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Advancing Sustainability in the Built Environment: A Bibliometric Review of Building Envelope Retrofitting on Energy Efficiency and Climate Adaptation

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Abstract Energy-efficient retrofitting of building envelopes is a cost-effective and scalable strategy for reducing energy consumption, lowering carbon emissions, and enhancing thermal comfort. This approach has gained increasing attention in recent years, driving significant growth in research publications. However, the rapid field expansion makes it challenging to discern the research landscape's direction, scope, and gaps. This paper provides a bibliometric review of the building envelope retrofitting research domain that focuses on energy efficiency and climate resilience, utilizing citation data from the Scopus database. 1214 relevant research articles were analyzed using the Biblioshiny application in the R-Studio package. Bibliometric analysis provides a comprehensive and up-to-date analysis and contributes to a deeper understanding of the research domain. The study maps publication trends, tracks trajectories, and identifies active collaboration networks among researchers. The review examines the evolution and distribution of frequently cited keywords, offering a detailed overview of emerging topics and dominant research themes. It highlights key sub-areas such as energy efficiency, energy conservation, materials and methods, energy simulations, life cycle analysis, performance assessments, and optimization. The study identifies research gaps and presents future opportunities to advance energy-efficient building envelope retrofitting for energy efficiency and climate resilience. This paper can guide future research and policy making and promote sustainable retrofit practices. The paper provides recommendations for future research and emphasizes the importance of continued innovation and international collaboration in an effort toward energy-efficient and climate-resilient buildings.

Keywords Energy-Efficient Retrofitting, Building Envelope, Bibliometric Analysis, Thermal Comfort, Net-Zero Retrofit

1. Introduction

Sustainable urban development has become a universal urgency in response to rapid urbanization and climate change. Cities are responsible for a significant share of global energy consumption and greenhouse gas emissions, with buildings alone accounting for nearly 40% of total energy use. Retrofitting the existing building stock presents significant opportunities for lowering the energy consumption in buildings and improving energy efficiency, leading to lessened greenhouse emissions, and a sustainable, low-carbon future [1]. Energy demand for heating, cooling, and ventilation can be significantly reduced with appropriate strategies and advanced materials in envelope retrofitting. Energy-efficient retrofitting makes the building resilient to climate change and helps attain larger sustainability goals. The cost of retrofitting (economic dimension) and the improvement in thermal comfort (technical dimension) are the two decisive factors affecting the retrofits. Various retrofit options exist within the current building scenarios, where the two main approaches are deep energy retrofit, and shallow energy retrofit. In the deep retrofit approach, the building as a whole is considered as a single integrated system of components like (i) building envelope, (ii) heating or cooling systems, (iii) renewable energy sources, and (iv) building operations [2]. Such retrofitting aims for a 50% reduction in total energy consumption from the building site, when compared to an unrenovated case. Shallow retrofits represent partial renovations or refurbishments, like upgrading the HVAC or lighting systems, which have low initial investments and short payback periods. Studies report that over the longer term, shallow retrofits turn out to be less productive and expensive than deep retrofits [1].

Krarti suggests three energy-efficient retrofit technologies applicable in existing buildings, which are found most feasible in producing tangible outcomes; they are (i) optimized and advanced building envelope systems (ii) energy-efficient heating/cooling systems (iii) improved lighting systems [3]. Among the three retrofit technologies, the building envelope retrofit is regarded as a system that can significantly reduce energy consumption and maintain indoor thermal comfort by adopting passive measures [4].

The rate of research publications in the area of envelope retrofitting is increasing at a fast pace, making it difficult for researchers and academicians to keep up with the trends and gaps in research. Literature review papers provide an overview of the latest advancements in the research domain. Several State-of-the-art review papers on building envelope retrofitting have been published, reviewing the energy performance requirements, retrofitting measures, and challenges [5], façade up-gradation using passive solar techniques in hot climates [6] and cold climates [7], the energy retrofits optimizing strategies [4], various experimental and simulation techniques adopted in evaluating thermal retrofit [8], life cycle assessment methodologies [9], and assessment of post-retrofit behavior [10]. However, there are no studies on approaching building envelope retrofit in terms of energy efficiency and climate adaptation on a higher scale beyond the individual building. Most of the studies have an inward-looking approach, where the focus is on retrofitting the individual building envelope, and not a systemic approach, including its immediate surroundings or the neighbourhood. Most of the studies lack evidence of scalability to broader building blocks.

An understanding of the scalability of the retrofit technique and regional retrofit strategies is essential to address cumulative energy performance, heat island effects and climate resilience. This study aims to fill this gap by providing a comprehensive picture of the status, challenges, and future directions in building envelope retrofit for energy efficiency and climate adaptation. This paper adopts bibliometric data analysis techniques to present an overview and evolution of sustainable, energy-efficient, and low-carbon retrofitting studies, highlighting key trends, influential publications, and emerging themes in the field. A systematic review aids the study to provide an in-depth understanding of the key research clusters and provide an evaluation of the scalability of the intervention. The findings offer valuable recommendations for policymakers, architects, and researchers to enhance the sustainability of the built environment [11].

By evaluating the evolution of research on this topic, his paper presents a bibliometric review, and the study aims to provide an understanding of the contributions of envelope retrofitting in energy efficiency and climate adaptation in sustainable urban development.

2. Materials and Methods

The study was carried out in four phases starting with gathering bibliometric data for the analysis. Bibliometric data of research publications are available in various databases. This paper gathered data from the Scopus database due to the limited accessibility to other prominent databases. Phase two of the study used the Biblioshiny package from R-studio to conduct a meta-analysis of the identified publications. This stage resulted in identifying the trends in the research domain and publications related to sustainable building envelope retrofit. Key research clusters and keyword occurrences identified from the bibliometric data analysis were further reviewed in phase three by conducting a systematic review and finally phase four lays out recommendations from the literature review (Figure 1).

2.1. Bibliometric Process

Bibliometric analysis is a data-driven approach that helps in formulating a trajectory and foundation of a research area, including influential works, emerging research areas, and the overall impact of scholarly contributions [12]. Bibliometric analysis uses citation data like paper title, abstract, keywords, author information and journal information, to give a bigger picture of the research field. Current research trends and direction of the sustainable envelope retrofit research finally aid in arriving at the existing research gaps [13].

