RETROFITTING OF BUILDINGS TO IMPROVE ENERGY EFFICIENCY: A COMPREHENSIVE SYSTEMATIC LITERATURE REVIEW AND FUTURE RESEARCH DIRECTIONS

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ABSTRACT: *A large body of research has been developed with the aim of assisting policymakers in setting ambitious and achievable environmental targets for the retrofit of current and future building types for energy-efficiency and in creating effective retrofit strategies to meet these targets. The aim of this research is to conduct a comprehensive study to identify the relationship between building type and sustainability, with a particular emphasis on retrofitting and try to identify research gaps in the most effective energy-saving strategies for retrofitting various types of buildings. In this regard, this study conducts a systematic literature review (SLR) utilizes artificial intelligence (AI) and natural language processing (NLP). Sixty relevant papers are selected and reviewed, establishing a comprehensive searching scheme. The research highlights retrofitting strategies for improving energy efficiency in buildings and discuss the limitations of current practises in terms of physical and technical developments, such as utilising new energy systems and innovative retrofitting materials. To overcome these, future studies could focus on in-depth building classification, developing tailored retrofitting alternatives, and establishing an adaptive solution framework. This framework aligns cohesively with diverse typologies, adapting to changing contexts and enhancing long-term performance.*

KEYWORDS: *retrofitting, typology of building, building energy performance, residential buildings.*

1. INTRODUCTION

Buildings account for 40% of the overall energy consumption in the European Union (Ballarini et al., 2017). Improving building energy efficiency is currently considering a top priority by the UK government as a major initiative for accelerating the decarbonization agenda for the building industry by 2050. European policy aims to achieve a 27% increase in energy efficiency by 2030, primarily by improving the energy efficiency of newly constructed buildings. However, the number of new buildings is small compared to the total stock of buildings in Europe, accounting for only 1%. Therefore, the most crucial aspect of energy-saving in Europe is retrofitting of existing residential buildings (Pungercar et al., 2021). Nevertheless, according to (Ortiz et al., 2020), the UK government's main barrier in this regard, tends to be reducing carbon emissions from existing residences. To improve the long-term energy performance of the building stocks and reduce carbon emissions, governments should develop a strategy to invest in building energy refurbishment(Ballarini et al., 2017). A large body of research has been developed to assist policymakers in setting ambitious and achievable environmental targets for converting a certain building type to energy-efficient structures and creating effective strategies to meet these targets (Re Cecconi et al., 2022). However, building regulations are frequently changed, depending on each country's vision, potential, capacity to implement such changes, and the complexity of architectural details and conditions within its building stock (Alabid et al., 2022).

Several variables play a pivotal role in shaping energy consumption within a building, including the building envelope's structure, age distribution among existing building stocks, prevailing climate conditions, building area and type, the building's age, and the efficiency of its system installations (Beagon et al., 2020). In order to promote local or national energy-saving strategies, typical residential building typologies are commonly used to model the energy efficiency of building portfolios (Loga et al., 2016).

Indeed, one crucial aspect that contributes to the complexity of retrofitting residential buildings lies in the fact that each building's characteristics can significantly vary based on the environmental conditions of its location. While previous research, as highlighted by (Kadrić, Aganovic, Martinović, et al., 2022), has delved into the challenges and opportunities of retrofitting different building types, there remains a notable gap in the literature concerning the explicit consideration of environmental factors during the retrofitting process. This research aims to address knowledge gaps by utilizing a novel searching framework that employs an AI algorithm. It seeks to analyse the existing literature concerning the correlation between building types and energy-efficient retrofitting, including the influence of environmental factors on energy-saving strategies according to building's typology. The goal is to identify crucial areas for future research and enhance the understanding of the relationship between building

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typology, energy efficiency, and retrofitting.

2. RESEACH METHODOLOGY

Highlighting the most recent developments in many areas of research is essential to ensuring progress and innovation in those areas. However, with an overwhelming number of publications, it becomes challenging to thoroughly read and analyze each one. Ignoring them entirely is not a viable option either, as valuable insights might be missed. Therefore, there is a pressing need to develop a new search scheme that effectively filters publications, ensuring a comprehensive review without overlooking significant contributions. The methodology employed in this research involves a multi-step approach to ensure a comprehensive and robust review of relevant studies (Figure 1).

