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ENHANCING BUILDING SUSTAINABILITY: A COMPREHENSIVE REVIEW AND METHODOLOGICAL ROADMAP FOR RETROFIT STRATEGIES

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Elena Imani,
School of Computing, Engineering and Digital Technologies, Teesside University
E.imani@tees.ac.uk

Huda Dawood,
School of Computing, Engineering and Digital Technologies, Teesside University
H.Dawood@tees.ac.uk

Nashwan Dawood,
School of Computing, Engineering and Digital Technologies, Teesside University
N.N.Dawood@tees.ac.uk

Annalisa Occhipinti,
School of Computing, Engineering and Digital Technologies, Teesside University
A.Occhipinti@tees.ac.uk

SUMMARY: *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 typology 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 discusses the limitations of current practices in terms of physical and technical developments, such as building retrofit assessment according to the typology of the building and environmental factors. To address these limitations, this study proposes a methodology for future research with a focus on in-depth building classification, developing tailored retrofitting alternatives, and establishing an adaptive solution framework. This framework aligns cohesively with diverse typologies, adapts to changing environments, and enhances long-term energy-efficient performance. It proposes detailed building categorization to understand the interconnections between a building's physical characteristics, technology, and energy needs. Additionally, it suggests tailoring retrofit solutions for diverse building types and creating an adaptable framework for changing conditions. Using qualitative research, literature review, quantitative analysis, and case studies, the methodology ensures research credibility. Prototyping is employed to refine processes, considering building types and environmental factors.*

KEYWORDS: *Retrofitting, Typology of Building, Building Energy Performance, Residential Buildings.*

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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 (Barrett et al., 2018). European policy aims to achieve a 27% increase in energy efficiency by 2030, primarily by improving the energy efficiency of newly constructed buildings (Economidou et al., 2020). 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 buildings and reduce carbon emissions, governments should develop a strategy to invest in building energy retrofitting (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 , priorities, and potential to implement such changes, and the complexity of architectural details and local conditions within its buildings (Alabid et al., 2022). This dynamic regulatory environment requires careful consideration of how these evolving regulations are tailored to meet the energy efficiency demands posed by diverse building variables. Understanding the interaction between retrofitting interventions and building-specific characteristics is vital for achieving the highest possible energy efficiency outcomes. This adaptability is key to ensuring that regulations remain relevant and effective in diverse contexts (Aldieri et al., 2021).

Several variables influence energy consumption within a building, including the structure of the building envelope, construction age (often referred to as building age bands), prevailing climate conditions, building area and type, and the efficiency of its system installations (Beagon et al., 2020). Among these, the type and age of buildings are particularly important, as they represent key physical parameters that influence energy use. The building's age band, for instance, is crucial for determining realistic building physics parameters, such as the materials and systems used, which directly impact energy performance and the suitability of retrofitting solutions. To promote energy-saving strategies, experts typically model the energy efficiency of building portfolios using representative residential building typologies (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 typology, energy efficiency, and retrofitting. Ultimately, this study proposes a methodology aimed at developing more effective retrofitting strategies that are specifically tailored to various building typologies.

2. RESEARCH 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 analyse 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 accurate study selection criteria. By implementing this approach, the research aims to identify and address gaps and limitations 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 and relevant 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.

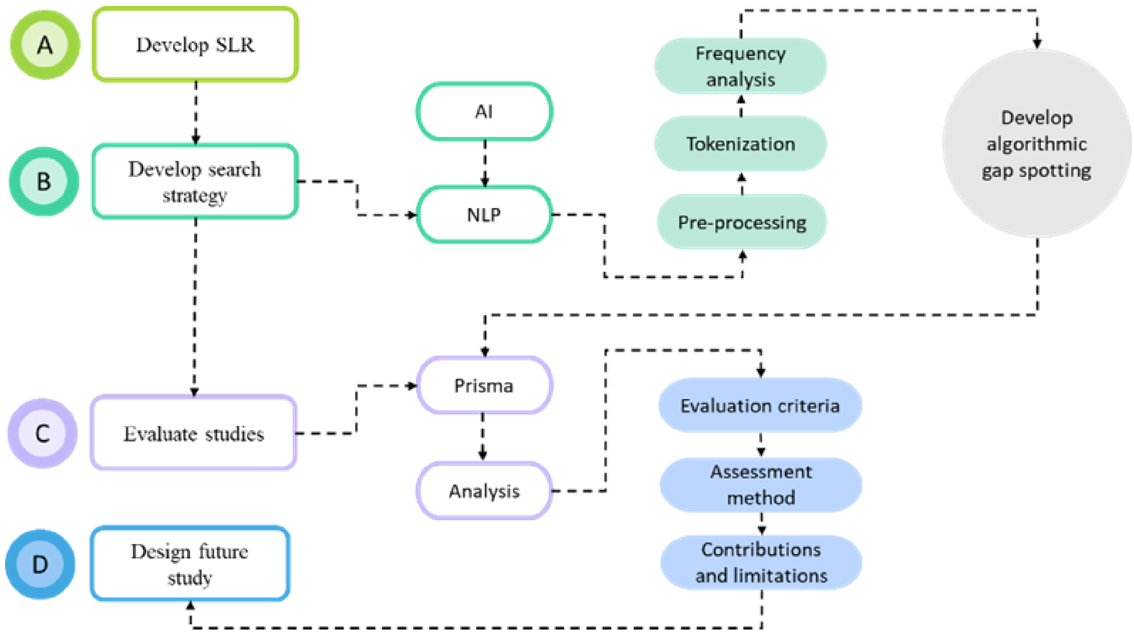

Figure 1: Research methodology.

