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A BIBLIOMETRIC ANALYSIS OF THE BIM ROBUSTNESS IN THE SUCCESS OF BUILDING REFURBISHMENT

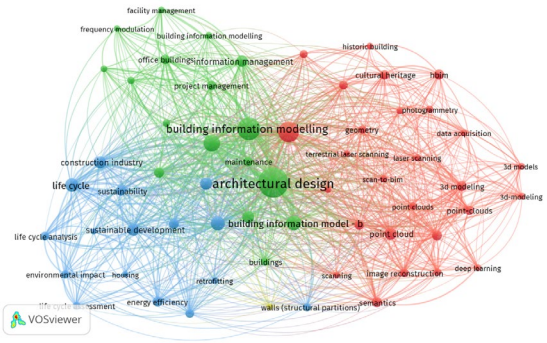
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Graphical abstract



Abstract

Building refurbishment is increasingly acknowledged as more complex than new construction due to uncertainties in existing structures, limited documentation, and higher risk levels. In response, Building Information Modeling (BIM) has evolved as a vital digital tool, offering powerful solutions for data integration, visualization, and multidimensional coordination. This paper presents a bibliometric analysis to examine the trends and impact of research on BIM robustness in the context of building refurbishment projects. A total of 339 publications from the Scopus database were analyzed using Scopus Analyzer and VOSviewer to explore patterns in publication growth, citation networks, co-authorship collaborations, and keyword co-occurrence. The analysis shows that during the past ten years, there has been a major increase in scholarly interest, with notable contributions from nations including the United States, China, and the United Kingdom. Four (4) key themes identified include architectural design, BIM, sustainability, and structural design. These findings reflect the evolving research landscape and growing emphasis on BIM's potential to address the complexities of refurbishment projects. This study contributes to the field by mapping existing knowledge and emphasizing the need for strategic benchmarking and further exploration of BIM's role in enhancing the success and efficiency of building refurbishment initiatives.

***Keywords*:** Building Information Modelling, Building Refurbishment, Architectural Design, Sustainability, Bibliometric Analysis

Abstrak

Pengubahsuaian bangunan semakin diakui sebagai lebih kompleks daripada pembinaan baharu disebabkan ketidaktentuan dalam struktur sedia ada, dokumentasi terhad dan tahap risiko yang lebih tinggi. Sebagai tindak balas, Pemodelan Maklumat Bangunan (BIM) telah muncul sebagai alat digital utama, menawarkan penyelesaian teguh untuk penyepaduan data, visualisasi dan penyelarasan pelbagai dimensi. Kertas kerja ini membentangkan analisis bibliometrik untuk mengkaji trend dan kesan penyelidikan terhadap keteguhan BIM dalam konteks projek baik pulih bangunan. Sebanyak 339

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penerbitan daripada pangkalan data Scopus telah dianalisis menggunakan Scopus Analyzer dan VOSviewer untuk meneroka corak dalam pertumbuhan penerbitan, rangkaian petikan, kerjasama pengarang bersama dan kejadian bersama kata kunci. Analisis menunjukkan peningkatan ketara dalam minat ilmiah sepanjang dekad yang lalu, dengan sumbangan ketara daripada negara seperti China, United Kingdom dan Amerika Syarikat. Empat (4) tema utama yang dikenal pasti termasuk reka bentuk seni bina, BIM, kemampanan, dan reka bentuk struktur. Penemuan ini mencerminkan landskap penyelidikan yang berkembang dan penekanan yang semakin meningkat terhadap potensi BIM untuk menangani kerumitan projek pengubahsuaian. Kajian ini menyumbang kepada bidang dengan memetakan pengetahuan sedia ada dan menekankan keperluan untuk penanda aras strategik dan penerokaan selanjutnya peranan BIM dalam meningkatkan kejayaan dan kecekapan inisiatif pengubahsuaian bangunan.