The research begins by conducting a SLR proceess and develop an algorithmic gap spotting framework, which serves as a fundamental aspect of the process. This framework encompasses the formulation of effective search strategies and the establishment of stringent study selection criteria. By implementing this approach, the research aims to identify and address gaps in existing literature, enhancing the overall quality of the review. Following the development of the framework, the quality of the studies included in the review is thoroughly evaluated. This evaluation focuses on determining the probability of bias and assessing the reliability of the supporting data. By conducting this assessment, the research ensures that only high-quality studies are considered in the analysis, enhancing the credibility and validity of the findings. Based on the results obtained from the algorithmic gap spotting framework and study evaluation, this research aims to identify gaps in the existing literature and design future study. These gaps indicate areas where further investigation is needed to address unanswered questions or explore novel perspectives. By identifying these research gaps, the study aims to contribute to the advancement of knowledge in the field.

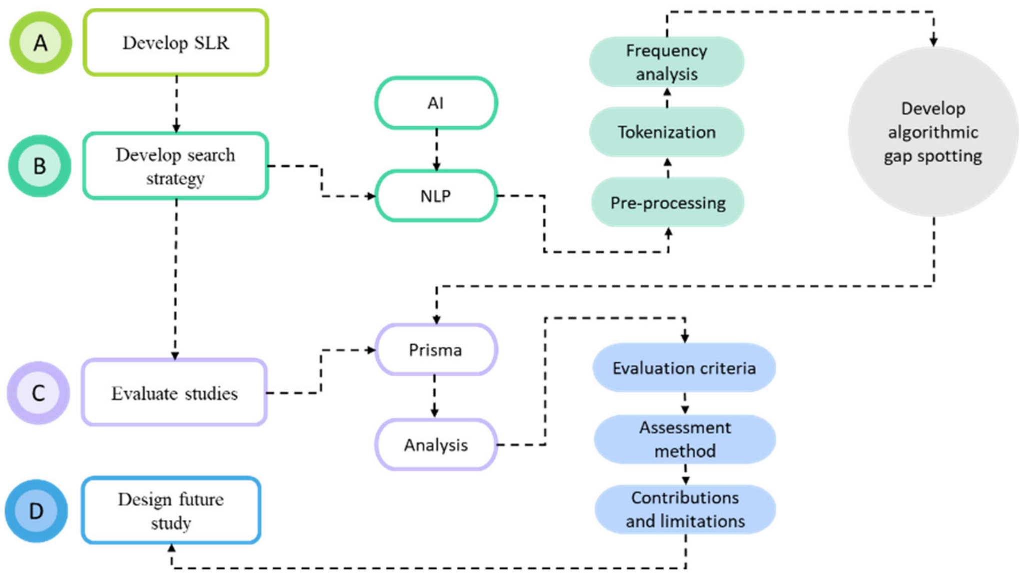

Fig. 1: Research methodology

2.1 Systematic literature review

To fully address a research topic, this study used (SLR) technique. The methodology employed in this publication for conducting (SLR) involves two main steps for defining keywords. Firstly, database selection was performed, and subsequently, a search strategy was developed. This process resulted in the identification of 402 relevant publications that were then selected for evaluation and analysis. The systematic literature review (SLR) process identified 60 relevant papers using PRISMA methodology (Figure 2). This approach provided valuable insights into energy efficiency, particularly building typology's role, crucial for decision-makers and designers.

