
Disparity between the buildings' energy efficiency levels & historical significance	[20-22, 33-36]
Disruptions to building occupants and end-users during retrofit execution	[23, 31, 37, 38]
High costs of retrofit projects	[10, 15, 16, 31, 39, 40]
Intricacy of retrofit projects due to the unique attributes of historic building	[18, 23, 28, 30, 34, 41-44]
Lack of definite energy efficiency evaluation frameworks for historic buildings	[10, 12, 20, 28, 38]
Lack of access to appropriate retrofit solutions	[10, 12, 19, 45]
Permanent impact of retrofit interventions	[10, 20, 23, 31]
Poor stakeholders' engagement and coordinated efforts	[12, 21, 23, 27, 34, 46]
Unforeseen impacts of retrofit implementation	[20, 21, 31, 40, 47]
Lack of technical competence for retrofitting works	[10, 12, 19, 45, 48]
Lack of economic viability of retrofitting projects	[10, 15, 16, 31, 39, 40]

Table 2. List of journals selected for the literature review.

Journal Titles	Articles Retrieved
Buildings	3
Energies	3
Energy & Buildings	3
Energy Policy	2
Heritage	2
Historic Environment: Policy and Practice	1
International Journal of Architectural Heritage	3
International Journal of Building Pathology and Adaptation	2
Journal of Architectural Conservation	4
Journal of Cultural Heritage	2
Journal of Green Building	1
Sustainability	2
Total	**28**

3. METHODS

In this section, a brief overview of the method employed to achieve the primary goals of the study is provided. Initially, an extensive examination of relevant literature was conducted through content analysis to identify the key factors that hinder retrofitting projects for historic buildings. The study selected the efficient expert-based survey assessment approach to guarantee the thoroughness, accuracy, and validity of the identified retrofitting impediments [54] (Fig. **1**).

At first, 50 industry experts were carefully chosen across various roles using a rigorous judgmental sampling method to take part in the evaluation process. However, only 32 experts ultimately responded and took part (Fig. **2**), resulting in a 64% response rate. This response rate is considered satisfactory for a research survey of this nature [55]. The reliability and validity of the results are improved by the use of judgmental sampling, which was essential in ensuring that only experts in the field of sustainable retrofitting of historical buildings were included in the assessment. The demographic characteristics of the survey participants are displayed in Figs. (**2**, **3**) and Table **3** accordingly.

The data in Fig. (**2**) indicates that the experts were highly competent, with over 90% reporting more than ten years of experience in historic building retrofitting projects. This highlights a significant level of expertise and knowledge among the experts, which can be instrumental in addressing retrofitting impediments hindering the sustainable conservation of historic buildings.

Notably, about 60% of the participants had been involved in over ten retrofitting projects (Table **3**), demonstrating a substantial level of practical engagement and hands-on experience in heritage conservation initiatives. In general, the results essentially suggest that the respondents possess a wealth of experience and have actively contributed to numerous projects for retrofitting historical buildings. Their expertise and involvement are valuable assets in the sustainable conservation and protection of historic buildings. The extensive experience and project engagement reflect a depth of knowledge and practical application that could enhance the effectiveness and success of future conservation efforts. Ultimately, the respondents' profiles and feedback further validate the outcomes of this study.