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 (SLR) process was applied afterward, leading to the identification of 60 relevant papers using the PRISMA methodology (Moher et al., 2009). This approach provided valuable insights into energy efficiency, particularly building typology's role, crucial for decision-makers and designers.

2.1.1 Database selection and design research questions

This research utilized the title/abstract/keyword search methodology as part of a systematic review approach. Two prominent academic databases, Scopus and ScienceDirect, were investigated to find relevant peer-reviewed papers. The articles were peer-reviewed journals from the two data sources. Science Direct is an online index of academic references that includes a collection of published scientific research by publisher Elsevier (Gonçalves et al., 2018). Scopus is an international database of peer-reviewed publications. Collecting peer-reviewed journals from both data sources contributes to the high quality of the studies reviewed in this research. The possibility of capturing a wide variety of studies and research that might have been published in one database but not the other is further increased using multiple databases. The systematic review methodology used in this study and the application of reliable academic databases give a strong and thorough overview of the research publications relevant to the study area. In this regard, the research questions addressed in this section are:

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

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

2.1.2 Development of a search strategy

The first attempt of this study was article selection process with comprising three steps: (1) title screening, (2) abstract screening and (3) keyword screening. A combination of pre-defined keywords was searched in peer-reviewed journals and conference papers published in English in digital databases to search for articles. Next, publications and scientific articles on different energy efficiency stages in buildings, published in peer-reviewed journals or peer-reviewed conference proceedings, with the determined terms in their titles, abstracts, or keyword lists, were reviewed. To catch the most relevant articles, this study reviewed literature related to, construction building technology, civil engineering, green sustainable science technology and environmental science. As a result, more than five hundred papers were scanned during this process from open-access articles that were selected to review over mentioned strategy for the last ten years.

To facilitate this comprehensive search, a novel searching framework utilizing three AI algorithms was developed as two data pre-processing steps and data mining. This framework efficiently filtered and navigated through the extensive collection, ensuring the inclusion of diverse perspectives and up-to-date findings. By employing advanced technology, the study adopted a systematic approach to extract knowledge from the available literature, enhancing the overall analysis and deriving valuable insights for the research.

2.2 Development of algorithmic gap spotting

In order to answer the research questions mentioned in the previous section, 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 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 limitations, and foster innovation in various fields.

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.

The applications of algorithmic gap spotting are manifold. Researchers can use this technique to gain insights into the current state of research in a particular field, helping them identify opportunities for innovation and improvement. By systematically identifying areas of research that have received less attention, algorithmic gap spotting can guide future research endeavors, ensuring a comprehensive and balanced exploration of knowledge. Moreover, this method could help researchers to filter and restrict the number of publications to review, focusing on those most relevant and pertinent to their study objectives.

In this study, the proposed technique leverages the power of the Python programming language along with NLP techniques. NLP is a multidisciplinary field that combines computer science, linguistics, and statistics to enable machines to process and understand human language (Sarker, 2022).

The methodology employed in this section involves a series of steps to define keywords for searching. Firstly, text pre-processing is conducted to clean and prepare the raw text data by removing unnecessary characters. This ensures that subsequent analysis focuses on meaningful information, improving the accuracy and relevance of results. Secondly, tokenization, a crucial NLP technique, is utilized as a data mining process to break down the text into smaller units such as words or phrases. This facilitates further analysis, enabling researchers to examine text composition and explore relationships between individual words or phrases. Additionally, a word count analysis is performed as another pre-processing step. This analysis provides valuable insights into the distribution and prominence of specific terms within the literature. By quantifying word frequency, researchers can identify keywords that have received significant attention or have been overlooked. Furthermore, to gain a deeper understanding of the literature, the proposed technique identifies the ten most common words in the analysed papers. This analysis illuminates the dominant themes and topics within the research corpus, highlighting areas of emphasis and potential gaps for further investigation (Figure 2).

2.2.1 Implementation of the methodology

This study employed a systematic approach to review literature on energy efficiency and building retrofitting. The methodology was carried out through a series of integrated stages designed to ensure a thorough and precise analysis of the relevant literature. As previously mentioned, the process began with a comprehensive literature search across multiple academic databases using carefully selected keywords based on the research questions. The literature search was conducted using keywords that were specifically chosen to align with the research question. Therefore, the keywords included ‘Energy Housing Design’ AND ‘Building retrofitting’, ‘Energy Housing Design’ AND ‘Energy Efficiency Improvement’, ‘Building retrofitting’ AND ‘Building typology’, ‘Building typology’ AND ‘Energy Efficiency Improvement’, ‘Energy Efficiency Improvement’ AND ‘Building retrofitting’. These keywords were used to search the titles, abstracts, and keyword lists of relevant articles. This targeted search yielded over 5,000 articles, ensuring that a broad spectrum of relevant studies was considered (Figure 3).