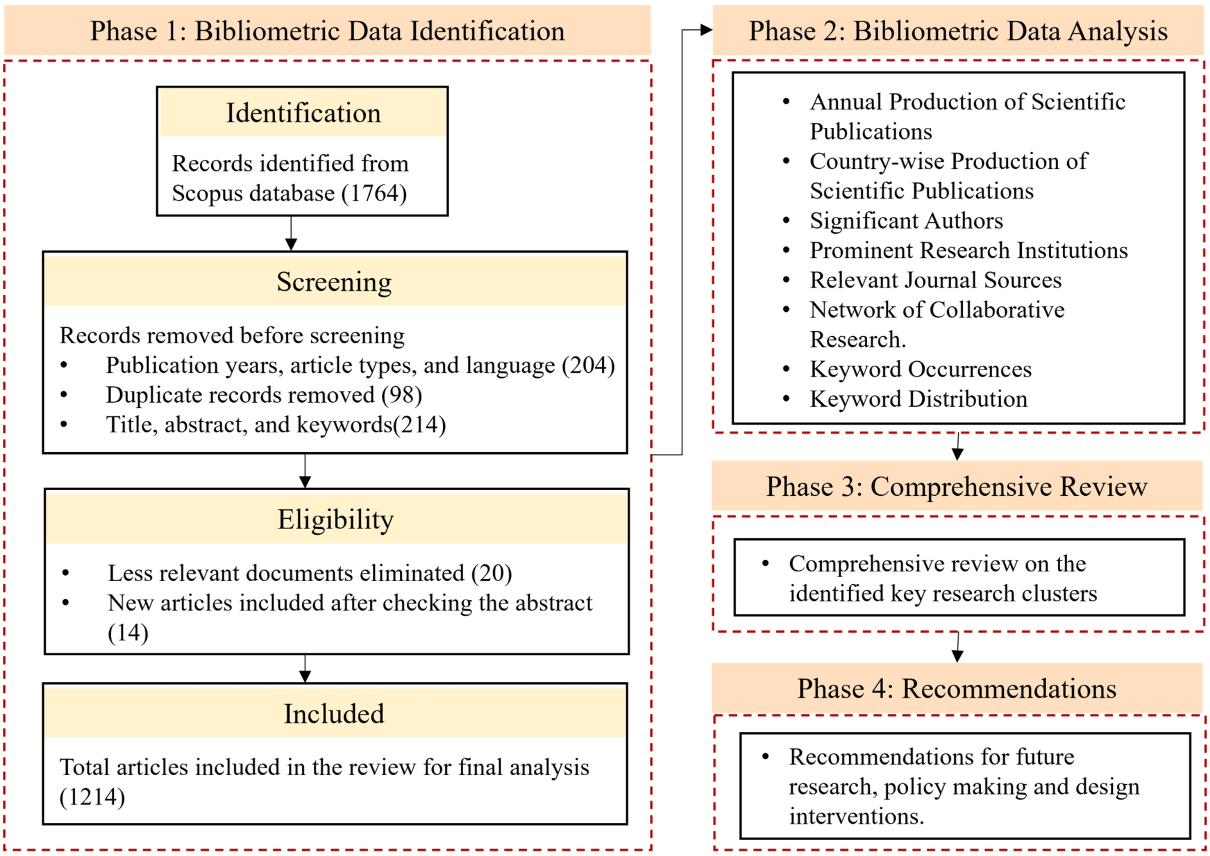


Figure 1. Methodology Flowchart

Bibliometric methodology plays a crucial role in research by providing quantitative insights into publication trends, author collaborations, and the evolution of scientific knowledge within a specific field. Bibliometrics techniques are employed for assessing the impact of research results, facilitating informed decisions about funding allocation and scholarly progress. This tracks the evolution of research topics, spots new trends, and reveals shifts in scholarly priorities by looking at publication and citation trends. Furthermore, by visualizing the relationships among authors, organizations, and countries, bibliometric approaches provide insights into networks of collaboration and the dissemination of knowledge.

The methodology for bibliometric analysis was developed from [14-17]. In this paper, the bibliometric data was screened from the Scopus database maintained by Elsevier. The initial search using the search string resulted in 1764 documents; screening the documents based on the year of publication (2014-2024), language (English), and published journals and reviews resulted in 1248 documents. Documents were further screened individually by reading the abstract and keywords. 1214 documents were finally selected for conducting bibliometric analysis using the Biblioshiny package.

The search string devised for identifying the relevant articles in the domain of building envelope retrofit, along with the main information about the identified articles, is presented in Table 1.

Table 1. Main information of the bibliometric search

Search string: TITLE-ABS-KEY ("building envelope" OR "building skin" OR "facade" OR "building enclosure") AND TITLE-ABS-KEY ("retrofit*" OR "rehabilitat*" OR "renovat*" OR "energy retrofit") AND TITLE-ABS-KEY ("energy efficien*" OR "energy performance" OR "energy conserv*" OR "climate adapt*" OR "climate resilien*" OR "climate-responsive design"))	
Timespan	2014-2024
Documents	1214
Sources	298
Keywords Plus	5043
Author Keywords	2955
Authors	3443
Single-authored documents	65
Co-Authors per Documents	3.83
International co-authorship %	25.04
Average citations per document	18.24

* TITLE-ABS-KEY is used to search the given terms in the TITLE/Title, ABS/Abstract and KEY/Keywords of the published paper.

The biblioshiny package in R-studio is used to conduct bibliometric analysis. This is a web-based graphical interface that is designed for analyzing the metadata from the scientific publications, identifying patterns and visualizing the data in an easy process without writing any R-codes. Biblioshiny supports data from Scopus, Web of Science, PubMed and other few bibliometric databases.

3. Results of Bibliometric Data Analysis

This section illustrates and elaborates on the bibliometric data analysis of the 1214 published articles. The publication is tracked for ten years, from 2014 to 2024, to analyze the publication trends, leading journals, keyword co-occurrences, influential themes, institutions, and countries in this research field.

3.1. Annual Production of Scientific Publications

The annual publication trend of articles related to building envelopes retrofit for energy efficiency and climate resilience from 2014 to 2024 is shown in Figure 2. The trendline of annual scientific production demonstrates a sheer increase in the number of published articles for the last ten years. Linear growth is exhibited when annual production has increased from 54 articles in 2014 to 159 articles in 2024. This consistent growth indicates that the research in the domain of building envelope retrofit for energy efficiency and climate resilience has been gaining significance over the years. The increasing number of publications makes it difficult for the researchers to stay updated about the field, identify research gaps and novelty in studies. The publication trend also leads to more systematic reviews and meta-analyses to provide a consolidated overview.

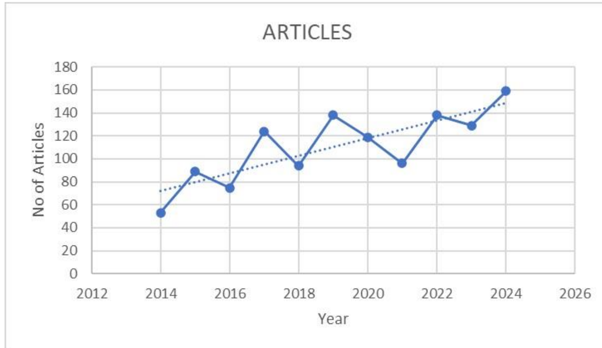
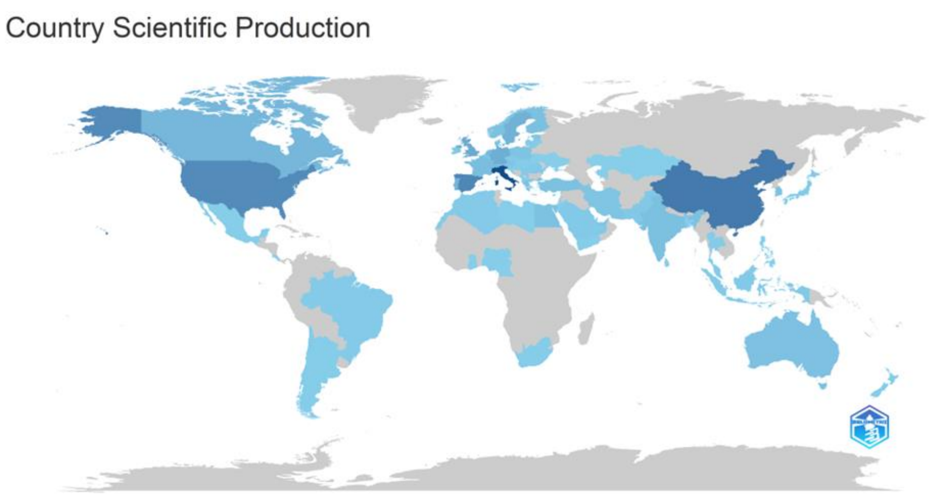