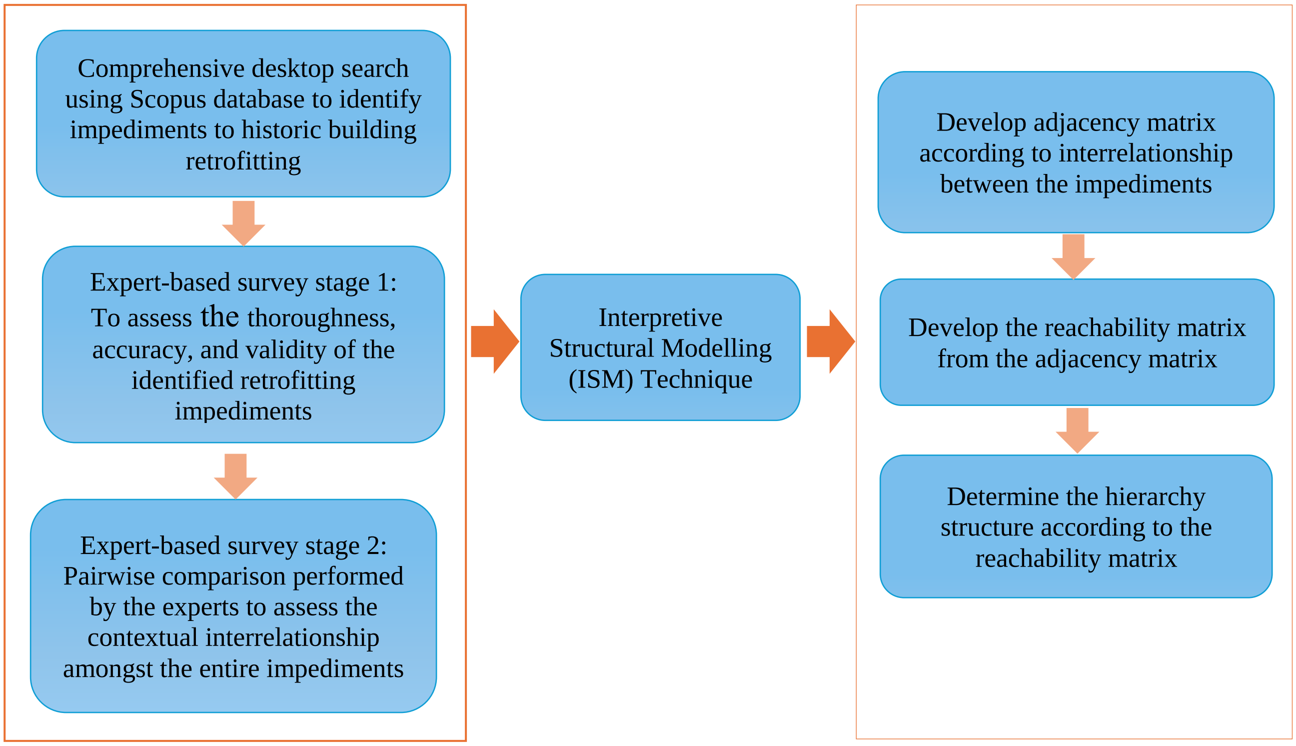

Fig. (1). Flowchart of the research methods.

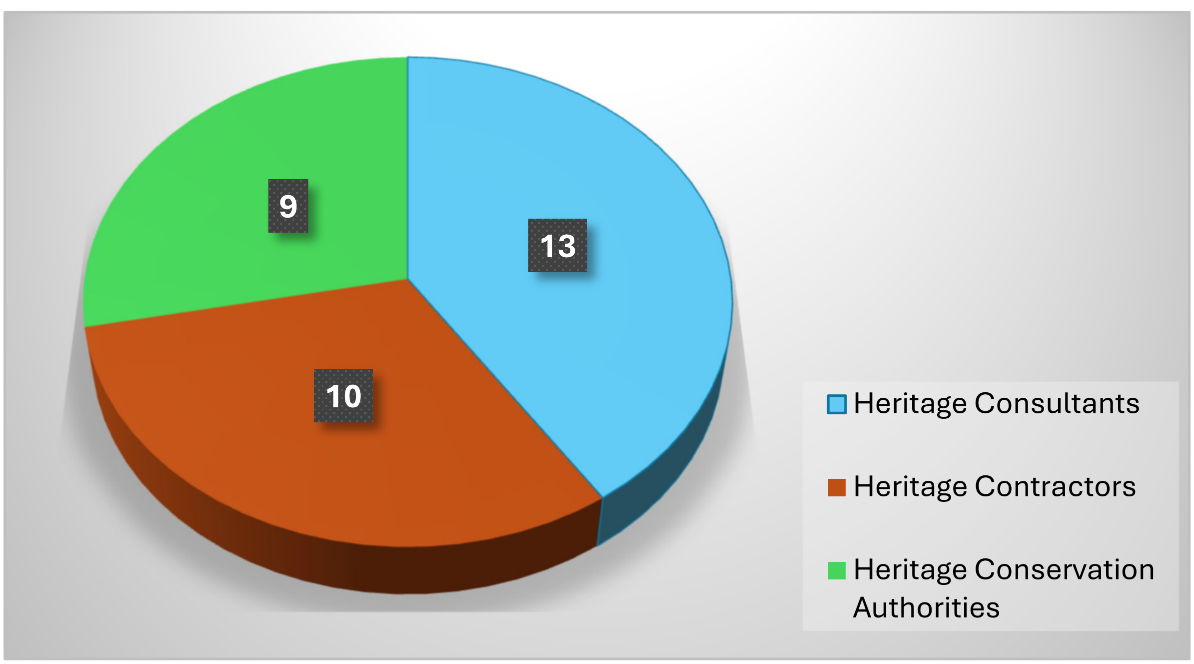

Fig. (2). Categories of respondents.

