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MAPPING THE EVOLUTION OF BUILDING MAINTENANCE (1948–2024): A BIBLIOMETRIC REVIEW

Oi Ling ONG[1], Hasniyati HAMZAH[1,2*], Yasmin MOHD ADNAN[1,2]

[1] *Centre for Sustainable Urban Planning and Real Estate (SUPRE), Faculty of Built Environment, Universiti Malaya, 50603 Kuala Lumpur, Malaysia*
[2] *Department of Real Estate, Faculty of Built Environment, Universiti Malaya, 50603 Kuala Lumpur, Malaysia*

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Abstract. This bibliometric analysis provides valuable insights into the evolving field of building maintenance. It not only charts the existing literature but also critically identifies key processes, essential research areas, central themes, gaps, and connections within the building maintenance (BM) sector while assessing the current state of research. This review utilised treemap analysis, thematic evolution, thematic mapping, and factor analyses, to analyse 483 Scopus-related studies between 1948 (first published article) and 2024. Microsoft Excel, Open Refine, VOSviewer, Biblioshiny, and biblioMagika were employed to preprocess and standardise the BM-related data. Subsequently, assessments of frequency, impact, and bibliometric networks were conducted. The analysis revealed significant growth in sustainability, innovative technologies, and maintenance management areas. Notably, Malaysia and the United Kingdom emerged as leading contributors to BM-related research. *Facilities* is recognised as a prominent publication in the sector. Major themes identified included maintenance, architectural design, building management, information management, construction, and facilities management. Additionally, several underexplored areas were highlighted, such as maintenance budgets, public housing, commercial buildings, maintenance costs, cost analysis, and maintenance procedures. Overall, the findings provide substantial insights for scholars and industry professionals, delineating trends, challenges, areas for further exploration, future policy considerations, and advocating for sustainable practices in building maintenance.

Keywords: building maintenance, maintenance, buildings, building maintenance management, evolution, mapping, bibliometric review.

*Corresponding author. E-mail: ***hasniyati@um.edu.my***

1. Introduction

Building maintenance (BM) in the United Kingdom constitutes approximately 50% of total annual construction activity, which was projected to experience a yearly growth of 8.3% in 2023 (Che-Ghani et al., 2016; Office for National Statistics, 2024). This activity encompassed several responsibilities, such as repairs, renovations, and continuous maintenance to guarantee the optimal performance and reliability of facilities (Ghanbari & Mojtahedzadeh Asl, 2021). Shen et al. (2023) also reported that installation and maintenance of building services in Hong Kong experienced significant growth of 18.4% (2020) and 10.2% (2021). Consequently, BM is essential in the design, construction, and preservation of these structures, aligning with ISO 55000 Asset Management Standards and ISO 41001, which sets the requirements for facilities management systems (Dzulkifli et al., 2021; Okoh et al., 2016; Renan Favarao & Gilberto Francisco Martha, 2022; Sarbini et al., 2021). Conventional BM has been perceived as a reactive activity in which issues are identified and resolved as they arise (Olanrewaju & Abdul-Aziz, 2014). Nonetheless, fundamental changes have occurred in BM approaches due to the rise of proactive and predictive maintenance (Gackowiec, 2019; Hanko, 2024). These changes have focused on several key areas, including maintenance procedure standardisation, BM modernisation, green building and sustainable maintenance adoption, lifecycle costing (LCC) integration, and fulfilment of regulatory obligations (Hauashdh et al., 2024; Sarbini et al., 2021). Other critical areas have also demonstrated rising importance, such as adopting total quality management (TQM), employing sophisticated technology, and enhancing an understanding of maintenance management during the design phase (Hauashdh et al., 2021). Therefore, proper BM is essential for safeguarding their worth and integrity while attaining the Sustainable Development Goals (SDGs) of the United Nations (sustainable cities and communities, industry, innovation, infrastructure, and climate action) (Fei et al., 2021; Hauashdh et al., 2024).