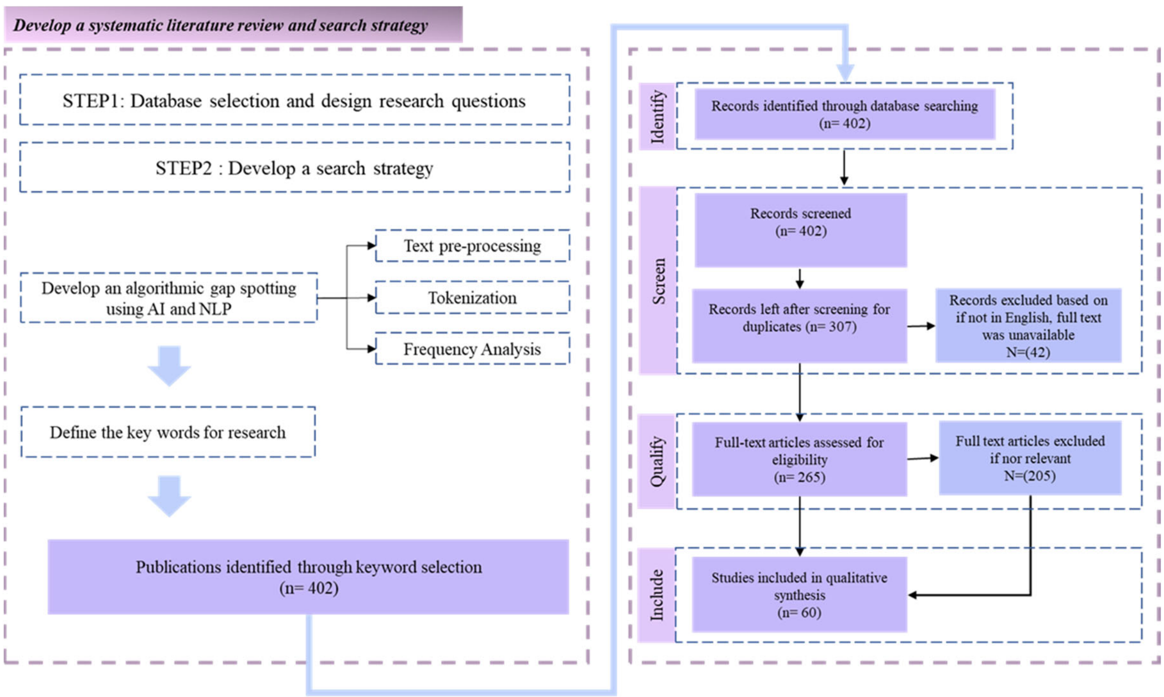

Fig. 2: Search strategy framework

2.2 Algorithmic gap spotting

The research questions addressed in this section are:

RQ1. How much publications have there been about relationship between building type and energy efficiency through retrofitting since 2011?

RQ2. What are the limitations of current research in this area?

In order to answer the research questions, this study reviewed literature related to construction building technology, civil engineering, green sustainable science technology and environmental science fields to catch the most relevant articles. This study introduces a novel approach to addressing the challenge of search strategy for identifying research gaps in existing literature. By leveraging AI algorithms, NLP techniques, and data analysis, a strategy called algorithmic gap spotting (algorithmic gap roadmap) is employed. This method offers an automated and systematic way to identify areas of research or knowledge where there are gaps, enabling researchers to guide future studies, recognize biases and limitations, and foster innovation in various fields (Figure 3).

Algorithmic gap spotting involves the utilization of computational tools to analyse and interpret large volumes of published research papers, articles, and other relevant documents. By applying AI algorithms and NLP techniques, patterns and trends within the data can be identified, such as keyword frequency, co-occurrence of terms, and the distribution of topics across different domains.