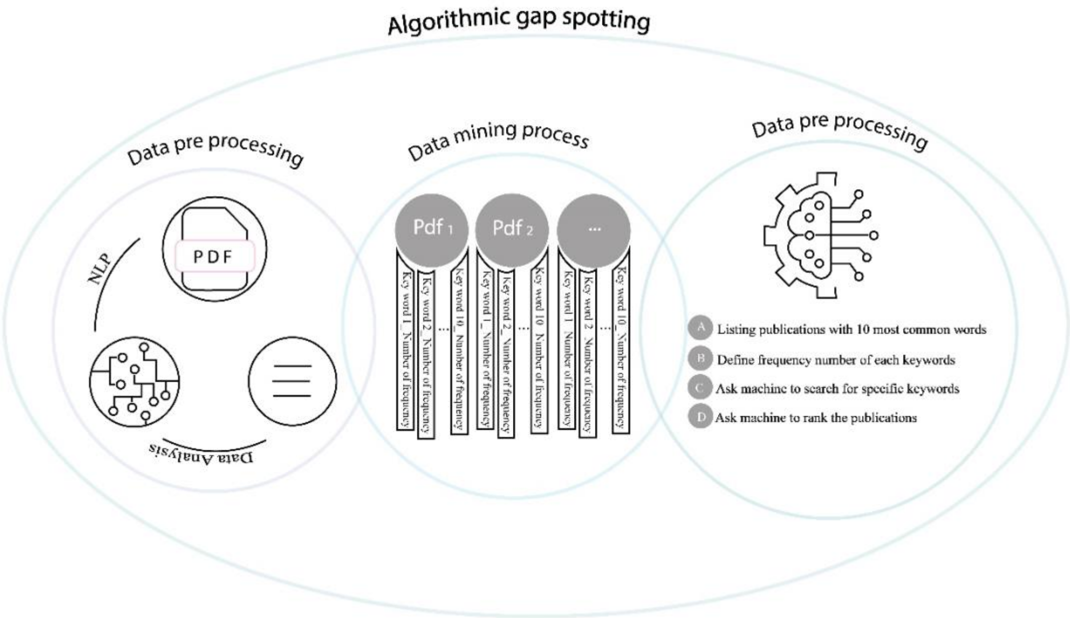

Figure 2: Algorithmic gap spotting design process.

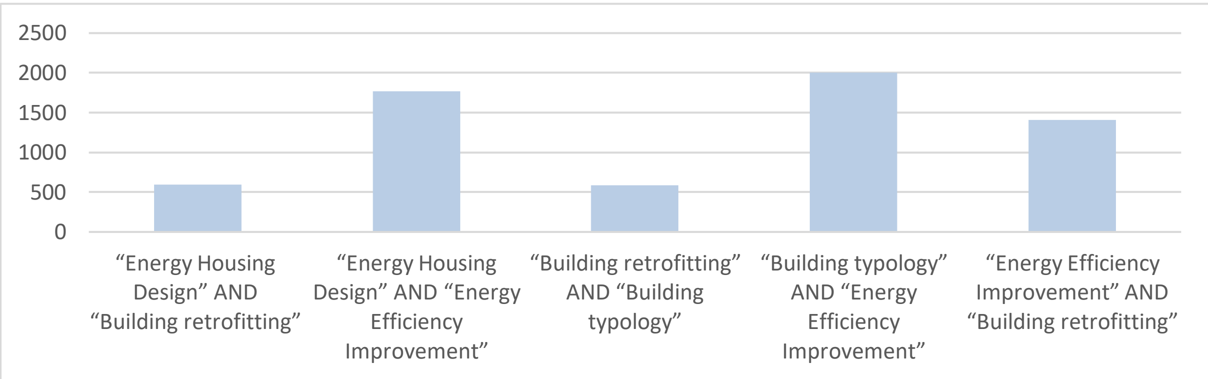

Figure 3: Number of articles published over last ten years.

However, the enormous number of publications presents a significant challenge—thoroughly reading and analyzing each one is impractical, yet ignoring them entirely is not a viable option, as it could result in missing many relevant and useful publications. To address this, it is crucial to implement a rigorous filtering process to select the most relevant papers. Once the relevant literature was collected as a PDF folder, the next step was to preprocess the content of publications to ensure their quality and relevance. In this regards, the text from each PDF document was extracted and cleaned using a series of NLP techniques. This cleaning process involved removing unnecessary characters, stop words, digits, and noise that could potentially distort the analysis. Custom filters were also applied to eliminate non-informative words, such "et," "al,", punctuation marks and etc, which are common in academic writing but do not contribute meaningfully to the analysis. This refined the data and prepared it for more detailed examination. Following the cleaning process, all documents were tokenized, breaking them down into smaller units such as individual words or phrases. Tokenization facilitated a more granular analysis of the literature, allowing the study to identify relationships between different terms within the text. A frequency analysis was then conducted on the tokenized texts, quantifying the occurrence of each word within the documents. This step was crucial in identifying the 10 most common words in each publication, which highlighted the dominant themes and topics, further refining the study's focus.