***Kata kunci*:** Pemodelan Maklumat Bangunan, Pengubahsuaian Bangunan, Reka Bentuk Seni Bina, Kelestarian, Analisis Bibliometrik

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1.0 INTRODUCTION

The rapid pace and scale of urbanization present significant challenges to the built environment, highlighting the increasing necessity of building refurbishment within the construction industry. It is projected that by 2030, urban populations will exceed rural populations, with over 82% of individuals residing in urban areas. This demographic shift, coupled with continued urban growth, results in increased pollution, developmental disruptions, and the deterioration of existing infrastructure [1, 2].

Furthermore, a significant portion of the existing building stock, is aging and does not meet current structural, energy, or seismic standards, necessitating extensive renovations [3, 4, 5]. Architectural heritage, being a finite resource, faces threats from urbanization, natural disasters, and inappropriate alterations, impeding the fulfillment of the Sustainable Development Goals (SDGs) [6, 7].

This imbalance between new developments and the need to manage and upgrade existing structures highlights a crucial gap. Nearly 20% of the current building stock needs to be renovated in order to solve climate problems and become zero-carbon ready by 2030 [8]. Refurbishing buildings has become a crucial tactic since it may increase operational energy efficiency, prolong the life of existing structures, and benefit urban regions economically and socially [9].

Refocusing on refurbishment works, it is important to note that there is no single, definitive definition of the term. According to the [10], refurbishment is described as the act of making something neat, clean, or complete through renovation, re-equipping, or restoration. A refurbishment encompasses a broader scope, extending beyond mere alterations to include rehabilitation, extension, improvement, conversion, modernization, fitting out, and repair of existing buildings to allow them to be repurposed [11]. In addition, a refurbishment as synonymous with rehabilitation, which also aligns with terms like restoration, reconstruction, and rehabilitation [12]. This definition implies an approach that considers not just individual structures but also the wider localized environment. Given these varying definitions, it is apparent that the concept of refurbishment can either be too vague, lacking clarity on the different procedures involved, or too narrow, restricting the reader's perspective. In this study, it can be concluded that building refurbishment works include any action in upgrading the existing structure to improve a building lifespan. This definition is supported by [13], which reported that refurbishment offers a way to improve the performance of existing buildings without the economic and environmental costs associated with new construction projects. Consequently, the term "refurbishment" will be used consistently throughout this study.

Therefore, refurbishment of existing structures is acknowledged as one of the most ecologically friendly, sustainable, and cost-effective techniques to maximize a building's energy performance [10, 11]. These challenges highlight a pressing need for building refurbishment as a crucial strategy for sustainable urban development. Radical changes are required in the way buildings are designed and conceived to mitigate environmental impacts and extend the lifespan of existing structures. Refurbishment, renovation, adaptive reuse, recosntruction and retrofitting are considered environmentally friendly, sustainable, and cost-effective techniques to maximize the energy and structural performance of existing buildings.

However, the conventional refurbishment, retrofitting, and renovation practices are typically fragmented and less efficient, often relying on two-

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dimensional (2D) drawings and paper-based documents for architectural heritage analysis and design [14, 15, 16]. These traditional methods frequently involve manual procedures for documentation and cost estimation, which can complicate collaboration and conflict avoidance among professionals [14].

In addition, it is contribute to inefficiency, fragmentation, and waste in construction [17, 14]. Significant challenges exist in information sharing and management, leading to a loss of integration of disparate data throughout the rehabilitation process [3]. Communication and coordination difficulties are common, exacerbating reworks and delays [17]. Manual processes for tasks like life cycle cost analysis are slow and prone to errors due to interoperability and compatibility issues between different software. Moreover, there is often a lack of formal procedures for data exchange among disciplines, resulting in inefficiencies, interoperability issues, and fragmented information [4].

Furthermore, traditional approaches frequently provide incomplete or imprecise data for architectural heritage analysis, as existing 2D drawings are merely approximations of reality, leading to inaccuracies and limitations [18]. Obtaining "as-is" information is difficult, and there's a lack of detailed and accurate information about building materials and structural specifics, particularly for heritage buildings where rigid information may be unavailable [4, 19]. Traditional survey-based modelling methods used for precise 3D building models are costly [20], and extracting construction and demolition waste information can be time-consuming, inaccurate, and complex [21].