Figure 2. Annual Scientific Production

3.2. Country-Wise Production of Scientific Publications

Figure 3 presents the top fifteen countries that lead the country's scientific production list in the domain of building envelope retrofitting. Italy, China, Spain, and the USA top the list in the frequency of publications. The country's scientific production figure gives an insight into the fact that building envelope retrofitting is a significant domain of research in countries from all climate zones. There is a global recognition for the role of sustainable retrofit of building envelopes that highlights both climate-specific strategies and broader sustainability goals.



ITALY	405	CHINA	258	SPAIN	217	USA	200	UK	108
GERMANY	94	SWEDEN	84	PORTUGAL	75	CANADA	68	SWITZERLAND	58
NETHERLANDS	57	FRANCE	49	FINLAND	40	GREECE	40	INDIA	40

Figure 3. Country Scientific Production

3.3. Contributions by Key Authors

The 1214 shortlisted publications involve contributions from 3443 authors. The top ten most productive authors and their details are provided in Figure 4. Ascione F and Bianco top the list with the largest number of articles, 19 and 18 respectively. Both these authors have made a sustained contribution to the research domain from 2015 to 2024 with a significant number of citations. Figure 5 gives an illustration of the countries of the corresponding author. The top two key contributing authors are from Italy, which reflects Italy's research focus and how Italy serves as a research hub for this research domain.

3.4. Prominent Research Institutions

Table 2 lists the most productive institutions with the highest number of contributing articles. Sapienza University of Rome, University of Napoli Federico, and Delft University of Technology top the list. Information about the centers of excellence in a particular research domain is helpful in understanding where relevant and cutting-edge research is produced and can aid collaboration and networking among researchers. However, the list might lead to overlooking emerging centers that focus on regional studies.

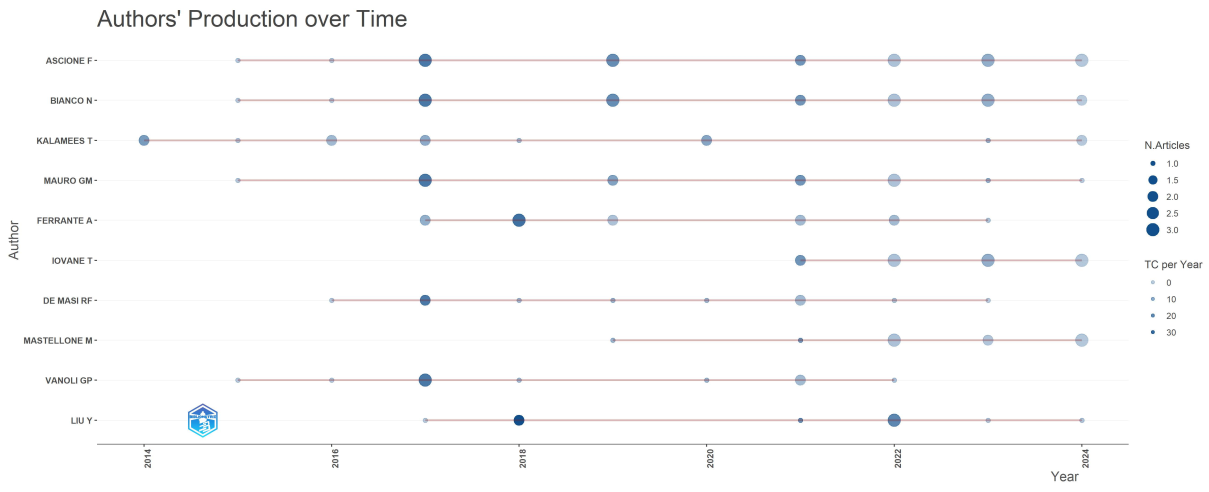


Figure 4. Author Contribution

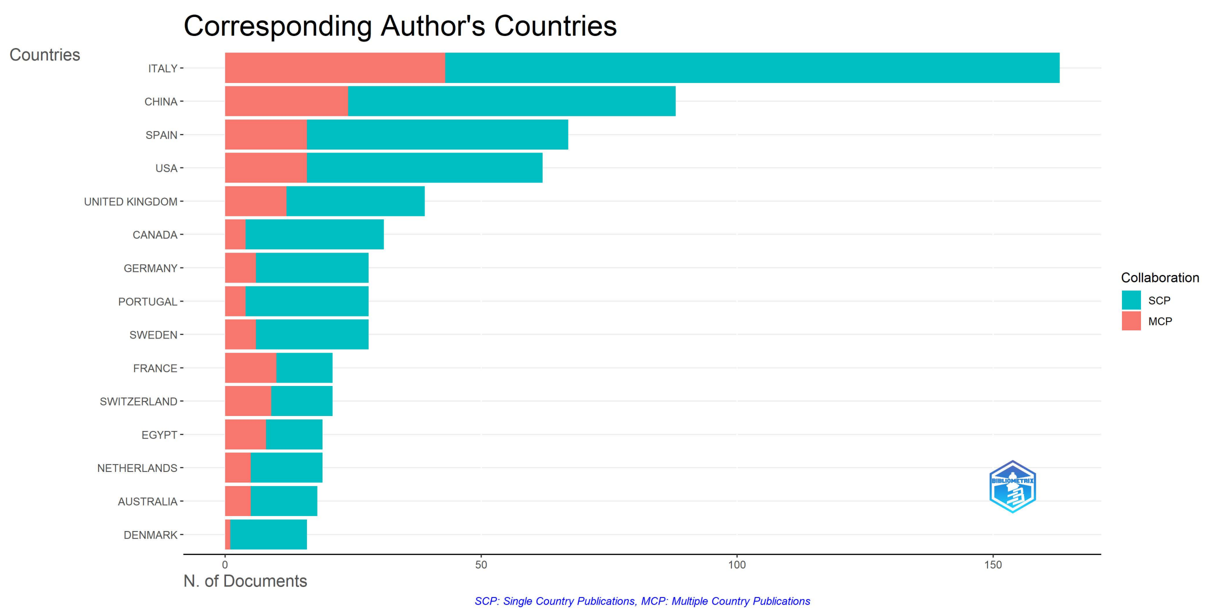


Figure 5. Corresponding Author Country

Table 2. Prominent Research Institutions and Contributions

Affiliation	Articles
Sapienza University of Rome	25
Università Degli Studi Di Napoli Federico Ii	23
Delft University of Technology	19
University of Bologna	18
Tallinn University of Technology	16
Lund University	14
University of Naples Federico Ii	14
Chalmers University of Technology	13
Tongji University	13
Università Degli Studi Del Sannio	13