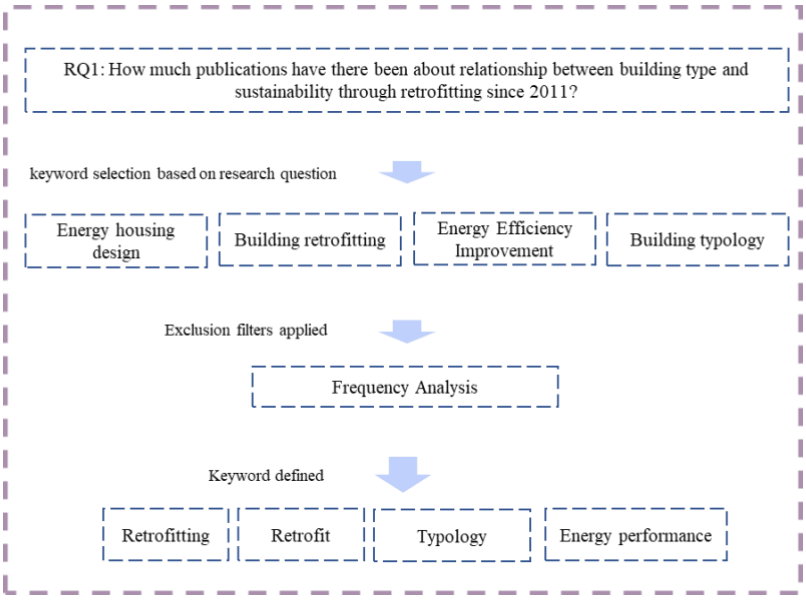

Figure 4: Defining keywords for search strategy.

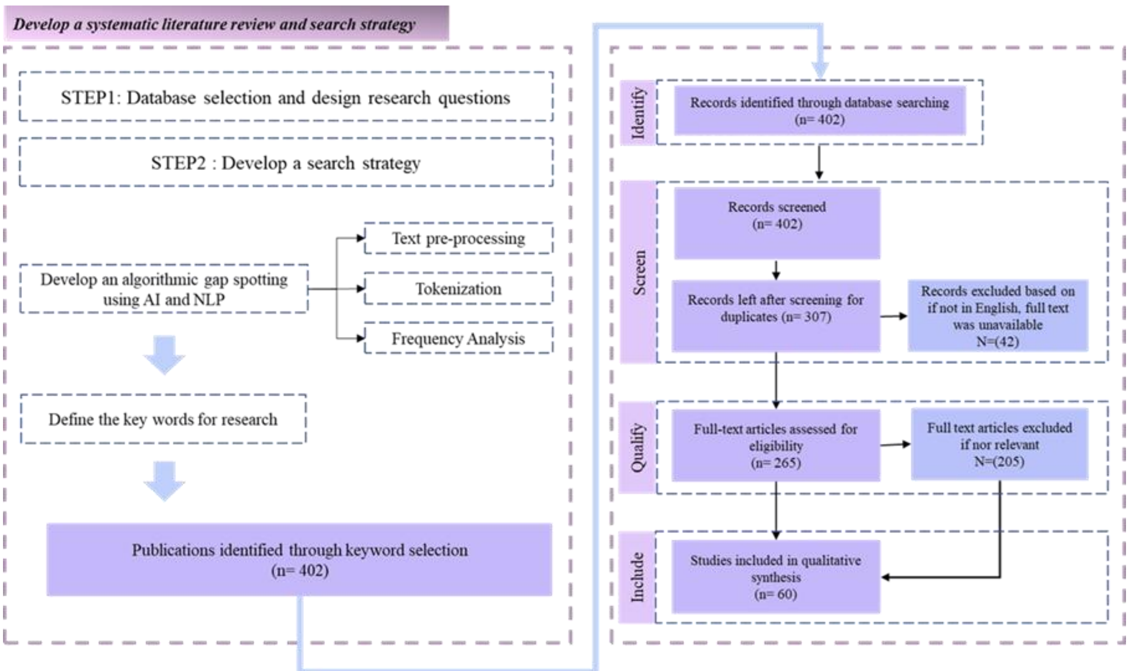

Figure 5: Search strategy framework.

The core of the methodology involved applying an algorithmic gap spotting framework. This automated and systematic approach allowed for the identification of research gaps by analyzing patterns and trends within the literature. The implementation of this framework was facilitated through two key Python scripts. The first script was designed to extract and list the 10 most common words from each PDF document, ensuring that the analysis concentrated on the most frequently discussed topics. This step provided a foundation for identifying gaps in the existing literature. The second script specifically targeted the identification of papers where the terms "Retrofitting," "Retrofit," or "Typology" "Energy performance" were among the previously selected 10 most common words (Figure 4).