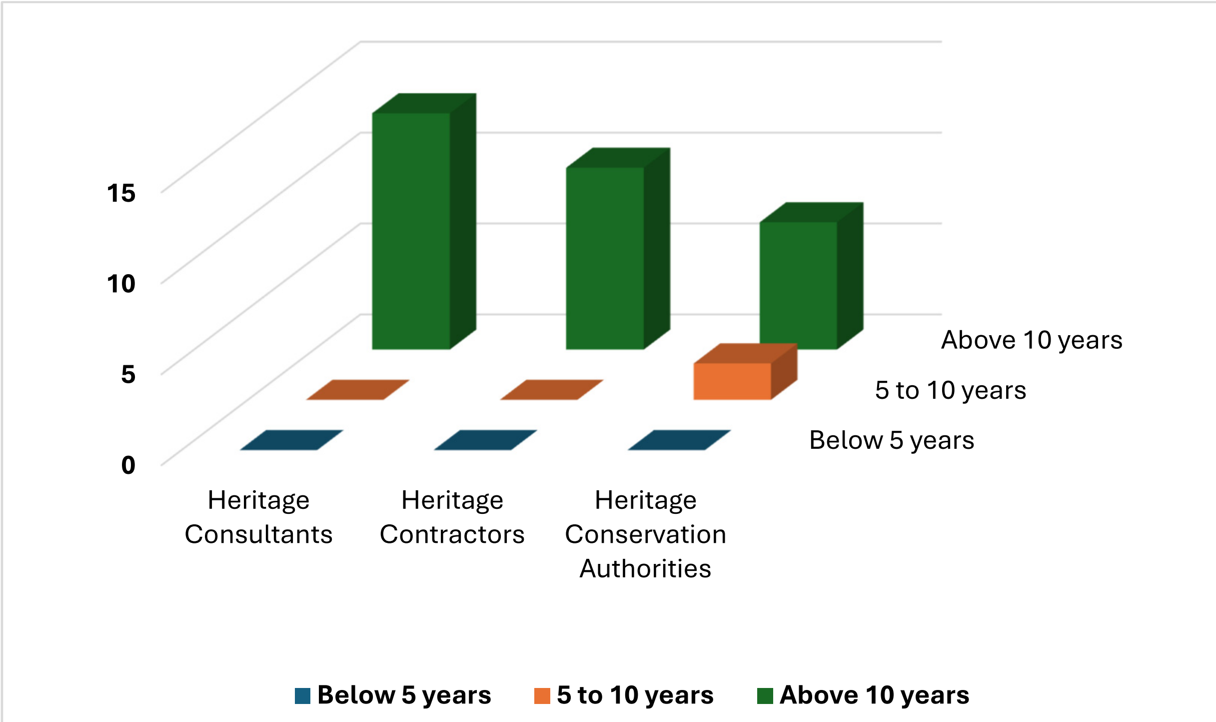

Fig. (3). Proficiency in historic building retrofitting projects.

Table 3. Respondents' participation in historic building retrofitting projects.

Categories of Experts	Heritage Consultants	Heritage Contractors	Heritage Conservation Authorities	Total
Less than 5 projects	0	0	0	**0**
5 to 10 projects	8	2	3	**13**
Over 10 projects	5	8	6	**19**

Table 4. Impediments affecting retrofitting projects for historic buildings.

Retrofitting Impediments ID	Description of the Retrofitting Impediments
I1	Appalling greenhouse gas emissions when executing retrofitting projects
I2	Complexity in evaluating and characterizing the current state of the buildings
I3	Complication in collecting and synthesizing diverse data sources
I4	Difficulty in securing required authorization from relevant authorities
I5	Disparity between the buildings' energy efficiency levels and historical significance
I6	Disruptions to building occupants and end-users during retrofit execution
I7	High costs of retrofit projects
I8	Intricacy of retrofit projects due to unique attributes of historic building
I9	Lack of definite energy efficiency evaluation frameworks for historic buildings
I10	Limited expertise and inaccessibility to appropriate retrofit strategies for historic buildings
I11	Permanent impact of retrofit interventions
I12	Poor stakeholders' engagement and coordinated efforts
I13	Unforeseen impacts of retrofit implementation

Based on the outcomes of the literature search, a compilation of 15 retrofitting impediments was made and shared with the experts for thorough evaluation and scrutiny. Subsequently, following multiple rounds of assessment, a consensus was achieved among the experts regarding the identification of 13 critical impediments affecting retrofitting projects for historic buildings. The identified impediments were then validated by the experts. Finally, the impediments were organized and coded in order as outlined in Table **4**.