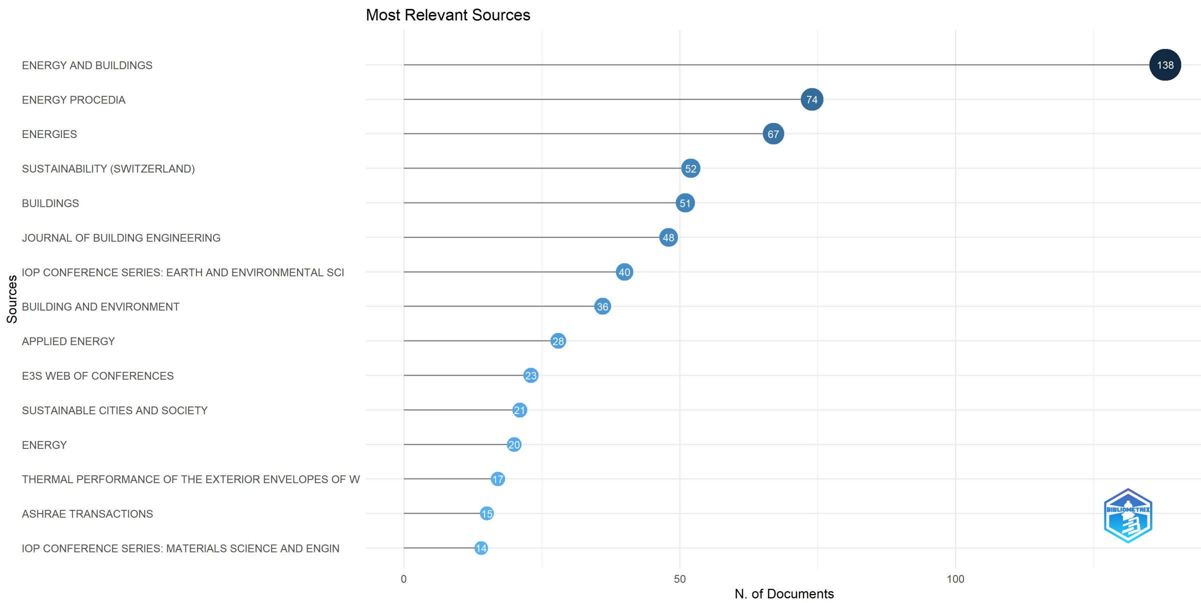


Figure 6. Most Relevant Sources

3.5. Most Relevant Sources

A total of 298 journal sources have contributed to the 1214 research publications that were selected for bibliometric data analysis. Figure 6 shows the leading journal sources in terms of the publication volume and citations. Energy and Buildings by Elsevier is listed as the top source with 138 publications and H-index of 44, indicating a strong citation index denoting that it is a leading source with significant research findings in the domain of sustainable retrofit strategies.

3.6. Keyword Frequency

Figure 7 and Figure 8 are tree maps representing the most frequently used keyword plus and the author's keywords, respectively. Energy efficiency is the most frequently used keyword listed by the author and appears in the abstract of the publication. Terms related to thermal comfort, enclosure structure, building retrofit, etc., are some of the most frequent keywords provided by the author of the publication. Energy conservation, energy utilization, building, retrofitting, enclosures, etc., are the most frequently found keywords in the abstract of the publication. Keyword frequency provides an understanding of the internal structure of the article and the focus of the research domain.

Figure 9 presents the data related to the most frequent keywords resulting from the bibliometric search. The keywords are graphically placed based on their network density and centrality. Based on the representations, energy savings, energy demand, façade retrofit, multi-objective optimization, cool roof, building insulation, energy conservation, etc. are categorized as the motor themes with the highest density and centrality. Energy savings, sustainability, life cycle assessment, climate change, and building envelope are the most basic themes; ETICS thermography, TRNSYS, and ventilated facade are categorized as the niche themes exhibiting a high degree of development; building energy efficiency, building energy retrofitting, urban heat island, etc., have low density and centrality and are hence categorized as either emerging or declining themes.