This process involved scanning each document for these key terms and filtering the publications accordingly. As a result, 402 publications were selected from the initial pool of over 5000 articles. These publications were further ranked based on their relevance, with the top 60 papers selected for detailed review using the Prisma technique (Figure 5). This rigorous and integrated approach ensured that the final selection of literature was both focused and highly pertinent to the research objectives. By systematically applying AI and NLP techniques throughout the methodology, the study effectively highlighted gaps in current research and provided a clear pathway for future investigations in the field of energy efficiency and building retrofitting.

3. RESEARCH FINDINGS AND REVIEW RESULTS

Algorithmic gap spotting method is particularly useful in analysing large volumes of publications, allowing researchers to identify patterns, trends, and gaps that traditional methods might overlook. These methods streamline the processes of data extraction, cleaning, and analysis, making literature reviews more efficient and comprehensive in many domains. 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 employing AI and NLP techniques in conjunction with a systematic literature review, thereby enhancing the identification of effective retrofitting strategies tailored to specific building types and environmental factors. The hypothesis driving this research was that utilizing algorithmic gap spotting would enable a more detailed and effective identification of retrofitting strategies compared to traditional methods. The application of these methods allowed for a more detailed analysis of large volumes of text data, facilitating the identification of patterns, trends, and gaps in the literature that might have been overlooked in a conventional literature review. This methodology proved particularly effective in isolating key factors related to building typology and environmental conditions that are crucial in determining the success of retrofitting strategies. 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

The term ‘building typology’ refers to a systematic description and catagorise buildings based on based on certain criteria, and it also includes examples of typical buildings that fit these categories (van Oorschot, n.d., 2016). type’ A 'building type' can be defined in three ways. First, by choosing a real building based on experience, known as a 'Real Example Building' (ReEx), especially when there are no statistical data. Second, by selecting a 'Real Average Building' (RrAv) through statistical analysis to find a building that represents the average features of many buildings. Third, by creating a 'theoretical building' (SyAv), or archetype, based on common features found in statistical data from a large sample of buildings (Y. Li et al., 2019).

Building typologies play an essential role in achieving energy performance requirements of buildings. By considering building typologies, a comprehensive understanding of a building's energy efficiency can be gained, making it an indispensable tool in ensuring sustainable and energy-efficient (Ballarini et al., 2014). 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., 2011). 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., 2011). 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 $CO2$ emission reductions associated with the implementation of energy retrofitting measures in the building stock at various scales (Fernandez-Luzuriaga et al., 2021). For instance, accoding to Sugár et al. (2020), the heating energy demand of a building depends on its architectural style therefore, typological features can be used to estimate a building's heating energy demand.

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 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 condition

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 minimizing the energy consumption of the buildings and maximizing the use of available energy resources (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 availability of sunlight and natural daylight should be considered in designing process to optimize solar energy use and reduce environmental impact. By integrating sustainable design strategies and passive techniques with active solar energy systems, cities can lower their reliance on non-renewable energy sources and move toward 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, green spaces 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., 2011)	(Dascalaki et al., 2011)	(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	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:

- In recent years, particularly over the last decade, numerous studies have focused on evaluating the energy efficiency of residential buildings and enhancing retrofitting strategies based on building typologies. Many of these studies have relied on the "Typology Approach for Building Stock Energy Assessment" (TABULA) report, which offers a framework for classifying housing typologies across Europe. However, since the data in the TABULA report dates back to 2011, there is a notable gap in comprehensive information regarding recent technological advancements in heating, cooling, and ventilation systems. Additionally, while there are estimates related to CO2 emissions and energy consumption for various building types, there is limited information available on the thermal comfort of these buildings. Furthermore, important factors such as building layout and landscape, which can significantly influence energy requirements, are often overlooked in these assessments.
- The TABULA report provides information on three levels of building retrofitting for each typology in various regions: Level 1 represents the existing state, Level 2 covers usual refurbishment, and Level 3 focuses on advanced refurbishment. However, for each of these levels, the report offers only a single recommended retrofitting technique without exploring other alternatives that could be tailored to specific typological and climatic features of the buildings. This lack of detailed options limits the adaptability of the retrofitting strategies to the unique characteristics of different regions and building types.
- The physical characteristics of buildings are frequently and significantly modified over time due to evolving regulations and technological advancements. These changes not only affect the parameters of urban areas but also alter the physical attributes and compositions of the buildings themselves. Consequently, it is essential to develop and update retrofitting solutions that can be adapted to the current features of buildings, ensuring that these solutions remain relevant and effective in improving energy efficiency and sustainability.
- 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 benchmarking are not consistent.

5. PROPOSED METHODOLOGY FOR FUTURE STUDY

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 (Imani et al., 2023).

- To address the lack of comprehension regarding the intricate connections among building's climate condition, 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 structures, architectural and environmental characteristics, 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 retrofitting 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 in a specfic climate zone 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.

Considering above-mentioned limitations, this section presents the research proposed methodology use to develop the research and discussed method design and method formulation. Proposed method offers a structured approach to data collection and analysis that helps ensure the validity and reliability of research findings. These are critical steps in this process, they span from organising and defining the research limitations to selecting the most appropriate techniques for collecting and analysing data. The use of both qualitative and quantitative methods is combined in this study.