Maintenance has evolved to reflect a unique phase in technological advancement. The first generation focuses on

corrective maintenance that responds reactively to failures. The second generation introduces preventive maintenance based on scheduled intervals and manual planning. The third generation utilises predictive maintenance through condition-based strategies and computer-aided planning, prioritising reliability. The fourth generation further refines predictive maintenance with enhanced monitoring, risk-based strategies, optimisation techniques, and the integration of artificial intelligence, aligning maintenance practices more closely with asset management objectives (Desbalo et al., 2024; Pintelon & Parodi-Herz, 2008; Renan Favarao & Gilberto Francisco Martha, 2022). As a result, maintenance has transformed from a technical issue to a strategic management priority, with options like outsourcing and leasing equipment. Advancements in technology, including new materials and sensors for monitoring, have added scientific dimensions to maintenance, Internet of Things (IoT)-based predictive maintenance, improved sustainability adoption, and implementation of digital tools [Building Information Modelling (BIM) and Digital Twins], a trend expected to accelerate in the twenty-first century (Falorca, 2026; Murtaza et al., 2024; Pintelon & Parodi-Herz, 2008; Zakiyudin et al., 2023). As a result, it is essential for building owners and facility managers to proactively adapt to the emerging trends associated with ongoing urbanisation. This strategic adjustment aims to enhance building efficiency, minimise costs, and effectively respond to the changing needs of residents (Surendra, 2022).

Despite the extensive literature on building maintenance, a considerable gap exists in comprehensive studies that delve into the trends, patterns, and research deficiencies within this evolving field. This paper seeks to conduct a thorough bibliometric analysis of the existing literature on building maintenance, systematically mapping the academic landscape, tracing the field's development, identifying research frontiers, and uncovering knowledge clusters and networks. The importance of this study lies in documenting the historical progression of research in building maintenance and emphasizing key influences and emerging areas of inquiry. Ultimately, this work aims to facilitate future scholarly endeavours and drive industry transformations toward sustainability.

This study seeks to address several pertinent research questions. The study establishes a robust framework for exploring key themes and clusters within this domain by employing bibliometric and network analysis techniques. The findings are critical for guiding the development of more effective and sustainable practices in alignment with the continuously evolving technological and regulatory environments.

RQ1: What are the recent emerging trends in BM-related studies?

RQ2: Which journals and publications are crucial to pioneering BM-related studies in BM by country?

RQ3: Which principal research themes facilitate the progression and growth of the BM sector?

Overall, this study aims to chart the intricate field of building maintenance. Through systematic analysis, it endeavours to create a coherent overview of the field's past and present while laying the groundwork for its future, all to promote a more competitive and sustainable building maintenance sector.

2. Literature review

Buildings are a significant asset that must be recognised; their preservation is vital for maintaining value, ensuring safety, and optimising functionality (Gabriela Alves Tenório & Alberto Casado Lordsleem, 2019; Hauashdh et al., 2024; Lluka, 2024; Mydin, 2015). The British Standard BS 3811 defines maintenance as the combination of technical and administrative actions, including supervisory tasks, to keep an item in or restore it to a condition suitable for its intended purpose. BS 3811 classifies maintenance into two primary types: "planned", which encompasses preventive measures such as scheduled maintenance and condition-based maintenance, and "corrective", which involves unplanned maintenance, including emergency repairs (Chanter & Swallow, 2008; Dzulkifli et al., 2021; Sarbini et al., 2021; Seeley, 1987). BM encompasses a variety of activities aimed at preserving and optimizing the value and benefits derived from earlier phases of an asset's lifecycle. This includes tasks such as preservation, adaptation, and deconstruction, all aligned with sustainable practices (Desbalo et al., 2024). Beyond the significant financial investment it entails, building maintenance is crucial for maximising the effective use of the nation's building stock, which serves as both a productive asset and a living space.

The advancement of understanding in any research field necessitates an exploration of the scope and intricacies of existing knowledge, which is often accomplished through a systematic literature review (SLR) (Xiao & Watson, 2019). This methodology entails a careful extraction of literature using a defined search strategy, the formulation of research questions (RQs), and a structured presentation of data. The SLR serves as a deliberate approach for identifying, evaluating, and synthesizing completed studies conducted by researchers and professionals (Shabahar et al., 2024). A literature review should enhance knowledge and maintain a focus on the topic by integrating available material with theoretical critique. Therefore, this review employed the SLR methodology to derive key insights from various studies in building maintenance through a transparent and replicable process.