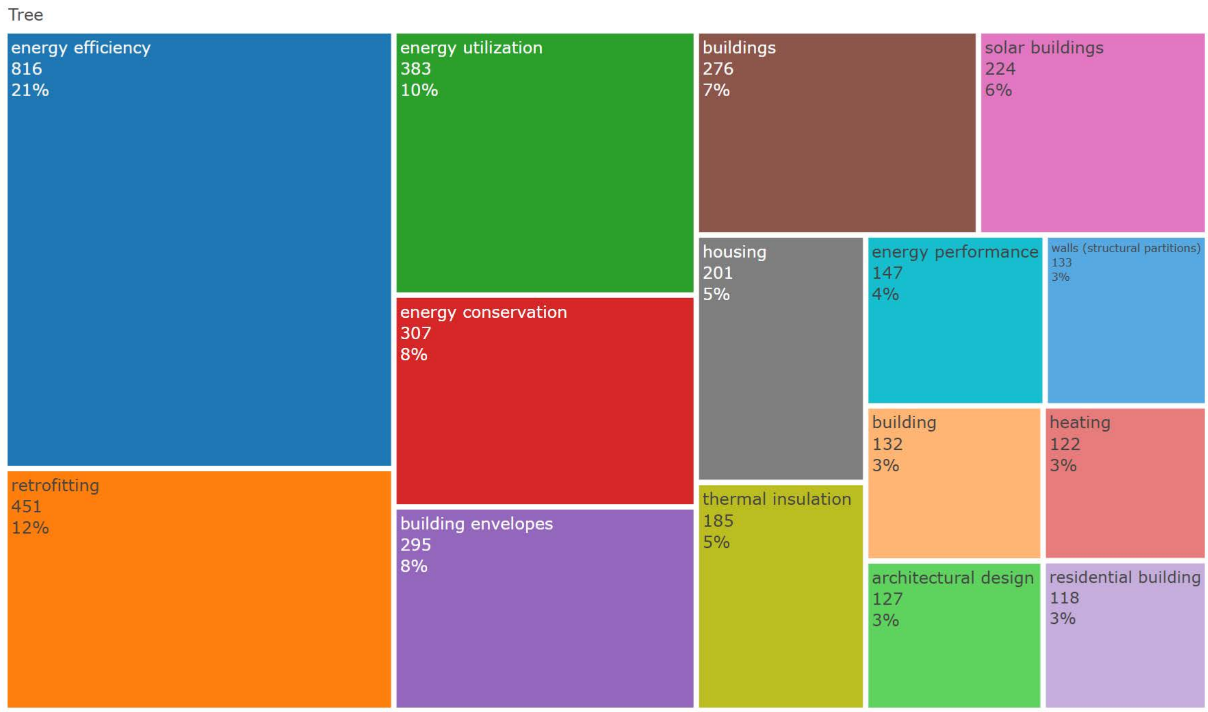


Figure 7. Frequency of Keyword Plus

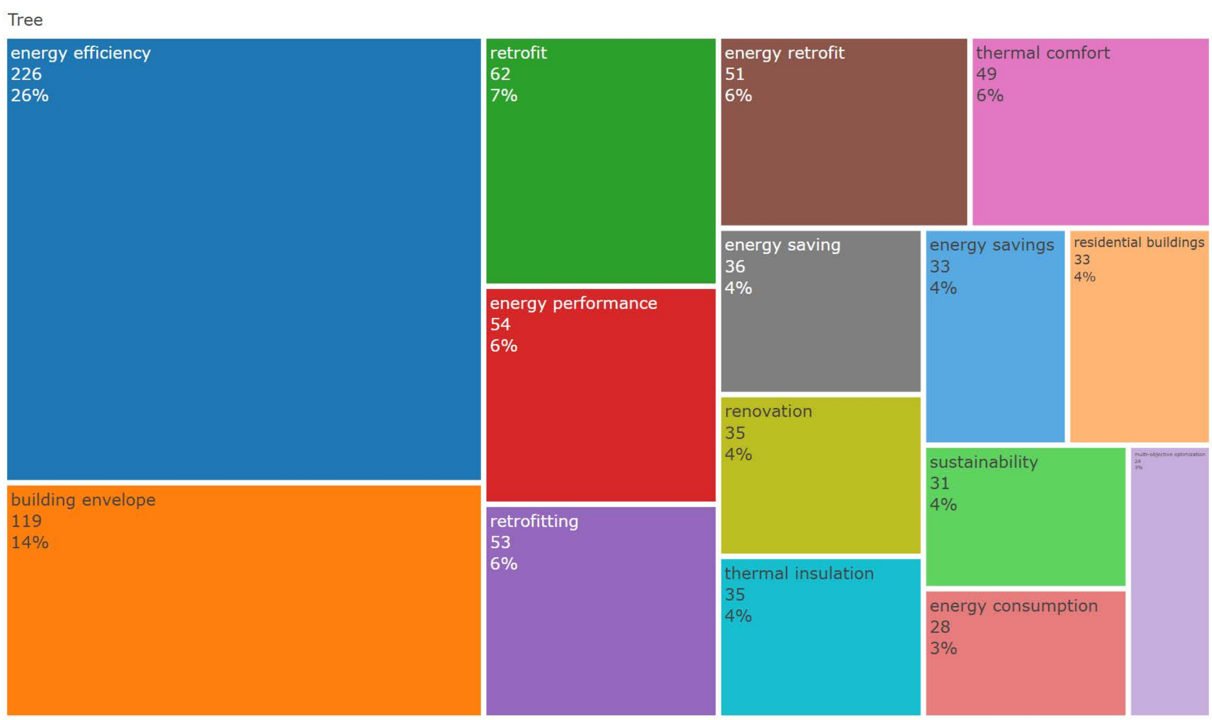


Figure 8. Frequency of Author Keyword

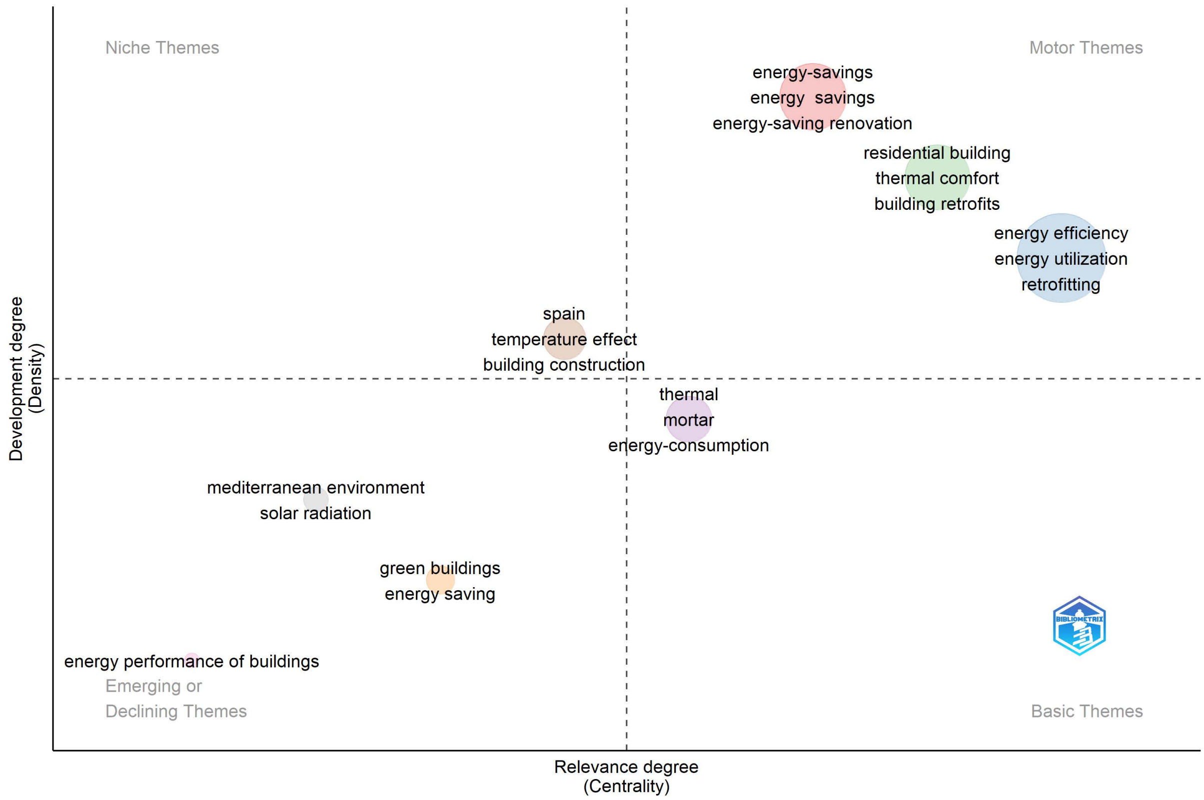


Figure 9. Keyword Distribution

The selection of keywords plays a crucial role in bibliometric analysis, enabling the identification of influential documents and databases by authors. A comprehensive understanding of research progress can be achieved by developing keyword networks within the research domain. A network visualization was conducted based on a predefined threshold of essential keywords, forming three clusters, as illustrated in Figure 10.a and Figure 10.b. The node sizes represent keyword frequency, highlighting fifty influential keywords with significant occurrences in the research domain. The link strength indicates the prioritization of certain research areas and their strong connections to other terms. The main Cluster 1 covers the aspects of energy efficiency, energy conservation measures, zero-energy buildings, thermal comfort, and energy performance. Cluster 2 contributes to life cycle assessments, green building, and environmental impact related to building enclosures. Cluster 3 relates to the performance assessment methods, energy simulations, and optimization methods.