5.1 Method design

The method design of this study is a systematic process aimed at planning the necessary steps to respond to the research questions. This process requires a thorough understanding of the research problems, available data, and research objectives. The stages of the methodology design are illustrated in Figure 6.

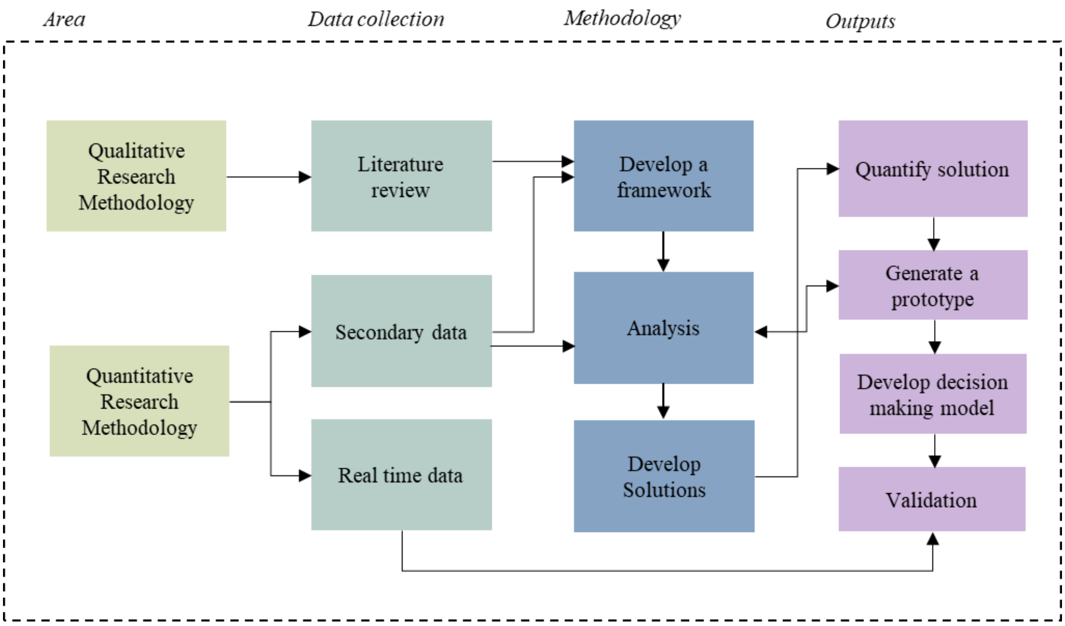

Figure 6: Method design framework.

This study employs both qualitative and quantitative research methodologies to ensure a comprehensive approach. Qualitative methods, such as literature reviews, help in understanding the depth of the research problem, while quantitative methods, such as statistical analysis, provide measurable and statistical insights. Based on the data collected from the literature review and secondary data, a framework is developed. This framework serves as a structured approach to address the research questions. Subsequently, analyses are conducted, and potential solutions are developed within this framework to tackle the identified problems. The solutions are then quantified to evaluate their feasibility and impact. Simulation models are created to analyse these solutions under different scenarios. Finally, a decision-making model is developed to facilitate the application of these solutions in real-world scenarios. Once the research design and solutions are developed, the final step is to validate the outputs with both real time and secondary data from existing buildings. This involves evaluating the validity and reliability of the results to ensure they are robust and applicable.

5.2 Method formulation

Following the design of the method, the research ultimately employs a prototyping methodology to assess and refine the retrofit process. This approach facilitates a comprehensive understanding of the retrofitting requirements, which vary with the building's typology and location, and highlights the design aspects that warrant further development. A series of parametric prototypes and models are created to simulate various retrofit scenarios and evaluate its viability. The methodology proposed to help modellers by finding potential design errors and refine the retrofit procedure before execution. The methodology is used to better understand the individual requirements of retrofitting for various building typologies. For instance, various types of buildings may have a variety of physical features, structural or technological systems that require the use of various retrofitting techniques. Similarly, different buildings may need different energy efficiency measures to function optimally in various climates. To create and test a decision-making model, four phases of the prototyping process were defined: extraction features, scenario analysis, solution development, and validation Figure 7.

To improve the process, four stages were carried out to extract the building characteristics. This includes collecting data on the physical features of the building, the requirements, and desired functions. At this stage, TABULA datasets and literature review were used. These stages play a crucial role in terms of defining the main variables affecting the energy performance of buildings, defining the building typological characteristics, and determining the relationship between energy saving and typology of buildings.