3.1. The ISM Technique

ISM provides a systematic way of analyzing, representing, and showing structure and order in complex social and economic systems [56]. The objective of the ISM approach is to establish a structural framework that enables the analyst to identify the root management issues and pertinent connections among them. The representation of this structure, once established, helps management in policy decision-making and strategy formulations [57]. The ISM approach provides a viable and effective method for the analysis of structurally rich complex systems. In real-life situations, systems are so complex in nature that their direct analysis from the structural point of view becomes very cumbersome and difficult. It is really difficult to have a comprehensive insight into all the components constituting a particular system, along with complex feedback interrelationships between the elements involved [54]. In such cases, ISM offers a distinct advantage over others as it simplifies complex situations. It simplifies qualitative analysis of complex systems and strategic validity. ISM has been effectively tested and used to solve real-life complex problems.

A study [6] affirmed that several strengths of ISM were observed. These include limited generation of subjective opinions in a well-structured framework, active participation of all participants, and low time consumption. Also, ISM introduces the possibility of an improved insight into structural or configurational aspects of complex systems and helps in identifying key factors that contribute disproportionately to shaping the desired outcome of interest. Similarly, ISM presents a framework for systematically assessing the many interconnections between various factors [57]. It facilitates the identification of the main dependencies and drivers, allowing for a thorough comprehension of the system. In addition, the relationships between various factors are represented by the hierarchical structure that ISM creates. By giving the experts the ability to rank and concentrate on the most crucial factors, this structure guarantees effective decision-making. Not that alone, the subjective opinions provided based on intensive knowledge of the experts lead to higher quality decision-making [54].

In essence, prior to the application of the ISM technique, the literature review could only be used to identify the impediments. However, the use of the ISM approach enabled the authors to study and describe the complex interrelationships among the various impediments. This was made possible through the use of the multi-level hierarchical structure and rating of the impediments. This is significant because, in comparison to the different retrofitting impediments considered independently, the interrelationships between the impediments will offer better clarification on the impediments surrounding the effective retrofitting of historical buildings. In the end, this is crucial for developing rules that support the effective execution of sustainable retrofitting projects for historic structures.

4. RESULTS AND DISCUSSION

In this section, the paper explores the analysis of the impediments that hinder retrofitting projects for historic buildings. The interpretive structural modelling technique was applied to analyze the hierarchical and stratified interaction between the different impediments.

4.1. Generating the Impediments' Hierarchical Structure

Initially, the interpretative structural modelling method was used to create a hierarchy of all the impediments that have been found to hinder historic building retrofitting initiatives. Through this procedure, a useful hierarchical framework that aids in understanding the complex relationships between various impediments was created.

4.1.1. Generating the Adjacency Matrix

An adjacency matrix was created using the interpretive structural modelling technique to accurately depict the contextual relationships between the obstacles that were found. These contextual interrelationships among the obstacles were established and validated in large part through expert assessments. Using the idea of "direct influence" to suggest that one retrofit obstacle directly influences another retrofit impediment, the goal was to comprehend the interaction interrelationships between the barriers. As an illustration, let's look at how a certain impediment, say, "I9 - lack of definite energy efficiency evaluation frameworks for historic buildings" affects a second impediment, say, "I1 - appalling greenhouse gas emissions when executing retrofitting projects" and how "I1" affects the third given impediment say, "I7 - high costs of retrofit projects". In this instance, the interaction between I9 and I7 is categorized as an indirect influence, whereas the interaction between I9 and I1 is categorized as a direct influence.

It is easy to convert the qualitative understanding of the relationships between the impediments into an adjacency matrix by using the interpretive structural modelling approach's guiding principles. In this matrix, the interpretation of the correlation between any two provided impediments is assigned a value of one or zero. The conditions for defining this interpretation are herein outlined. If any given impediment say, I9 has a direct influence on another impediment say, I1, a value of 1 will be assigned in the corresponding entry (i,j) of the matrix and if there is no direct influence, a score of 0 will be assigned. On the contrary, if impediment I1 has a direct influence on I9, a value of 1 will be assigned in the corresponding entry (j,i) of the matrix and if there is no direct influence, a score of 0 will be assigned. Nonetheless, if I9 has a direct influence on I1, and at the same time, I1 has a direct influence on I9, then, a score of 1 will be assigned in both the (i,j) and (j,i) entries of the matrix.