This systematic literature review (SLR) comprehended previous BM-related studies and their associated themes, revealing multiple research gaps regarding the overall research output and the trajectory of BM. The significant paradigm shift in the apartment BM system was demonstrated by the emergence of BM in Finland throughout the 1970s, overhauling conventional maintenance procedures (Raouf & Kettunen, 1977). The 1980s also highlighted the necessity for BM standardisation to safeguard quality,

Table 1. Evolution summary of BM

Period	Year	Main discussion	Reference
1980s	1984	The publication of a British Standard draft on BMM	Streeter (1984)
1990s	1992	The modernisation of BM caused facilities management to attract greater diversity	Quah (1992)
2000s	2004	The statutory obligations in Hong Kong related to building services maintenance were delineated in multiple ordinances and regulations	Lai and Yik (2004)
	2007	The IT-driven LCC applications were presented. Enhanced LCC decision-making was also demonstrated by evaluating the cost performance of different construction approaches and materials (excluding energy calculations)	Fu et al. (2007)
	2007	An emery analysis was conducted on a building to assess the primary energy and material inflows associated with the construction, maintenance, and utilisation processes for housing sustainability	Pulselli et al. (2007)
2010s	2012	An occupational safety assessment at maintenance worksites in high-rise buildings was discussed	Mélo Filho et al. (2012)
	2013	A comprehensive knowledge-based BIM system could offer sophisticated functionalities for construction activities	Motawa and Almarshad (2013)
	2014	The identified CSFs and principal factors served as a valuable reference for maintenance contractors to comprehend the demands of the BM market in Hong Kong	Tan et al. (2014)
2020s	2020	Even though numerous higher education institutions continued to struggle with its implementation in the facilities, the TQM demonstrated efficiency in enhancing quality in building facility maintenance	Akinlolu et al. (2020)
	2022	The Digital Twin solutions to historical building stock maintenance cycles were discussed	Wong et al. (2022)
	2022	Standardised MM structures could direct maintenance efforts for the maintenance budget	Ogunbayo et al. (2022)
	2023	The maintenance elements were considered earlier or during the design phase	Abdullah et al. (2023)

Notes: IT – Information technology; CSFs – Critical success factors; MM – Maintenance management.

Table 2. Summary of previous studies involving bibliometric analysis in the assessment of historical buildings and public universities

Author and year	Domain/search strategy	Data source and scope	Total documents examined	Attributes investigated
Rocha and Rodrigues (2017)	Research, building maintenance, quality assessment, bibliometric review, building maintenance performance	Emerald, Google Scholar, Scopus, and Science Direct (2000–2016)	745	1. Publication trend (by years) 2. Publication sources (journal) 3. Co-authorship analysis 4. Collaboration among countries
Adegoriola et al. (2021)	TITLE-ABS-KEY ("Heritage building" OR "historic building" AND "maintenance" OR "decision making" OR "building condition" OR "decision-making" OR "facilities management" OR "facility management" OR "Maintenance challenges" OR "heritage building reuse" OR "conservation" OR "Adaptive reuse")	Scopus-English journals published between 2000 and 2020	1144	1. Publication trend (by years) 2. Publication sources (journal) 3. Co-occurrence of keywords 4. Co-authorship analysis 5. Collaboration among institutions 6. Collaboration among countries
Goretti and Kaming (2023)	"Building Information Modeling" OR "BIM" OR "Building Information Modeling" AND "Operation and Maintenance" OR "OM"	Articles, conference papers, and reviews in Scopus (2009–2023)	219	1. Publication trend (by years) 2. Co-author analysis 3. Co-occurrence analysis (keywords and countries) 4. Co-citation analysis
Grącki and Plebankiewicz (2024)	Maintenance, strategy, model, university building, cost, educational building, maintenance strategy, building	Articles, reviews, and conference papers in Scopus (1986–2024)	316	1. Publication trend (by country) 2. Co-occurrence analysis (keywords)

Note: This table format was adopted from Wahyudi et al. (2022).

which resulted in BM modernisation involving implementing operation and maintenance, knowledge-based systems (KBSs), and integrated building management systems (IBMs). Subsequently, legislative mandates and LCC during the 1990s highlighted the importance of green and sustainable BM. The sector then emphasised occupational safety and health (OSH) in BM, BIM, and the essential success factors of BM by 2010. Hence, recent studies have underscored the significance of BM planning during the design phase, building maintenance management (BMM), TQM, and Digital Twin integration. Table 1 tabulates the critical discussions occurring for BM.