Moreover, project management in refurbishments is often difficult and unexpected because there is a great deal of uncertainty about the current conditions, physical constraints, and restricted access to working areas, especially when projects remain operational during construction [4]. Inadequate skills, abilities, and technical limitations of existing tools all serve as impediments [16]. Crucially, serious damages can occur during refurbishment processes, indicating inadequate risk assessment or planning in these conventional approaches [22, 23].

2.0 BIM ADVANTAGES IN THE CONTEXT OF BUILDING REFURBISHMENT

Thus, Building Information Modelling (BIM) is a novel way to get over the drawbacks of traditional construction methods in the age of digitization and the Fourth Industrial Revolution (IR 4.0). In this context, BIM is defined based on the researcher's comprehension. Contrary to what many in the construction industry assume, BIM is not software. To improve efficiency in building design and construction, BIM is the use of 3D (three-dimensional) data in the development of producing and managing building data throughout a project lifecycle [24]. Throughout a project's lifecycle, BIM is used to integrate data from several project management domains, such as design, modeling of existing conditions, budgeting, scheduling, digital manufacturing, site design and analysis, and project review [25].

Building Information Modelling is a crucial technology for integrated project management because of its ability to provide all stakeholders engaged in the project with the most up-to-date information on building risk management, which was previously done conventionally [26]. BIM allows for improved collaboration, communication, and data analysis throughout the entire project lifecycle [27]. BIM can be used as a tool to aid in decision-making when a problem occurs. BIM encompasses the entire process of generating and managing data for a constructed object. BIM incorporates structured, multidisciplinary data by creating a digital representation of an asset throughout its lifecycle. Also, BIM combines data from diverse disciplines to generate precise digital representations that are administered on an open cloud platform to facilitate real-time collaboration.

Internationally, BIM deployment has advanced significantly in a few developed and developing countries. BIM is required in the United States, the United Kingdom, and several European nations. With a 50% adoption rate, Singapore has already made it mandatory for all projects to be filed electronically using BIM. Since 2016, the government has released a number of BIM implementation guidelines and norms of practice. Furthermore, a high degree of acceptance has been attained in Australia, where roughly 42% of SMBs use BIM at levels 1 and 2, and 5% try level 3 [28].

Current study on the use of BIM for renovating existing structures is still in its infancy, particularly in Malaysia [29]. Nonetheless, the Malaysian Public Works Department (PWD) has integrated BIM through a number of programs, with the goal of applying it to 10% of public projects under RMK12 that cost more than RM 50 million. Furthermore, starting in 2018, any public projects with a budget of RM100 million or above will need to use BIM [30]. Therefore, there is fierce competition in these countries' construction industry to embrace technology and switch from traditional procedures to BIM-based technologies.

BIM provides significant benefits for refurbishment projects, assisting in alleviating the complexities often faced when dealing with existing structures, as outlined in Table 1.

Table 1 The benefits of BIM in the building refurbishment context

No.	Benefit in BIM	References
1	Improved project management and coordination	[31], [4]

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2	Improved communication and decision-making among stakeholders	[32], [33], [34]
3	Enhanced design accuracy and visualization	[32], [34], [20]
4	Cost and time efficiency	[32], [35], [36], [15]
5	Sustainability and environmental performance	[30], [32], [37], [34], [38]
6	Risk mitigation and safety	[35], [39]
7	Improved maintenance and operations	[20], [39], [23], [40]
8	Enhanced data management and accessibility	[32], [20], [41]

Overall, BIM's robustness in building refurbishment projects lies in its ability to centralise, manage, and visualise complex, multi-dimensional data across the entire building life cycle, supported by continuous integration with cutting-edge digital technologies to enhance accuracy, efficiency, and sustainability. Thus, to provide useful guidelines for future practices and developments in building refurbishment projects, it is essential to prioritize a comprehensive and well-reviewed objective that examines the trends and impact of research on the robustness of Building Information Modeling (BIM) in this context.

Therefore, there are two sources that were used to formulate the research question. First method, concepts from earlier investigations [42]. The second method combines the PICo mnemonic with a meta-aggregative review. In this context, "P" stands for "problem," "I" represents "interest," and "Co" refers to "context." This approach serves as a tool to help researchers develop clear and focused research questions for their review. The findings are then aggregated and presented without any re-interpretation [43]. In contrast, a meta-analysis is a systematic process used to synthesize or merge the findings of individual studies. It employs statistical methods to calculate an overall or 'absolute' effect [44].