To assess the contextual connection amongst the entire impediments, a pairwise comparison was conducted by the 32 participants. For instance, each participant gave their response to the question, "Do you believe that I9 has a direct influence on I1?" Since several specialists can have different perspectives on the relationships, the final conclusions were arrived at using the tenet that "the minority yields to the majority." As a result, as shown in Table **5**, the interrelationships between the 13 impediments were determined and documented in the adjacency matrix.

4.1.2. Generating the Reachability Matrix

The indirect relationships between the impediments were not specifically identified; instead, the adjacency matrix shown in Table **5** mainly depicts the direct relationships between the whole impediments. To determine the direct and indirect relationships between the impediments, it was necessary to generate a reachability matrix. The reachability matrix was generated by leveraging power iteration analyses and expanding on the direct correlations found in the adjacency matrix. A score of one indicates that there is either a direct or indirect relationship between the two impediments being compared, according to the reachability matrix, which is shown in Table **6**. To sum up, the reachability matrix offers a thorough understanding of the interrelationships, both direct and indirect, between the impediments.

4.1.3. Generating the Hierarchical Structure

There were level divisions for each retrofitting impediment that needed to be determined in order to create the hierarchical structure. Table **7** gives the first level partitioning for all retrofitting impediments studied. Besides the number of level partitions, the table also shows reachability, antecedent and intersection sets.

Finding the level partition between the impediments is the first step in creating the hierarchical structure. To accomplish this, one must find the impediments whose reachability and intersection sets match. For instance, I4 in Table **7** contains the same combination of intersection and reachability contents. In a similar vein, I6's reachability and intersection sets are identical. As a result, these two impediments (I4 and I6) were partitioned into Level 1 retrofitting impediments. In the following examination, the Level 1 impediments (I4 and I6) would be the first to be removed from Table **7** based on the principles of the interpretive structural modelling technique. Accordingly, the impediments that will be removed at later stages were identified using the same methodology. Thus, this procedure is performed till the last segment level is reached. The first level segment refers to the lowest ranking position in the hierarchical formation of the entire impediments, while the last level (10^{th} level) indicates the highest-ranking position. The level segmentation process for each impediment is summarized in Table **8**.

From Table **8**, it is clear that I7 (High costs of retrofit projects), I12 (Poor stakeholders' engagement and coordinated efforts), and I5 (Disparity between the buildings' energy efficiency levels & historical significance) are the retrofitting impediments with the highest-ranking positions at the 10^{th} level. It can be deduced that these impediments have the propensity to influence the other impediments and are vital in promoting efficient management of retrofitting projects for historic buildings. Therefore, these impediments should be given due consideration when developing policies and formulating strategies for overcoming impediments that hinder retrofitting projects for historic buildings. On the contrary, Table **8** shows that I4 (Difficulty in securing required authorization from relevant authorities) and I6 (Disruptions to building occupants & end-users during retrofit execution) are the retrofitting impediments with the lowest-ranking positions at the 1^{st} level. This suggests that these particular impediments, though superficial, are largely dependent on and influenced by a broader range of impediments that play a more significant role in ensuring efficiency in retrofitting projects. In other words, if the other impediments associated with retrofitting are effectively managed, these specific impediments would also be addressed. Therefore, these impediments are not deemed essential for ensuring efficiency in retrofitting projects, especially concerning historic buildings.

Table 5. The generated adjacency matrix.

-	I13	I12	I11	I10	I9	I8	I7	I6	I5	I4	I3	I2	I1
I1	1	0	1	0	0	1	1	0	1	0	1	1	1
I2	1	0	1	0	0	1	1	1	0	0	0	1	0
I3	0	0	0	0	0	1	1	0	0	1	1	1	0
I4	0	0	1	0	0	0	0	0	0	1	0	0	0
I5	1	0	1	0	1	1	1	0	1	1	1	1	0
I6	0	0	0	0	0	0	0	1	0	0	0	0	1
I7	1	1	1	1	1	1	1	1	1	1	1	1	1
I8	1	0	1	0	1	1	1	0	1	1	1	1	0
I9	1	0	1	0	1	0	0	0	0	1	0	1	0
I10	1	0	1	1	1	0	0	1	1	0	0	1	1
I11	1	0	1	0	0	0	1	0	0	1	0	1	0
I12	1	1	1	1	1	1	1	1	0	1	1	1	0
I13	1	0	1	0	0	0	0	0	0	1	0	1	0

Table 6. The generated reachability matrix.