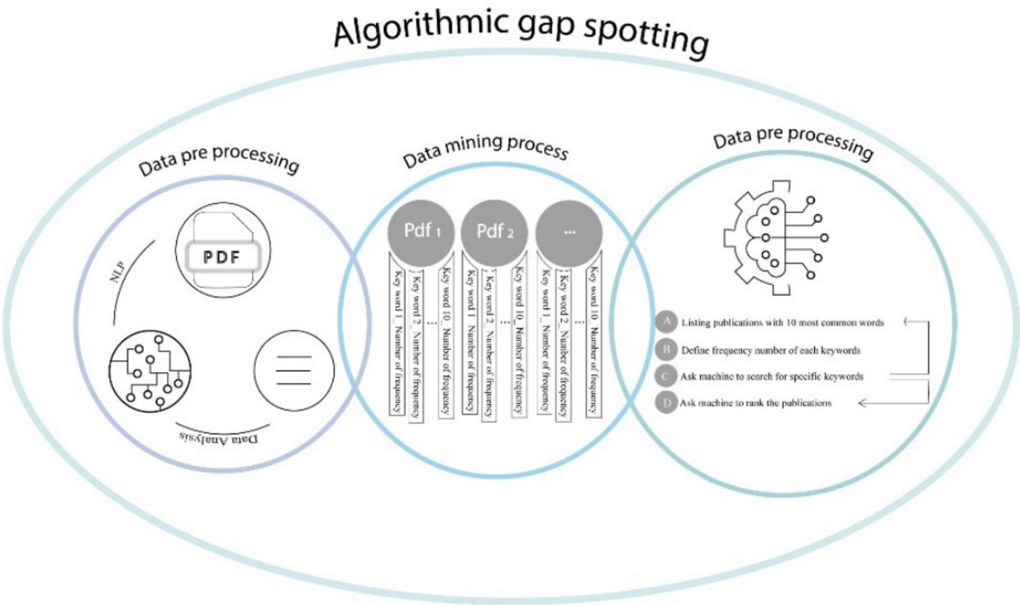

Fig.3: Algorithmic gap spotting design process

3. RESEARCH FINDINGS AND REVIEW RESULTS

As mentioned before, building retrofitting is an effective approach to reducing energy consumption and carbon emissions. However, it is a complex process that requires consideration of various factors. Despite its potential benefits, there is still a lack of information on factors that impact retrofitting solutions. This research aims to address these gaps by conducting a comprehensive literature survey. Reviewed publications in the previous section identified two main areas that remain a gap in the literature, which are building retrofit assessment according to the typology of building and building retrofit assessment according to environmental factors. This paper discusses the importance of addressing these gaps and presents recommendations for future research in these areas.

3.1 Building retrofit assessment according to the typology of building

Building typologies play an essential role in achieving energy performance requirements of buildings. By considering building typologies, a comprehensive understanding of a building stock's energy efficiency can be gained, making it an indispensable tool in ensuring sustainable and energy-efficient buildings (Y. Li et al., 2019).

Numerous pieces of evidence have been identified through the analysis of architectural typologies related to energy in the European Union, at both national and regional levels. Typological data and criteria are being used to develop informational materials and provide energy advice for buildings (Dascalaki et al., 2011a). Moreover, typical residential building typologies are also being employed as tools for modelling the energy efficiency of building portfolios to promote local or national energy-saving strategies (Ballarini et al., 2011a). The main purpose of building typology is to determine the best energy-efficiency techniques to implement in existing structures and quantify the potential energy savings and CO_2 emission reductions associated with the implementation of energy refurbishment measures in the building stock at various scales (Fernandez-Luzuriaga et al., 2021).

According to (Sugár et al., 2020), building typology also plays a crucial role in determining a building's energy consumption. For instance, the heating energy demand of a building depends on its architectural style, and typology can be used to calculate a building's heating energy requirement. The main objective of this research is to present a study through literature related to the connection between sustainable retrofitting and building typology. The process systematic search method for retrofit decision-making intends to provide thought-provoking insights into the shortcomings and outlines the most important directions for future research.

3.2 Building retrofit assessment according to Environmental factors

The influence of the surrounding environment on building heating energy consumption has been recognized as a critical factor in addition to the physical condition of a building. While the latter factors have been extensively studied, (Song et al., 2020) highlights the importance of urban morphology and climatic conditions in determining the overall heating demand in buildings. There are various global environmental assessment schemes that evaluate the impact of projects on different factors related to sustainability (Del Rosario et al., 2021). This section tries to investigate and comprehend the environmental aspects that influence the energy efficiency of buildings. It highlights a requisite for additional research to advance more precise and comprehensive assessment frameworks that encompass the environmental sustainability of retrofitting strategies.

3.2.1 Building retrofit assessment according to the climate conditions

The classification of buildings varies depending on the climate condition of the region and retrofitting strategies must be tailored to specific climate conditions and building types to ensure their effectiveness (Boardman, 2007). The primary aim of building typology is to create structures that are responsive to their environment while maximizing the use of resources available (Kirkegaard & Foged, 2011) (Tompkins & Adger, 2003). Retrofitting strategies towards energy-efficient buildings in specific climate conditions may have a common target; however, they differ in their strategies. Numerous studies conducted in various locations highlight retrofitting solutions tailored to their specific climate conditions, which might not be applicable to other regions.

The decision-making process for retrofitting buildings can be significantly impacted by the availability of retrofitting alternatives that are specially created for various climate zones (Liu et al., 2022). To increase the adoption of energy-efficient retrofitting solutions and reduce greenhouse gas emissions, it is advised to develop and promote options tailored to local climatic conditions, while considering the typology of the building. By adopting climate-specific retrofitting strategies, energy efficiency can be significantly improved by taking into consideration the unique weather conditions of a region.

3.2.2 Building retrofit assessment according to the surrounding environment

Besides climate factors, there are other environmental factors that are essential for reducing greenhouse gas emissions and improving energy efficiency in cities (Bouw et al., 2021). For instance, the architect must consider solar and daylight availability to optimize solar energy production and minimize environmental impact in design. By integrating sustainable and passive design solutions with active solar energy systems, cities can reduce their reliance on non-renewable energy sources and promote a more environmentally sustainable future (Webb et al., 2016). Many energy models have been developed recently, but they tend to neglect the importance of phenomena that occur at the urban scale, such as the effect of urban geometry on energy consumption (Mirzabeigi & Razkenari, 2022).