3.7. Author, Keywords and Countries

Figure 11 shows a three-field plot representing the association of the top productive authors, the associated country, and the keyword contribution. This information is imperative in understanding the major research focus of different countries and the prominent authors who lead the research. This will also help map the research gaps to create more collaborative research.

3.8. Collaboration Network

Figure 12 illustrates the collaborative network spanning and connecting different geographical areas present within the research area of sustainable building envelope retrofitting. A strong research collaboration among countries, affiliations, and authors improves the quality and visibility of scientific production. This is important in fields that address global sustainability goals and require localized solutions that are climate-specific with regional priorities. Dense network collaboration around certain countries indicates that these countries play key roles in acting as a hub of research activities.

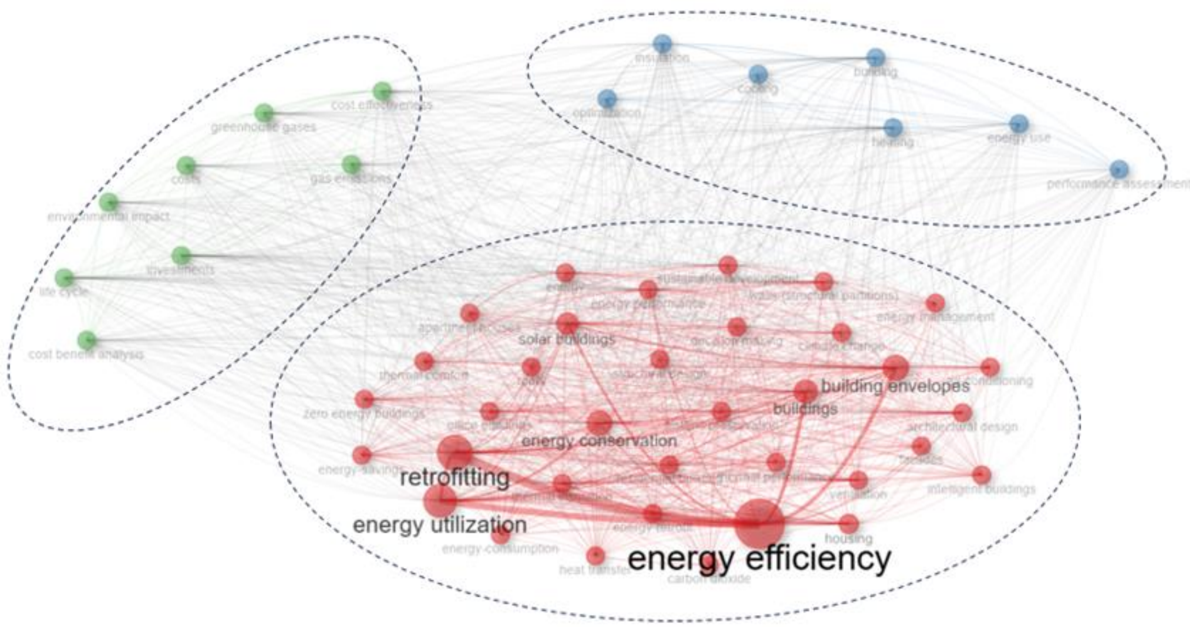


Figure 10a. Co-occurrences- Keyword Plus

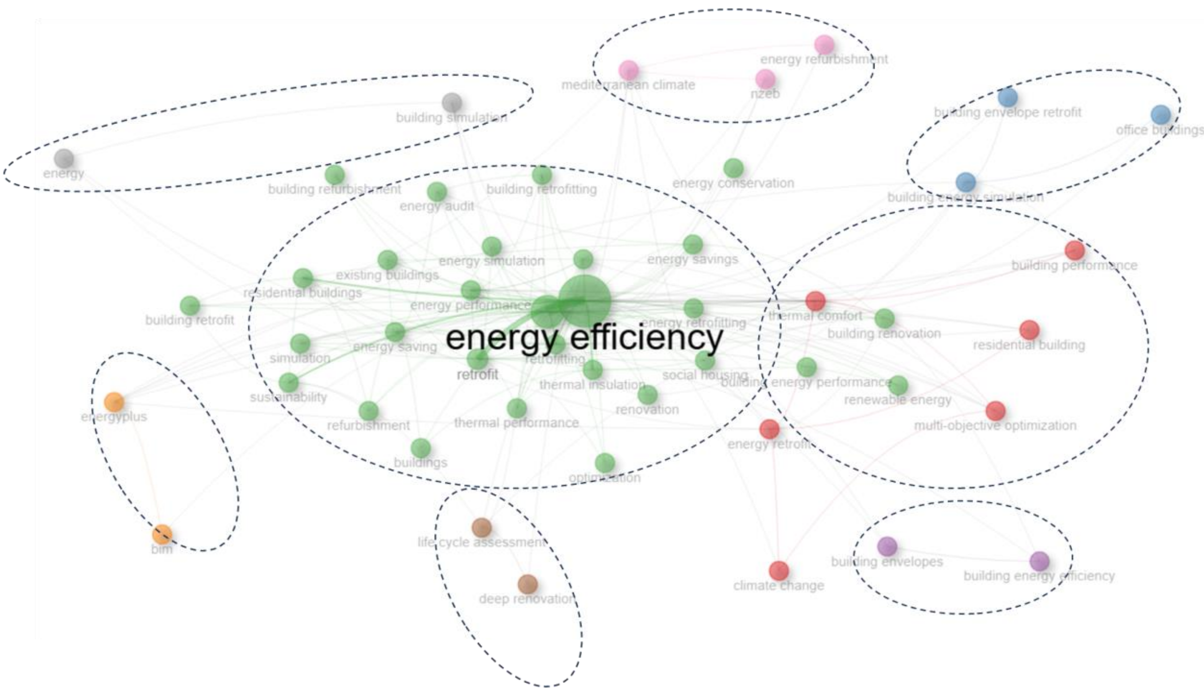


Figure 10b. Co-occurrences- Author keywords

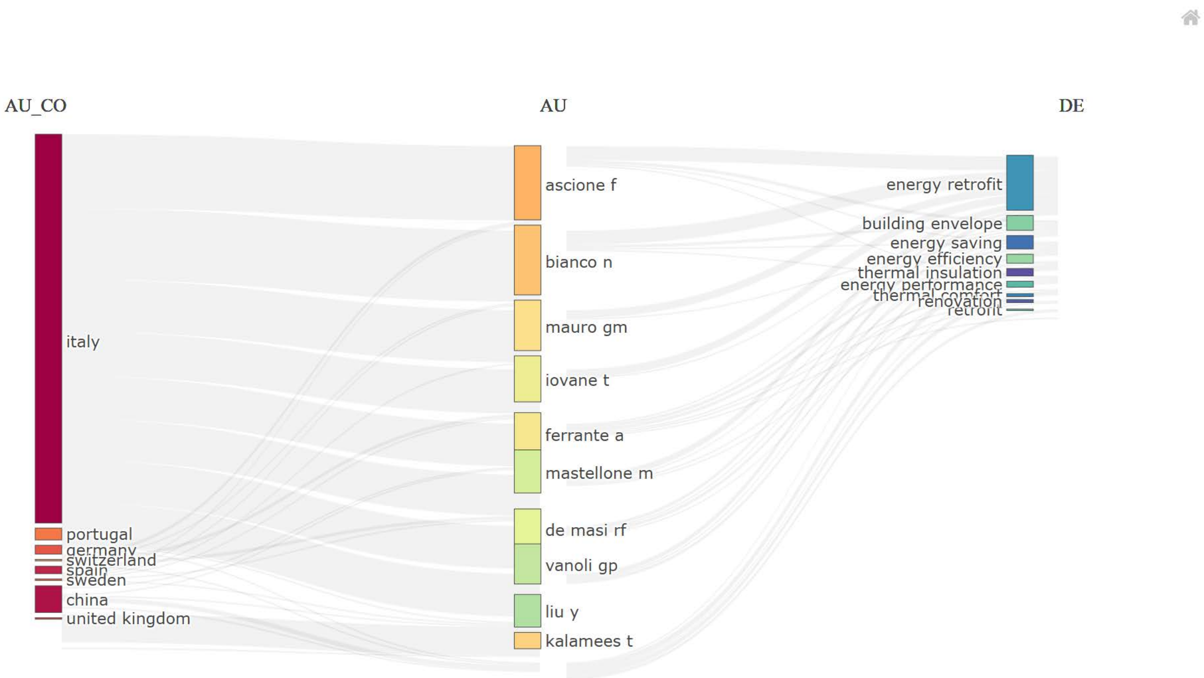


Figure 11. Author Country Keyword

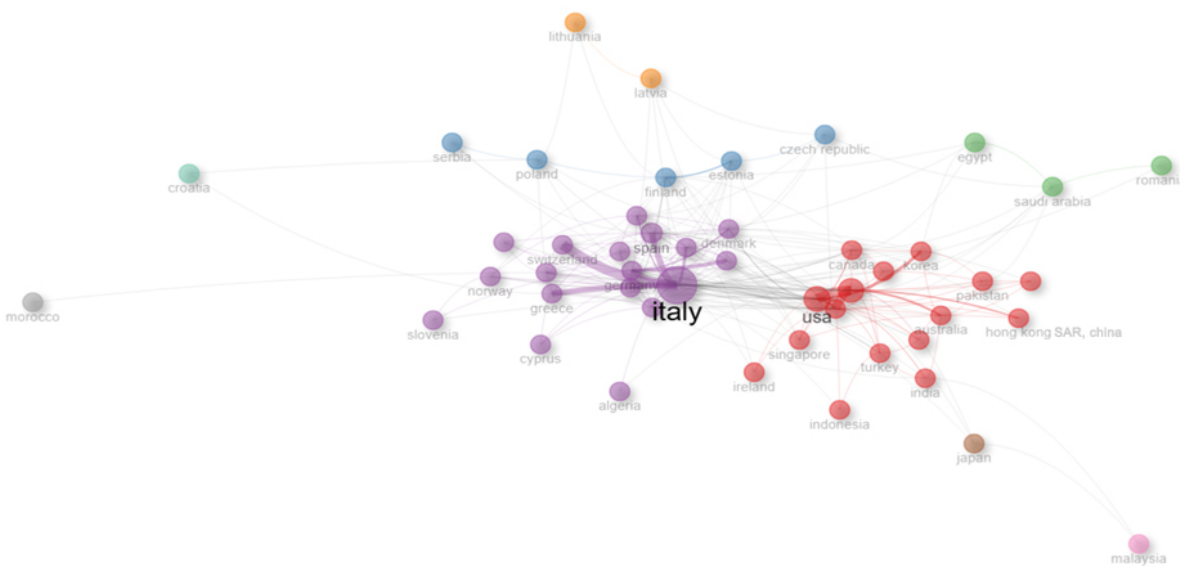


Figure 12. Collaboration network - Countries and Regions

4. Key Findings and Recommendations

Building envelope retrofitting is a prominent field of research in countries with developed economies and is gaining momentum in developing economies. Retrofitting building envelopes for energy efficiency and climate resilience is a popular approach to attain the goal of energy conservation in the building sector. The bibliometric analysis on energy efficiency and climate resiliency through building envelope retrofits identified key research trends, influential publications, and major thematic clusters. The study revealed a growing body of literature emphasizing the role of envelope retrofits in enhancing building sustainability, reducing energy consumption, and improving thermal comfort in response to climate change.

The most cited works focused on energy efficiency through life cycle assessments, energy conservation measures, and thermal comfort studies. This is identified as a key research cluster. Another prominent research cluster identified is related to sustainable retrofit materials. However, the publications lack strategies related to the climate resilience of envelopes like adaptive building envelopes, green roofs, and phase-change materials. Computational modeling and simulations also make up a prominent cluster of keywords. The following sections elaborate on the identified research clusters.

- **Cluster 1: Energy efficiency strategies**