-	I13	I12	I11	I10	I9	I8	I7	I6	I5	I4	I3	I2	I1	Drv*
I1	1	0	1	0	0	1	1	0	1	0	1	1	1	**8**
I2	1	0	1	0	0	1	1	1	0	0	0	1	0	**6**
I3	0	0	0	0	0	1	1	0	0	1	1	1	0	**5**
I4	0	0	1	0	0	0	0	0	0	1	0	0	0	**2**
I5	1	0	1	0	1	1	1	0	1	1	1	1	0	**9**
I6	0	0	0	0	0	0	0	1	0	0	0	0	1	**2**
I7	1	1	1	1	1	1	1	1	1	1	1	1	1	**13**
I8	1	0	1	0	1	1	1	0	1	1	1	1	0	**9**
I9	1	0	1	0	1	0	0	0	0	1	0	1	0	**5**
I10	1	0	1	1	1	0	0	1	1	0	0	1	1	**8**
I11	1	0	1	0	0	0	1	0	0	1	0	1	0	**5**
I12	1	1	1	1	1	1	1	1	0	1	1	1	0	**11**
I13	1	0	1	0	0	0	0	0	0	1	0	1	0	**4**
Dep*	**10**	**2**	**11**	**3**	**6**	**7**	**8**	**5**	**5**	**9**	**6**	**11**	**4**	-

Note: *Drv Pwr – Driving Power; *Dep Pwr – Dependence Power.

Table 7. Level 1 partition of the reachability matrix.

Impediments	Reachability Set*	Antecedent Set*	Intersection Set*	Partition Level*
I1	13,11,8,7,5,3,2,1	10,7,6,1	7,1	-
I2	13,11,8,7,6,2	13,12,11,10,9,8,7,5,3,2,1	13,11,8,7,2	-
I3	8,7,4,3,2	12,8,7,5,3,1	8,7,3	-
I4	11,4	13,12,11,9,8,7,5,4,3	11,4	**Level 1**
I5	13,11,9,8,7,5,4,3,2	10,8,7,5,1	8,7,5	-
I6	6,1	12,10,7,6,2	6,1	**Level 1**
I7	13,12,11,10,9,8,7,6,5,4,3,2,1	12,11,8,7,5,3,2,1	12,11,8,7,5,3,2,1	-
I8	13,11,9,8,7,5,4,3,2	12,8,7,5,3,2,1	8,7,5,3,2	-
I9	13,11,9,4,2	12,10,9,8,7,5	9	-
I10	13,11,10,9,6,5,2,1	12,10,7	10	-
I11	13,11,7,4,2	13,12,11,10,9,8,7,5,4,3,2,1	13,11,7,4,2	-
I12	13,12,11,10,9,8,7,6,4,3,2	12,7	12,7	-
I13	13,11,4,2	13,12,11,10,9,8,7,5,2,1	13,11,2	-

Note: *Reachability Set – impediments traced row-wise.
*Antecedent Set – impediments traced column-wise.
*Intersection Set – impediments common to reachability set and antecedent set.
*Partition Level – ranking position in the hierarchical formation of the entire impediments.

Table 8. An overview of the level segmentation process that addresses every impediment.

-	Reachability	Antecedent	Intersection	Partition Level
I4	11,4	13,12,11,9,8,7,5,4,3	11,4	**Level 1***
I6	6,1	12,10,7,6,2	6,1	**Level 1***
I13	13,11,2	13,12,11,10,9,8,7,5,2,1	13,11,2	**Level 2**
I11	11,7,2,	12,11,10,9,8,7,5,3,2,1	11,7,2	**Level 3**
I2	8,7,2	12,10,9,8,7,5,3,2,1	8,7,2	**Level 4**
I9	9	12,10,9,8,7,5	9	**Level 5**
I3	8,7,3	12,8,7,5,3,1	8,7,3	**Level 6**
I1	7,1	10,7,1	7,1	**Level 7**
I8	8,7,5	12,8,7,5	8,7,5	**Level 8**
I10	10	12,10,7	10	**Level 9**
I5	7,5	7,5	7,5	**Level 10***
I12	12,7	12,7	12,7	**Level 10***
I7	12,7	12,7	12,7	**Level 10***

Note: *Level 10 – highest ranking impediment.
*Level 1 – lowest ranking impediment.

4.2. Discussion

Very few studies have been published that specifically examine the interdependencies and linkages between the different critical impediments to retrofitting historic buildings to reach net zero emissions using the ISM modelling technique. Therefore, rather than directly challenging current knowledge, the goal of this paper is to introduce the critical impediments to historic building retrofitting that can be specifically tailored and applied to managing historic building protection while also achieving net zero emissions. As the results indicate, “high costs of retrofit projects (I7),” “poor stakeholders' engagement and coordinated efforts (I12),” and “disparity between the buildings' energy efficiency levels & historical significance (I5)” are the top-three critical impediments. In essence, these impediments are crucial to enhancing the retrofitting of historic buildings to increase their sustainability and lower carbon emissions since they have the greatest influence on other impediments. Thus, this study's findings are consistent with earlier research that emphasized the limitations and impediments faced by construction specialists working in the heritage sector in determining the barriers and constraints related to historic building retrofitting in order to achieve net zero emissions and increase the sustainability of the historic structures.