The current practice in the building refurbishment (problem), BIM robustness (interest), and related refurbishment works (context) were the three primary elements that the authors incorporated in the review based on these ideas. There are four (4) research questions that the authors were able to construct as a result.

(i) What are the research patterns in this study area, based on the year of publication?
(ii) Who are the authors, and how much has been published in this area?
(iii) What is the collaboration among co-authorship countries?
(iv) What are the study's most popular keywords?

3.0 METHODOLOGY

3.1 Bibliometric Analysis with VOSViewer visualization

Bibliometric analysis is the process of collecting, organizing, and analyzing bibliographic information from scientific publications. The data information was supported by using VOSviewer to create co-occurrence networks. Additionally, a visualization map of the dataset was produced. This map includes advanced approaches such as co-citation analysis and descriptive statistics like publishing journals, publication years, and primary author classification [45, 46]. Finding appropriate keywords, looking through pertinent material, and doing a thorough analysis are all steps in an iterative process that is necessary to conduct a full literature review, provide a comprehensive bibliography, and produce trustworthy results [47].

3.2 Publication dataset

Accordingly, the research focuses on impact articles since they offer important insights into the theoretical frameworks influencing the development of the discipline. The SCOPUS database was chosen as the main source for data collecting in order to guarantee data accuracy.

Using the Scopus database, a bibliometric analysis was carried out to determine the amount of research on BIM robustness in relation to the building refurbishment's success. Advanced searching on the Scopus database is a feature that allows researchers to perform highly specific and targeted searches to retrieve relevant academic publications.

As indicated in Table 2, the keyword combinations were processed in Scopus databases using search techniques such as field code functions, phrase searching, wildcards, truncation, and Boolean operators.

Table 2 The search strings

Database	String
Scopus	TITLE-ABS-KEY ("Building information model*" OR "BIM") AND ("Building Refurbishment" OR "Building Restoration" OR "Building Rehabilitation" OR "Building Reconstruction") AND PUBYEAR > 2007 AND PUBYEAR < 2025 AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English"))

Additionally, the study's papers were either accepted or denied based on a set of criteria that are listed in Table 3. In order to conform to the notion of "research field maturity," as stressed by [48], this

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evaluation restricted the screening process to include only articles from 2008 to 2024.

It is because empirical research papers provide primary data, the authors made the decision to review them. Only English-language materials were taken into consideration to prevent confusion. By limiting the extensive database content to fit specific topics, authors, time periods, document kinds, or other pertinent factors, this aids writers in finding the exact information they require.

Table 3 The inclusion and exclusion criteria

Criterion	Inclusion	Exclusion
Timeline	2008-2024	<2008
Document Type	Articles	Conference Paper, Review, Book
Language	English	Non-English
Publication	Final	Article in press

4.0 RESULT AND DISCUSSION

4.1 Research patterns based on the publication year

Figure 1 shows the annual trend of 339 publications in Scopus from 2008 to 2024, showing a consistent rise in research production, particularly in the last five years. Notably, publication numbers significant increase in publication output from 2008 and peaked at 55 in 2024. This upward trend highlights growing academic and industry interest in refurbishment-related technological research and suggests that it will remain a research priority moving forward.