A bibliometric review of energy research reveals a distinct cluster focused on energy efficiency and conservation in the built environment, encompassing topics such as energy efficiency strategies, energy conservation measures, zero-energy buildings (ZEBs), thermal comfort, and overall energy performance [18], [19]. This cluster highlights the integration of advanced technologies and passive design strategies to optimize energy use in residential and commercial structures. Researchers within this domain explore innovative insulation materials, smart energy management systems, and renewable energy integration to achieve ZEB standards. Additionally, studies emphasize the balance between reducing energy consumption and maintaining indoor thermal comfort, assessing parameters such as air quality, temperature regulation, and occupant satisfaction. The evolving landscape of this research cluster underscores the role of policy frameworks, building codes, and emerging technologies in enhancing energy performance while minimizing environmental impact. Nevertheless, there is a lack of integration between energy-efficient and resilient technologies. Also, there is a minimal coverage of technologies like adaptive facades.

- **Cluster 2: Material Selection and Carbon Emissions**

This cluster looks at how to assess the environmental impact of construction methods, building materials, and operational performance. Research in this field examines how LCA can guide building enclosure material choices, energy efficiency enhancements, and carbon footprint mitigation techniques. The study also emphasizes how cutting-edge technologies like adaptive façades and high-performance insulation can improve sustainability. This cluster advances environmentally responsible construction practices and reduces the built environment's long-term ecological impact by combining LCA with green building certifications and regulatory frameworks [9], [20]. However, there is an under-representation of sustainable region-specific materials and the adoption of innovative materials like phase change materials.

- **Cluster 3: Simulation and Optimization**

This cluster encompasses studies that evaluate the effectiveness of energy systems using key performance indicators, such as energy efficiency, cost-effectiveness, and environmental impact. Researchers utilize advanced energy simulation tools to model and predict system behaviors under various conditions, enabling the identification of optimal operational strategies. Additionally, optimization methods, including machine learning algorithms, metaheuristic approaches, and multi-objective optimization frameworks, play a crucial role in enhancing system performance by balancing trade-offs between energy consumption, cost, and sustainability. The integration of these methodologies contributes to the advancement of smart and sustainable energy solutions, aiding policymakers, engineers, and researchers in making data-driven decisions for improved energy management and resource utilization [20–23]. An in-depth analysis of the keywords identifies a need for more real-time and AI-driven simulation models that consider the climatic conditions and user behaviour.