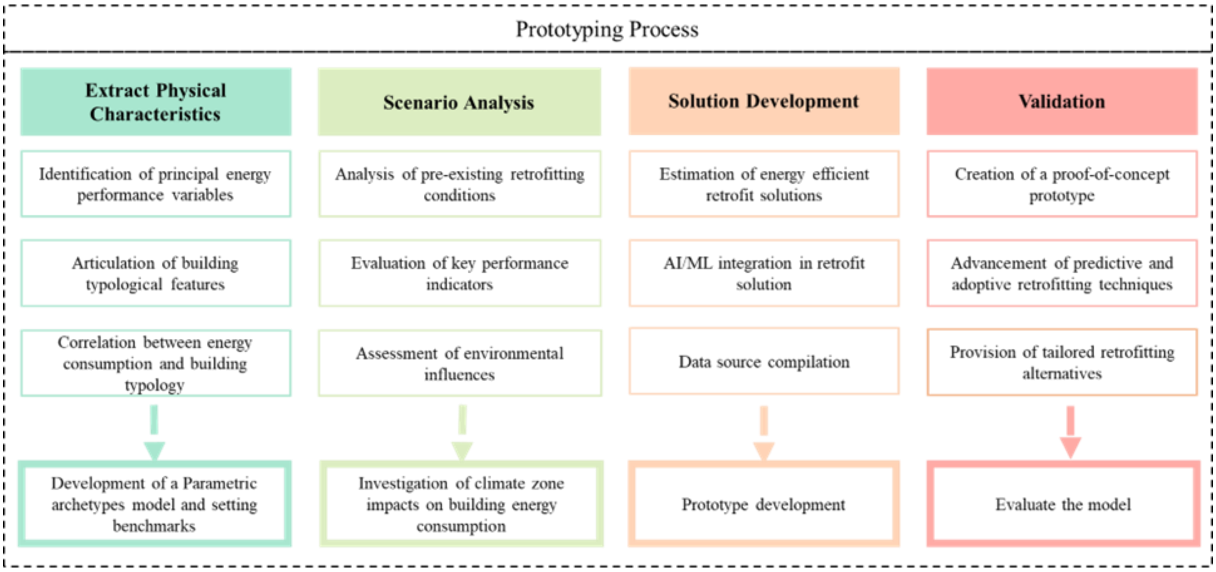

Figure 7: Prototyping process.

5.2.1 Extract physical characteristics

The commencement of our proposed methodology, designated "Extract Physical Characteristics," is purpose-built to address the principal factors that influence the energy efficiency of building retrofits. This initial phase is systematically divided into critical steps aimed at the construction of a novel classification framework.

Step 1: Identification of principal energy performance variables. Our approach initiates with a comprehensive identification of the primary variables impacting the energy performance of buildings. This multi-dimensional process acknowledges various contributing factors, from insulation quality to user behaviors. Leveraging data analytics, we aspire to categorize these variables, forming the groundwork for targeted energy optimization.

Step 2 Articulation of building typological features. This phase involves a refined classification system that integrates UK National Statistics with TABULA and EPISCOPE projects. By considering building size, construction year, and codes, this phase categorizes buildings into detailed groups like Single-Family Houses, Terraced Houses, Multifamily Houses, and Apartment Blocks, enhancing energy performance analysis and targeted retrofitting solutions.

Step 3: Correlation Between Energy Conservation and Building Typology. In the subsequent step, the intersection of typological characteristics with identified energy performance variables is explored to discern their interrelated effects. Through the application of statistical methodologies and algorithmic modeling, we aim to reveal patterns that elucidate the dependency of energy conservation on building typology.

Outcome: Development of an archtype model and setting benchmarks. This phase concludes with the creation of a robust parametric model. This model is envisioned to delve into the composite physical, structural, and technological attributes of buildings, as well as environmental features, to explore the intricate relationship between architectural characteristics, technological advancement, and energy performance. The modeling phase concludes with the creation of a robust parametric model developed using advanced tools like Rhinoceros (Rhino) for detailed 3D modeling and Grasshopper for dynamic parametric algorithms.

5.2.2 Scenario analysis

In this section, we explore a scenario analysis that delves deeply into the current retrofit conditions, evaluates performance metrics, and examines the environmental effects on a variety of building types. The primary aim of this analysis is to understand how different climate zones influence energy consumption in buildings, thereby informing the creation of tailored strategies for energy conservation that are effective at a regional level.

Step 1: Analysis of pre-existing retrofitting conditions. This step, undertake a detailed analysis of current retrofitting conditions and energy performance across various building types. After development a parametric achtype model, to ensure accuracy, we gather extensive data on building features, including typology, size, construction year, and compliance with UK building regulations. This data is sourced from open access data sources such as TABULA and EPISCOPE projects, providing a solid foundation for precise energy performance simulations. Using tools like Ladybug, Honeybee, and EnergyPlus, the model simulates energy use and environmental performance across different climate zones over a full year. These simulations account for various factors, providing a high-resolution analysis of energy consumption and thermal comfort.

Step 2: Evaluation of key performance indicators. The following step encompasses the assessment and scoring of key performance indicators within the retrofitting process. The step examines the correlation between retrofitting methods and building typology by leveraging the Correlation Coefficient/Analytic Hierarchy Process (CC/AHP) hybrid model. Initially, extensive data is extracted and pre-processed from diverse secondary data sources to ensure clarity and consistency. Statistical methodologies are then applied to analyse and prioritise key energy performance variables, revealing their corelation with various building typologies. This comprehensive approach facilitates the systematic prioritization of retrofitting solutions, directing focus toward the most impactful interventions and thereby enhancing overall energy efficiency and sustainability in residential buildings.