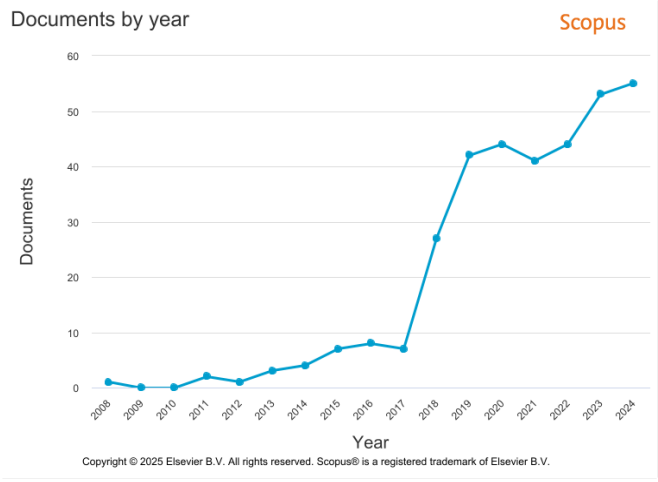


Figure 1 Number of publications by years 2008-2024

4.2 Number of documents published by sources and authors

The number of publications by source on the robustness of BIM in the context of associated building renovations from 2008 to 2024 is shown in Figure 2. Initially, from 2008 to around 2024, the source publication volume from Automation in Construction remained relatively consistent and stable, with minor fluctuations each year. This suggests that research interest in BIM in refurbishment environment was limited during this period, possibly due to the novelty of the concept or limited awareness and adoption of BIM technology. Researchers may have focused on foundational studies exploring the potential benefits and challenges of applying BIM in building refurbishment without widespread implementation.

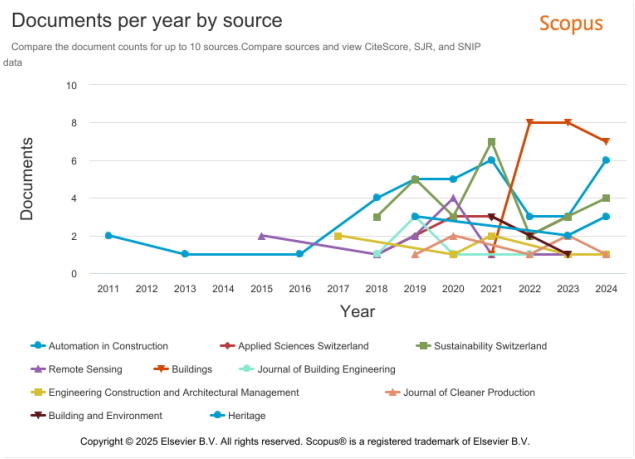


Figure 2 Number of publications by sources

Meanwhile, Table 4 tabulated the top 10 most-cited authors from 2008 to 2024 on the topic of BIM in building refurbishment nature context, revealing significant contributions to the field through various impactful studies. Leading this most-cited authors is the Pətrəucean, Armeni, Nahangi, Yeung, Brilakis, and Haas, which explores the '*State of research in automatic as-built modelling*', gathering 310 citations. With an emphasis on the geometric modeling aspect of reconstructing buildings, their work has been offering a broad perspective of the as-built modeling process.

Another prominent study by Xia, Liu Z, Efremochkina, Liu, and Lin, which ranks even higher in citations with 226. Through a review and bibliometric analysis of the integration of building information modeling and geographic information systems, this work aims to quantify the advantages of BIM and offers an empirical method for evaluating its worth in sustainable city planning.

The high citation count indicates that quantifying BIM's tangible benefits has been a priority for academia and industry, reinforcing the importance of data-driven evaluations in validating BIM's role within related refurbishment context. MIn contrast, Charef, Alaka, and Emmitt's 2018 study on '*A systematic review of the literature and evaluation of professional opinions*', which has 189 citations,

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highlights the importance of both supporting and facilitating the deconstruction process when choosing components during the design phase.

Table 4 Top 10 most-cited authors on BIM in building refurbishment context

No.	Authors	Title	Cited by
1	Pətrəucean, Armeni, Nahangi, Yeung, Brilakis, and Haas [49]	'State of research in automatic as-built modelling'	310
2	Xia, Liu Z, Efremochkina, Liu, and Lin [50]	'Study on city digital twin technologies for sustainable smart city design: A review and bibliometric analysis of geographic information system and Building Information Modeling integration'	226
3	Charef, Alaka, and Emmitt [51]	'Beyond the third dimension of BIM: A systematic review of literature and assessment of professional views'	189
4	Thomson and Boehm [52]	'Automatic geometry generation from point clouds for BIM'	185
5	Ochmann, Vock and Klein [53]	'Automatic reconstruction of fully volumetric 3D building models from oriented point clouds'	174
6	Figueiredo, Pierott, Hammad, and Haddad [54]	'Sustainable material choice for construction projects: A Life Cycle Sustainability Assessment framework based on BIM and Fuzzy-AHP'	160
7	Arayici [55]	'Towards building information modelling for existing structures'	157
8	Biagini, Capone, Donato, and Facchini [56]	'Towards the BIM implementation for historical building restoration sites'	140
9	Hosseini, Maghrebi, Akbarnezhad, Martek, and Arashpour [57]	'Analysis of Citation Networks in Building Information Modeling Research'	132
10	Ding, Liu, Liao, and Zhang [58]	'A digital construction framework integrating building information modeling and reverse engineering technologies for renovation projects'	131