In conclusion, the surrounding environment and building design that considers solar and daylight availability are crucial factors in reducing greenhouse gas emissions and improving energy efficiency in buildings. While various energy models have been developed, they often neglect the impact of the surrounding environment on energy consumption. Therefore, it is important to consider factors such as building height, the density of the building in urban design, shape factors and etc, to optimize energy usage and minimize environmental impact. By integrating sustainable and passive design solutions with active solar energy systems, buildings can reduce their reliance on non-renewable energy sources and promote a more environmentally sustainable future. Overall, these findings emphasize the need for integrated approaches to urban planning and building design that prioritize environmental sustainability and energy efficiency.

4. DISCUSSION OF RESULTS

In order to determine the limitations and contributions of building retrofit assessments with regard to building typology and environmental factors, a review of the relevant literature was conducted in this research. This research aims to identify and evaluate the most relevant publications concerning building retrofitting assessments, with a specific focus on their respective key areas. The methodology involves the selection of 60 publications, followed by a thorough analysis of their contents. In this section, this paper selects 27 publications that align closely with its goals and methodology, and delves into their assessment methods (see Table 1). In addition, this paper thoroughly assesses the selected publications, examining their typological and geometrical parameters as evaluated in these studies. Furthermore, it considers other parameters such as the exploration of different climate conditions, cost analysis, CO2 emissions, as performance metrics and various retrofitting alternatives. These factors are crucial to understanding the assessment of achieving low-energy retrofitting in residential buildings.

Table 1: Summarised Publications for Building Retrofit Assessment based on Focused Parameters

Evaluation criteria	Assessment method	Typology									Retrofitting											Energy performance					
		(Ballarini et al., 2017)	(Coma et al., 2019)	(Ballarini et al., 2011b)	(Dascalaki et al., 2011b)	(Beagon et al., 2020)	(Salehi et al., 2015)	(Kragh et al., 2014)	(Kristensen et al., 2021)	(Loga et al., 2016)	(Ignjatović et al., 2021)	(Bennadji et al., 2022)	(Alavirad et al., 2022)	(Wang et al., 2022)	(Alabid et al., 2022)	(Merlet et al., 2022)	(Carletti et al., 2014)	(Yazdi Bahri et al., 2021)	(Marasco et al., 2016)	(Lee et al., 2019)	(Liu et al., 2022)	(Kadrić et al., 2022)	(Sugár et al., 2020)	(Becchio, 2012)	(Q. Li et al., 2021)	(Aksamija, 2015)	(Xiong et al., 2019)
Architectural features	Geometry	x		x			x					x				x						x	x				
	Building size			x	x		x			x		x								x	x	x					
	Building age		x		x	x	x	x	x	x	x	x				x			x		x			x			
	Material	x		x	x	x		x					x	x			x		x	x		x			x	x	x
	Window to wall ratio					x										x	x					x			x		x
	Building layout												x			x											
	Building orientation																x										
	Building type					x		x			x		x								x		x	x			
	Various climate zones	x	x		x	x	x			x			x	x			x	x			x	x	x	x			x
Retrofitting and energy efficiency criteria	Thermal insulations	x	x		x	x		x					x	x	x		x	x		x		x			x		x
	Window replacement	x															x			x		x					
	Heating systems	x	x	x	x	x			x					x	x	x		x	x	x		x	x				x
	Humidity																	x									

	Cooling systems					x								x	x				x								x
	Water systems													x	x												
	Lighting performance													x	x		x	x	x			x				x	
	Shading devices																x									x	
	Acoustic performance																x										
	DHW		x	x															x				x				
	Ventelation												x	x					x								
	HVAC													x					x	x		x				x	
	Renewable sources											x		x	x				x	x						x	
	Retrofitting alternatives													x		x	x	x	x		x	x			x	x	
Performance metrics	Energy demand				x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x
	Energy cost		x										x	x	x	x			x	x		x					
	CO2 emissions	x	x		x								x		x									x		x	
	Thermal comfort														x		x	x							x		x

The findings indicate that most of the publications propose retrofitting alternatives as solutions to improve energy efficiency and sustainability in buildings. However, there remains a lack of understanding regarding various metrics and calculation methods for evaluating retrofitting solutions, potentially hindering the development of standardized and readily available approaches. The studies identify that no single retrofitting solution can address all challenges, while also raising awareness about the importance of adoptable retrofitting strategies.