Historical building retrofitting can be expensive and may not be a desirable financial decision. In order to guarantee the building's long-term sustainability, the cost-effectiveness and economic viability of retrofit solutions must be carefully considered. The cost of retrofitting ancient buildings might rise significantly due to additional regulations and complexity. This may make it less viable economically. Nonetheless, the building's historical significance can enable its proponents to generate extra revenue from tourists. An additional advantageous financial incentive may come from the higher valuations resulting from the architectural, cultural and historical significance of the buildings. As it is witnessed today, many historic structures are currently being transformed into tourist attractions due to their heritage values [58]. While most retrofits for heritage properties can be costly, certain case studies have demonstrated less expensive yet nonetheless successful solutions [16]. According to a different study, price may act as both a deterrent and an incentive. It can be advantageous when consumers believe that energy efficiency offers high advantages at little cost. In general, energy retrofit might or might not result in energy savings as there are significant variations in how different buildings operate from one another [18, 59]. Also, the cost-effectiveness of a retrofit is impacted by the variations in electricity costs. For instance, the installation of solar PV systems will trigger considerable reduction in electricity usage, some local regulations may stipulate that solar panels cannot be seen from the front of the buildings [58]. Thus, in this scenario, it might not be feasible to put solar PV panels in every building to avoid violating local regulations.

The efficient engagement and coordinated efforts of relevant stakeholders in retrofitting historic buildings are considered as one of the best practices for improving the sustainability of the buildings. As pointed out [19], the major stakeholders involved should be dedicated to overcoming the retrofitting impediments in order to remodel historic buildings for energy efficiency while maintaining their heritage values. Nonetheless, one of the crucial problems being faced in retrofitting issues is that the major stakeholders involved are not willing to be committed and collaborate effectively in the intervention. Ideally, all parties involved in retrofitting ancient buildings, including building owners, authorities, architects, and contractors must be dedicated to the project and work together. Various authors [9, 14, 15, 60, 61] have suggested the use of stakeholder engagement models like the one-stop shop retrofit model and building information modelling when it comes to stakeholder collaboration. As [18, 45, 48] pointed out, the distinctive qualities of historical structures make retrofitting works quite difficult, complex, challenging, costly, and time-consuming.

There is always a disparity between the buildings' energy efficiency levels & historical significance when retrofitting historical structures because it is essential to strike a delicate balance between increasing energy efficiency and maintaining the building's historical and cultural significance. A combination of compatible and reversible retrofit techniques can be used to accomplish this. When one of these two goals is accomplished, the other must be sacrificed because they are usually incompatible. Nonetheless, creative solutions may exist that allow for the simultaneous achievement of both goals. For instance, producing energy on-site with a biogas unit would be a better idea than using conventional solar panels that will ruin the historic appearance of a roof. Therefore, when retrofitting ancient buildings, the use of unique materials and inventive ideas can contribute to retaining historical value and achieving energy efficiency. For historical building retrofits, for example, the building information modelling can be combined with an integrated project delivery techniques [33]. While the building information modelling facilitates the information management component, the integrated project delivery technique guarantees cooperation amongst the project's stakeholders.

Limited expertise and inaccessibility to appropriate retrofit strategies for historic buildings are other crucial impediments to retrofitting historic buildings to improve their sustainability and achieve net zero emissions. It is not impossible that appropriate retrofit solutions for historical structures are unavailable or poorly understood. It is apparent that technology is required to overcome the limited expertise and inaccessibility of appropriate retrofit solutions strategies for historic buildings [29, 33]. For instance, the majority of contractors working on projects for retrofitting historic buildings are small and medium-sized businesses. To finish the projects, they constantly struggle with scarce technical and human resources [60]. Ironically, the construction sector has the necessary technology, but the skills needed and the cost are obstacles to utilizing it to its full potential [15]. For instance, aerogel has been found to be a superior insulating material for historical structures since it will not adversely affect the fabric of the building [62]. Moreover, it has been demonstrated that Aerogel windows maintain building aesthetics while providing the maximum level of insulation [2]. Conversely, these technologies come at a hefty price. The skills necessary to operate with these technologies are few. It is challenging to get competent individuals with the necessary knowledge and skills to deal with the distinctive architectural elements of historical structures, given the industry sources of information.