4.3 The co-authorship countries' collaboration

The co-authorship analysis was performed using VOSviewer as revealed in Figure 3 reveals the global landscape of collaborative study on BIM in building refurbishment nature context, with notable contributions from countries across multiple continents. China leads in document count (57) and citations (1,647), reflecting its significant with total link strength of 28 that influence and extensive research output in this field.

The United Kingdom follows with 41 documents and 1,870 citations, showing strong research activity and a high level of collaboration with a total link strength of 24, indicating extensive international partnerships. Other top contributors include the Spain (34 documents, 1,227 citations) and Italy (34 documents, 1,102 citations), highlighting Europe's substantial role in advancing BIM research.

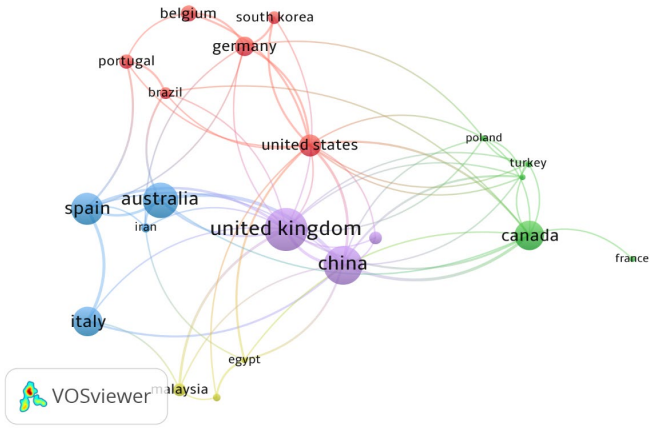


Figure 3 The global landscape of co-authorship countries' collaborative research on BIM in building refurbishment

Several Asian countries are also highly active contribute in BIM in building refurbishment. South Korea, for instance, has 16 documents and a notable 346 citations, with a total link strength of 5, suggesting robust connections with other researchers worldwide. Iran (10 documents, 215 citations) also shows considerable research engagement, underscoring the importance of BIM in Asia's construction industry. Malaysia also stands out with 12 documents and 357 citations and a relatively high total link strength of 6, indicating Malaysia's emerging position in this research area and its collaborative ties with other countries, potentially due to its emphasis on BIM and government support for digital construction technologies.

Some countries, though producing fewer documents, have substantial citation counts, which signifies the impactful nature of their research. For example, Australia has only 32 documents but has garnered 1,429 citations, showing the high-quality and influence of its contributions. This trend suggests that even though China and the United Kingdom

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dominate in volume, smaller countries can still significantly impact, especially through high-quality publications and focused international collaborations. Future research could benefit from increased collaborations among less-represented regions to broaden the scope and application of BIM in building refurbishment globally.

4.4 The keyword co-occurrence analysis

To further understand the focus areas within this body of research, keyword co-occurrence analysis was performed using VOSviewer on the same dataset of 339 documents. The analysis identifies key terms most frequently used by researchers, offering insights into dominant themes and evolving interests in idea between BIM robustness in building refurbishment. A total of 62 keywords with a frequency of ≥ 30 were selected from 86 keywords, and a co-occurrence analysis was performed on these 62 keywords after filtering and merging with synonym terms, as shown in Figure 4.

As shown in Table 5, top keywords include "architectural design" (180 occurrences), "building information modelling" (108), "bim" (90), "information theory" (64), and "life cycle" (41). The keyword "sustainable development," "reconstruction," "refurbishment," and "building" also appear frequently, indicating strong research momentum toward BIM in refurbishment context.