Step 3: Assessment of Environmental Influences. The final step in this stage involves a thorough evaluation of environmental parameters influencing building conditions. In this stage, we aim to utilize advanced data automation tools, to streamline the collection and processing of environmental data. By automating hourly data analysis across different climate zones, we enhance both the quality and quantity of data collected. This process includes inputs like building geometries, façade performance, and user parameters, ensuring that retrofit solutions are precisely tailored to environmental contexts. The automated system enables real-time updates, ensuring robust and reliable assessments of energy consumption, CO2 emissions, and thermal comfort.

5.2.3 Solution development

In this section, we delve into crafting tailored retrofit solutions that are both energy-efficient and viable for various building types. Our approach starts with a detailed analysis of potential energy savings and the different aspects of retrofit technologies. We then enhance these strategies by incorporating AI and machine learning, which help to optimize and scale our interventions. The section culminates in the development of a prototype that not only demonstrates the effectiveness of our solutions but also their potential for broader application.

Step 1: Estimation of energy efficient retrofit solutions. Commencing this phase is the task of quantifying energy-efficient retrofit solutions, individually tailored to each building typology. This involves an intricate balance of calculating energy savings while also evaluating the viability of various retrofit technologies.

Step 2: AI/ML integration in retrofit solutions. Subsequently, we explore the intersection of theoretical and empirical data in the integration of AI/ML technology within retrofit solutions. This stage is pivotal in understanding the capabilities of AI/ML to refine retrofit strategies, amplify predictive maintenance, and elevate energy management protocols.

Step 3: Data source compilation. This step is dedicated to the identification and compilation of data sources vital for the implementation and scaling of retrofit solutions. The comprehensive data collection ranges from historical energy utilization figures to current performance indicators, all crucial for the effective application of AI/ML technologies in the field of retrofitting.

Outcome: Prototype development. Following the above-mentioned methodologies, we will create a prototype that presents an adaptive retrofitting solution. This prototype, representing the integration of state-of-the-art retrofit technologies and AI/ML insights, aims to demonstrate the practical applications and scalability potential of our proposed solution.

5.2.4 Validation

In this section, we validate our proposed solution through three key steps. First, we create a proof-of-concept prototype embodying the framework's principles. Next, we refine predictive and adaptive retrofitting techniques to ensure real-time accuracy. Finally, we propose tailored retrofitting alternatives suited to diverse scenarios, ensuring adaptability.

Step 1: Creation of a proof-of-concept prototype. The initial phase of validation involves creating a prototype that demonstrates the main ideas and functions of the overall plan. To ensure accuracy, physical features of the building were verified using the UK building metrics and validated against the TABULA dataset. This validated model serves as a baseline for further validation and refinement in subsequent stages.

Step 2: Advancement of predictive and adaptive retrofitting techniques. We then advance into refining predictive and adaptive retrofitting techniques, evaluating a spectrum of algorithms that could foresee and dynamically adapt to changing performance data, thus ensuring real-time retrofitting accuracy.

Step 3: Provision of tailored retrofitting alternatives. In the concluding step, we propose a range of retrofitting solutions, each tailored to different building scenarios, ensuring adaptability to various typologies, environmental conditions, and energy performance needs. To validate these solutions, we aim to collect data from buildings in the UK using cutting-edge IoT techniques. This includes deploying sensors and loggers to gather both historical and real-time data from buildings equipped with various low-carbon systems. This comprehensive data collection will provide critical insights, enabling us to refine and optimize the proposed retrofitting strategies for maximum effectiveness and sustainability.

6. CONCLUSION

Building retrofitting assessments have become a major focus for researchers, particularly since 2019, with a notable increase in published works on this subject. This study aimed to thoroughly explore the literature on the relationship between building typology and energy efficiency, with a specific emphasis on retrofitting, while also identifying research gaps and proposing a roadmap for future investigations. Our review, which encompassed journal articles from 2011 to 2023, highlighted several key findings. While existing literature has predominantly concentrated on categorizing building typologies and tailoring retrofitting solutions accordingly, significant knowledge gaps persist. These gaps include the need for a deeper understanding of technical advancements, building structures, environmental factors, and their interplay, as well as alternative strategies for executing retrofitting and accurately predicting energy savings. Moreover, the limitations of the energy-efficient building design method based on climatic zoning underscore the need for a comprehensive methodology and toolset to support adaptable energy-efficient building retrofits across diverse climates and building types, ages, and sizes. Addressing these limitations is crucial for developing responsive and adaptable solutions that cater to the unique characteristics of each building. In this context, the proposed methodology for future study aims to comprehensively address these limitations. By conducting an in-depth building classification considering structural compositions, architectural designs, and evolving technological aspects, researchers can tailor retrofitting alternatives to various building typologies. This approach, coupled with the development of an adaptive retrofitting solution framework, seeks to enhance the long-term performance and environmental compatibility of buildings. Ultimately, by bridging these knowledge gaps and developing tailored solutions, we aim to empower stakeholders with the tools and insights needed to navigate the complex landscape of energy-efficient building retrofits, ultimately contributing to a more sustainable built environment.

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