On the other hand, the intricacy of retrofit projects due to the unique attributes of historic buildings continues to pose serious impediments to retrofitting historic buildings to improve their sustainability and achieve net zero emissions. Considering the distinctive qualities of historic buildings and the need to strike a balance between improving energy efficiency and conserving heritage values, retrofitting historical buildings may be extremely complicated. Some of the building features that are difficult to address make retrofitting more difficult. Moreover, each historic building is unique from the others. Although the adoption of the life cycle approach and use of technology, such as BIM, will aid in managing the intricacies of historical building retrofits, using specialist knowledge can be a beneficial focus [29]. It is well known that no specific standard was followed in the design and construction of the majority of the historic buildings. Thus, this makes it quite challenging to implement retrofit measures as the retrofit strategy for a particular building will be different from others [18].

While general retrofit procedures may be comparable, there are notable variances amongst historic buildings. In this scenario, the experts will need to create customized retrofit plans for each building independently. As pointed out [20], incentives are crucial for preserving historical values. People tend to hurry to improve energy efficiency without considering the heritage values because of the complicated nature of the methods and the possibility of greater expenditures as a result of this complexity. In this case, providing financial incentives will spur people to action rather than stipulating regulations [14]. It's crucial to remember that managing the impediments to retrofitting historic buildings requires effective planning, communication, and standardization [34]. Therefore, the retrofitting of historic buildings can be improved by adopting cutting-edge technologies and following more conventional procedures.

CONCLUSION

This study examined the main barriers to retrofitting historic buildings to increase their sustainability and attain net zero emissions, providing an early investigation into a potentially important field of study. The top-ranking impediments that have the greatest impact on other impediments and are crucial for projects involving the retrofitting historic buildings in order to improve their sustainability and achieve net zero emissions are "high costs of retrofit projects (I7)," "poor stakeholders' engagement and coordinated efforts (I12)," and "disparity between the buildings' energy efficiency levels & historical significance (I5)." An existing gap in the literature is filled by the study reported in this paper, which also offers useful insights into a crucial area of managing historic building conservation and enhancing energy performance. The study also provides a thorough examination of the impediments to historic building renovations that are sustainable. By identifying these impediments, the study further contributes to our understanding of the complexities involved in overseeing historic building retrofitting projects. Notwithstanding its contributions, the research may possess significant constraints. It is crucial to keep in mind that this study was limited to Saudi Arabia while analyzing its results. Therefore, care should be taken when extrapolating the findings to other nations where projects for retrofitting historic structures may have similar conditions. Furthermore, the study's representativeness may be constrained by the sample size or the selection process. Therefore, identifying and resolving these issues would improve the validity and reliability of the study even more.

The major managerial implication of this research is the need for strategic planning and decision-making. The study findings should be carefully considered by policymakers and heritage conservation practitioners in order to create a comprehensive strategy that successfully addresses the critical impediments that have been identified. To do this, well-informed decisions must be made on the distribution of resources, involvement of stakeholders, risk management, use of technology, sustainability objectives, training and development, performance evaluation, and long-term planning. Conservation project managers can successfully overcome the impediments associated with retrofitting historic buildings and achieve sustainability improvements and net zero emissions targets by strategically planning and making well-informed decisions based on the research findings. This strategic approach, which is in line with broader organizational goals and objectives, will ensure the sustainability and success of retrofitting projects for historic buildings.

Building on the results of the current study, future research can explore certain areas to further develop knowledge and practice in this area. Initially, it is important to investigate how heritage conservation and sustainability intersect particularly when retrofitting historic buildings. Additionally, there is a need to investigate how historical authenticity and values can be preserved while enhancing energy efficiency and cutting emissions through the integration of sustainable retrofitting approaches with preservation initiatives. Meanwhile, comprehensive case studies of successful retrofitting projects on historic buildings that have achieved sustainability goals and net zero emissions are required. On the other hand, it is pertinent to examine the strategies, technologies, and techniques employed to overcome the impediments and determine the best practices for upcoming retrofitting projects.

AUTHORS' CONTRIBUTION

M.S.: Writing - Original Draft Preparation; A.S.: Data Analysis or Interpretation.

LIST OF ABBREVIATIONS

ISM	=	Interpretive Structural Modelling
HVAC	=	Heating, Ventilation, and Air Conditioning

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIAL

All data generated or analyzed during this study are included in this published article.

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CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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