Table 5 Keyword used in previous research according to VOSviewer analysis

No.	Keyword	Occurrences	Total link Strength
1	architectural design	180	2165
2	building information modelling	108	1340
3	information theory	64	784
4	life cycle	41	593
5	construction industry	35	480
6	sustainable development	35	464
7	information management	31	368
8	three-dimensional reconstruction	26	366
9	decision making	26	363
10	building	33	358
11	point cloud	33	351
12	energy efficiency	26	324
13	semantics	26	324
14	construction	24	313
15	sustainability	26	306
16	historic preservation	20	287
17	image reconstruction	19	253
18	environmental impact	17	250
19	maintenance	23	248
20	project management	22	220
21	heritage buildings	22	207
22	hbim	25	187
23	retrofitting	12	144
24	facility management	13	141
25	scan-to-bim	14	134
26	restoration	9	114
27	performance management	8	106
28	architectural heritage	9	99
29	heritage conservation	8	99
30	gis	9	95
31	optimization	9	88
32	virtual reality	6	80
33	industry foundation classes-ifc	7	79
34	uncertainty analysis	5	78
35	unmanned aerial vehicles (uav)	5	76
36	structural analysis	5	74
37	refurbishment	6	72
38	conservation	7	69
39	sensitivity analysis	6	69
40	deterioration	5	68
41	visualization	8	68
42	remote sensing	5	67
43	waste management	6	66
44	demolition	6	65
45	extraction	5	65
46	stereo image processing	4	65
47	carbon footprint	7	64
48	topology	6	64
49	existing buildings	4	49
50	digitization	4	44
51	renovation	4	36
52	recycling	2	34
53	reuse	3	33
54	spatiotemporal analysis	2	31
55	sustainable conservations	3	31
56	digital twins	3	30
57	iot	3	30
58	reverse engineering	2	30
59	prefabricated construction	2	27
60	green building	3	26
61	topology reconstruction	2	26
62	augmented reality (ar)	2	5

In addition, the research on theme mapping within the study context, illustrated in Figure 4, reinforces the findings from Table 5 by visually depicting clusters and relationships between commonly used terms.

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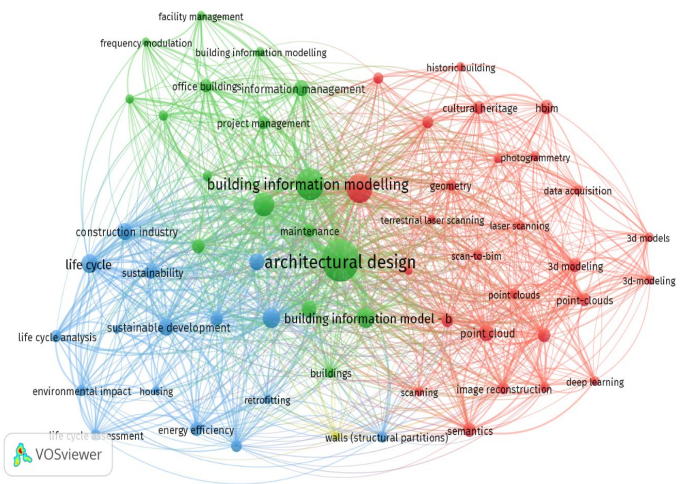


Figure 4 The outcomes of the research theme mapping conducted with VOSviewer.

The results of the research theme mapping indicate that the study of Building Information Modeling (BIM) in the context of building refurbishment is a highly active field. It shows significant interconnections among four key themes: architectural design, building information modeling, sustainability, and structural design. A detailed explanation is provided in Table 6.