As observed in Table 1, the majority of the publications focus on implementing energy-saving techniques based on specific climate conditions and personalized retrofitting options. Nevertheless, it is crucial to recognize that certain limitations still require attention and resolution. Limitations in current liturature are outlined below:

- Several studies have been conducted, particularly in the last decade, to assess the energy efficiency of dwellings and improve building retrofitting according to their typologies. Although, most have used the "Typology Approach for Building Stock Energy Assessment" TABULA report to provide methods for classifying housing typology in Europe. However, there is still a lack of comprehensive information regarding technical developments, building structures, building layouts, and their relations which could affect energy requirements in buildings.
- TABULA report offers two levels of refurbishment for each typology, usual and advanced refurbishment. According to these refurbishment techniques, there is only one recommendation for each level but no elaboration on other refurbishment alternatives for each typology.
- The physical characteristics of buildings are regularly and significantly altered over time, changing not only the parameters of urban areas but also their physical characteristics and compositions. Therefore, there is a need to develop and amend adoptable retrofitting solutions based on building typologies.
- The energy-efficient building design methods have limitations when applied in regions with diverse climate characteristics. The method may not account for microclimatic conditions, extreme weather conditions or changes in building usage or occupancy patterns. It may not be suitable for regions with different building types or sizes and may require extensive data collection and processing.
- Numerous methods and tools have been created globally for assessing the energy efficiency of buildings. However, each of these methods and tools is different in its own way, and there is no consensus on how to score or weigh them. Furthermore, there is a shortage of building environmental assessment methods for retrofitting stages and approaches for determining carbon emissions and benchmarking are not consistent.

5. FUTURE STUDY DESIGN

In order to address the limitations observed in current liturature and develop more effective energy-efficient building retrofitting, a comprehensive approach is proposed for future studies.

- To address the lack of comprehension regarding the intricate connections among building layouts, technical progress, and energy demands, an in-depth building classification can be undertaken. This entails not only categorizing building typologies but also delving into the details of their structural compositions, architectural designs, and evolving technological aspects.
- Expanding on the predefined retrofitting solutions, a future study could focus on developing retrofitting alternatives tailored to various building typologies. This could involve an in-depth exploration of alternative refurbishment techniques precisely suited to specific building typologies. By considering an array of innovative materials, construction methods, and emerging technologies, researchers could propose retrofitting strategies that cater to the unique characteristics of each typology while also optimizing energy efficiency and sustainability. This approach would provide a richer set of retrofitting solutions for architects, designers, and stakeholders to choose from, ensuring a more adaptable and effective retrofitting process that aligns with diverse building needs and environmental contexts.
- To propose an adaptive retrofitting solution framework that aligns cohesively with diverse building typologies and could respond to their evolving physical features or environmental contexts. By incorporating advanced assessment methodologies, responsive strategies, and a unified assessment framework, the proposed adaptive retrofitting solutions aim to enhance the long-term performance and environmental compatibility of buildings.

6. CONCLUSION

Building retrofitting assessments have recently gained a lot of attention from researchers. Since 2019, the number of published works on this topic has increased significantly. The goal of this study is to thoroughly examine the available literature on the relationship between building typology and energy efficiency, with a particular emphasis on retrofitting. In addition, this study attempts to identify research gaps and plan a future study on the most effective energy-saving solutions for retrofitting various types of buildings while taking specific environmental and physical aspects into account. Based on the review of journal articles (n = 60) between 2011 and 2023, this study summarized: (1) building retrofitting, (2) energy efficiency improvement, and (3) building typology. The main findings of this study include the following: the current body of existing literature on building retrofits has primarily focused on classifying building typologies and tailoring retrofitting solutions accordingly. However, there is a significant gap in knowledge regarding technical advancements, building structures, environmental factors, and their relationship, as well as alternative strategies for executing standard or deep retrofitting and accurately predicting energy savings. The energy-efficient building design method based on climatic zoning has limitations when applied to diverse climates and building types/sizes, which necessitates the development of a comprehensive methodology and tool for transferring knowledge to support adoptable energy-efficient building retrofits. Addressing these deficiencies is crucial for developing responsive and adaptable solutions that are tailored to the unique characteristics of each building rather than relying on a generic approach. It would also facilitate designers and policymakers with relevant information on energy-efficient building retrofits to make informed decisions.

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