Table 3 summarizes the representative studies from each of the three key clusters and highlights the status of the current research. The latest research in cluster 1 explores an integrated approach for retrofitting involving passive measures, active measures, role of occupant behavior and renewable energy sources. The trend points towards intelligent building monitoring systems towards low-carbon cities. Representative studies from cluster 2 provide life cycle focused studies for material selection and impact assessments, exploring both advanced and regional materials. Cluster 3 represents innovative and futuristic studies of climate prediction models, multi-objective optimization and energy prediction algorithms.

4.1. Recommendations

- Future research should focus on developing climate-responsive retrofitting strategies specific to different geographic regions. Retrofit strategies and policies should consider the variations of climatic conditions, building typologies, and socio-economic constraints. Studies should emphasize the development of adaptive facades adopting phase change materials, green walls, and bio-based materials that are deemed suitable, considering local environmental conditions and energy needs.
- Future research should leverage artificial intelligence and advanced optimization techniques like machine learning and genetic algorithms to advance sustainable retrofitting decision-making, based on real-world building performance data. Multi-objective optimization frameworks need to be explored to balance energy efficiency, cost-effectiveness, and occupant comfort.
- More studies should focus on sustainable building envelope materials. Locally sourced, low-carbon, and recyclable materials, particularly in developing nations. Innovative materials, such as phase-change materials, bio-based insulation, and dynamic facades, have the potential to enhance building energy performance while reducing embodied carbon emissions.

Table 3. Representative studies from the identified clusters

	Research Goal	**Methodology**	**Key Findings**	**Author (s)**
Cluster 1	Investigate intelligent building monitoring systems for low-carbon city.	Literature reviews on building energy analysis, conservation and intelligent monitoring of buildings.	Various energy analysis and prediction models are identified. Occupant behaviour and renewable energy utilization are analyzed. Research gap in identifying, selecting and using building monitoring systems.	Yan Su et al. (2024) [23]
	Explores passive and active measures promoting energy efficiency, and the role of occupant behaviour and renewable energy sources.	Literature reviews sustainable, green and smart buildings in healthcare buildings.	Including Building Information Modelling (BIM) for retrofitting for energy performance and environmental quality. Striking a balance between energy reduction and user comfort through integrated measures.	Brenda V.F. et al. (2024) [24]
Cluster 2	Advanced material research to enhance thermal performance and energy efficiency.	Systematic review of advanced energy-efficient building materials.	Potential of advanced materials in thermoregulation, energy and carbon reduction. Identify challenges for broader applicability.	Khalid Ghazwani et al. (2025) [25]
	Exploring envelope retrofit methods for energy efficiency, aesthetics and environmental quality.	Comprehensive review of integrated sustainable practices in building envelope retrofitting.	Distinct retrofitting techniques for building envelope components like walls, roofs, windows and solar shading. Integral role of simulation platforms and tools in assessing material performance and the significance of cost-benefit analysis.	Saleh Abu Dabous (2025) [26]
	Integrates Life Cycle Assessment and Life Cycle Costing to guide material selection, retrofit impact, and certification.	Development of a software tool using Microsoft Excel.	Demonstrated how material choices influence carbon footprint and compliance with green rating systems. Ideates a software tool for LCA/LCC.	Andrea Jorge-Ortiz (2025) [27]
Cluster 3	Investigating the effectiveness of envelope retrofits and photovoltaic systems in building envelope retrofit.	Simulation studies using DesignBuilder and PVsyst software.	Formulation of climate-specific building envelope retrofits and economic considerations are significant optimizing parameters.	Liao, X., et al. (2023) [28]
	Addressing single and multi-factor retrofitting scenarios for comprehensive and practical application.	Optimization using orthogonal experiments and DeST-h simulations. Entropy method for performance assessments.	Optimized multi-factor retrofits outperform single factor retrofits.	Liu, P (2025) [29]
	Exploring the use of machine language-based optimization under future climate projections.	Machine Learning-based surrogate models, climate models and multi-objective optimization.	Enabled optimized and robust retrofit scenario under uncertainty, highlighted need for climate adaptive design frameworks.	Ding, Z (2024) [30]
	Balancing energy savings and comfort in green retrofit design through optimization.	Computational Simulation and Response Surface Methodology for sensitivity analyses and optimization according to green building standards.	Produced an energy-comfort optimization model integrating computational simulation and response surface methodology. Identified critical parameters for optimization.	Qing Li (2021) [31]
	Exploring Urban building energy model (UBEM) to support the design of energy-efficient communities.	Solar-based building interdependency and spatio-temporal graph convolutional network (ST-GCN) algorithm.	Develops a ST-GCN algorithm for hourly energy prediction in urban building energy model and tests its validity on campus buildings.	Yuqing Hu (2022) [32]

Bibliometric analysis has its limitations, as it relies on a single citation database and the possible exclusion of relevant keywords in the search string formulation. Future studies can integrate data from databases such as Google Scholar and Web of Science to provide a more comprehensive perspective on research trends in the research field. Expanding the scope by including emerging technologies and regional adaptation strategies in the search string will further enrich the field.

5. Conclusions

The study identifies bibliometric analysis as a valuable tool for understanding the structure and trends in a research domain, aiding policymaking and design strategy formulation. Bibliometric mapping of published articles on the topic of sustainable building envelope retrofitting was conducted using the ‘Biblioshiny’ web interface within the R-Studio package. The bibliometric search was limited to citation data from the Scopus database with a search string formulated by combining keywords identified from an initial literature review. A total of 1214 articles were selected for citation data analysis to extract insights on country-wise scientific production, the most productive affiliations, authors and their impact factor, the most relevant journal sources and their growth, keyword frequency and trends, and the network of collaborative research among different countries, institutions, and authors.

The analysis indicated a steady increase in scholarly interest, particularly in the past decade, driven by global sustainability goals and climate adaptation policies. Key authors and institutions driving the discourse were identified, with collaborations often occurring between universities, government agencies, and industry stakeholders. Highly cited works provided insights into best practices, policy recommendations, and innovative technologies in envelope retrofitting.

The publication rate in the field of building envelope retrofitting has increased, reflecting growth in thermal retrofitting policies and strategies, retrofitting technologies and materials, assessment methods, evaluation parameters, and optimization networks. Among the most studied topics, thermal insulation stands out with consistent growth in publications, while artificial neural networks, multi-objective optimization, and green retrofits have emerged as recent trend topics. However, the analysis reveals a research gap, with most studies originating from developed countries, leaving significant opportunities for exploration in developing regions, where this can lead to transformative decision-making addressing climate challenges and building performance.

The future of building envelope retrofit lies in promoting global collaboration, inclusive research and innovative context-sensitive interventions, because sustainable and resilient buildings are a shared global endeavor.

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