Table 6 Four key themes associated research on BIM in building refurbishment

No.	Key theme	Detail	Explanation
1	Architectural Design	3D Digital Models with Data-Rich Information	BIM generates a shared digital representation of a built thing that includes geometrical attributes, functional specifications, and item performance data, providing a solid foundation for decision-making throughout its life cycle. This covers both graphical and non-graphical data. High levels of detail (LOD) are essential for capturing regional characteristics and documenting harm to cultural resources. Semantic enrichment enables the incorporation of exact and accurate data such as physical qualities, pricing, and certificates.
		Parametric Design Capabilities	BIM is a parametric design process that allows for element changes by parameter adjustments, allowing for detailed modelling of architectural, structural, and MEP components. This is critical for reflecting the complicated geometries and imperfections found in heritage buildings.
2	Building Information Modelling	Interoperability and Data Exchange	BIM systems attempt to increase interoperability by enabling the integration of various programs and data sources. Efforts to develop formats such as Industry Foundation Classes (IFC) and Application Programming Interfaces (API) that use automated simulations to anticipate, plan, and manage building assets are continuous.
		Integration with Reality Capture Technologies	BIM's usefulness is boosted by its integration with laser scanning, photogrammetry, and drone technologies to generate precise "as-is" models of real situations.
		Collaboration Platforms (CDE)	BIM frequently use Common Data Environments (CDE) to centralize data management, information, and data streams, ensuring constant synchronization and simultaneous access across all disciplines.
		Analytical and Simulation Capabilities	BIM supports a variety of analyses, including energy performance simulation, structural analysis, cost prediction, waste measurement, and 4D (time) simulations. It can also conduct spatial analyses for emergency services.
		Adaptability for Renovation-Specific Needs	BIM is being tailored to meet the unique requirements of refurbishment, such as managing new and existing materials, evaluating historical phases, and incorporating diagnostic data from non-destructive testing (NDT).
3	Sustainability	Sustainability Focus	Enhancing environmental performance throughout the building life cycle is the main goal of integrating life-cycle assessment (LCA), BIM, and circular economy (CE) principles. This includes a dedication to reducing energy use and carbon footprints.
		Whole Life Cycle Management	There is a trend toward adopting BIM to manage the whole life cycle of buildings, including operation, maintenance, refurbishment, and demolition. This includes examining the environmental impact of different end-of-life situations.
4	Structural Design	Semantic Enrichment	Understanding complex existing buildings requires transdisciplinary applications in construction and administration, which are made possible by adding new values to existing models, such as geometric, non-geometric, and topological information.

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Predictive Capabilities	The integration of artificial intelligence and machine learning provides predictive maintenance and damage prediction. There is a rising interest in using BIM for structural health monitoring, damage identification, and predictive maintenance in heritage and existing buildings. Ontology development, such as for concrete surface faults, is intended to improve inspection, diagnosis, and repair information modelling.

In summary, the increasing volume and diversity of research publications highlight the strategic importance of continuous knowledge generation to support the industry's transition toward a more digital, efficient, and future-ready framework.

Several gaps have been identified that future research and industry initiatives should address. It is recommended to develop and enforce national standards for Building Information Modeling (BIM) practices, including clear regulations and contractual standards for its use.

A BIM evaluation framework should be established with clear objectives, Key Performance Indicators (KPIs), regular monitoring, and feedback mechanisms to ensure continuous improvement and alignment with organizational goals. Additionally, government initiatives should incentivize BIM implementation through mandates, tax benefits, or financial aid to help overcome cost barriers and facilitate adoption.

Efforts should also encourage deep refurbishment and retrofitting of existing buildings to enhance their structural and energy performance, extend their lifespan, and significantly reduce the overall environmental impact compared to complete demolition and new construction.

This approach provides social and economic benefits to cities as well. By implementing these recommendations, the industry can significantly contribute to building a more sustainable, resilient, and historically conscious built environment.

5.0 CONCLUSION

In conclusion, the bibliometric analysis shows a clear upward trend in research output related to Building Information Modeling (BIM) in the context of building refurbishment, with a significant increase starting in 2008. This growth corresponds with the global rise in interest in digital transformation within the construction industry. It is also supported by advancements in BIM technology, industry demands for increased productivity, and government initiatives promoting digitalization.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Data availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethics declaration

Formal ethical approval was not obtained for this study. However, the authors confirm that the research was conducted in accordance with established ethical principles and good research practices, with due consideration given to participant rights, informed consent, confidentiality, and responsible data handling.

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