Table 2 lists the previous studies highlighting the application of bibliometric analysis in assessing historical buildings and public institutions. Despite these studies aiming to improve BM while incorporating BIM, an insufficiently detailed study evaluating BM using scientometric metrics was observed. Thus, this review employed the Scopus database as a prominent search engine to address the research gap. Various scientometric metrics were utilised to rigorously assess the collected publication data spanning 77 years (1948–2024). The primary objectives of this review also consisted of two goals: analyses of trends in BM-related studies and the corresponding scientific findings over the past 77 years (1948–2024) based on their publication patterns (article with source types, languages, subject area, publication year, annual citations, trending topic, most cited articles, and countries).

3. Methodology

The SLR methodology used in this review commenced with identifying appropriate keywords for the literature search as suggested by Wankhede and Vinodh (2022). Numerous researchers participated in the compilation and categorisation of studies to reduce individual bias (Tranfield et al., 2003). These studies were examined and analysed rigorously following a meticulous methodological technique essential for any literature review (Okoli & Schabram, 2015). The SLR methodology also comprised multiple phases. Initially, studies were obtained from the SCOPUS database utilising shortlisted keywords pertinent to the chosen BM-related research domains. The bibliometric analysis was then based on biblioMagika, Biblioshiny, and VOSviewer. Subsequently, the thematic topic and keywords were produced through theme mapping and factor analysis. The themes and topics were examined, and future study suggestions were presented. Lastly, the answers to the research questions were addressed in the conclusion.

De Bellis (2009) define bibliometric analysis is a scientific computer-assisted review technique that enables researchers to identify the leading research, authors, and their relationships by including all documented studies relevant to a specific study domain. Specifically, Donthu et al. (2021), Khan et al. (2021) note that this analysis has garnered considerable attention in business and management research. Ellegaard and Wallin (2015), bibliometric analysis also involves two primary processes: quantitative article assessment and identification of primary keywords, journals, researchers, affiliations and research collaborations among institutions, countries, and researchers by Rejeb et al. (2020), Wahyudi et al. (2022), Ahmi (2024). As Wallin (2005) explains, this process is frequently employed to acquire and manipulate data through citation or content examination. Several notable examples of bibliometric analysis tools are Pajek, Gephi, BibExcel, and R. In this study, the Bibliometrix R-package was employed for bibliometric analysis to construct data matrices for scientific collaboration and co-word analyses (Agrawal et al., 2022). Meanwhile, biblioMagika and VOSviewer facilitated the overview and keyword co-occurrence analyses, respectively. The fundamental connections among various keywords in BM-related studies were also determined from the insights into trending topics and the significance of different themes in the BM sector. Subsequently, R through the Biblioshiny web interface for visual bibliometric analyses. Since Ellegaard and Wallin (2015) bibliometric analysis necessitates a substantial volume of data to establish dependability, this process is typically observed as statistically accurate and advantageous owing to its computerised data. Thus, this review applied the bibliometric analysis to explore the current information concerning BM-related studies.

The studies were sourced from the SCOPUS database, encompassing information between 1948 and 2024. The search was performed by using the article title as the primary search field. This method ensured accurate and relevant results related to BM. Various combinations of keywords such as “BM”, “buildings”, “maintenance”, “maintain”, “BM management”, and “build” were explored to ensure a comprehensive search. The search focused on article titles using the query TITLE((building PRE/3 maintenance)), which returned 563 documents, encompassing a wide range of articles on BM. The dataset was refined by removing duplicates and irrelevant articles (80), resulting in a dataset of 483 original research articles. This dataset provides the basis for our systematic review, facilitating an accurate representation of the state of the field and the identification of emerging trends and challenges within building maintenance. These articles were used to assess the current state of building maintenance research and identify key trends, challenges, and opportunities within the field. This strategy ensured that our analysis was based on primary sources, capturing recent and relevant findings within the field of building maintenance. This process is visualised in Figure 1, the flowchart of the search approach. The trends in BM-related topics, a word cloud of the indexed keywords, and a treemap were then produced using Biblioshiny visualisation software (https://bibliometrix.org/Biblioshiny.html). Various clusters, trending topics, and research directions were also generated using multiple correspondence analysis (MCA). Table 3 delineates the bibliographic statistics summary for this review.

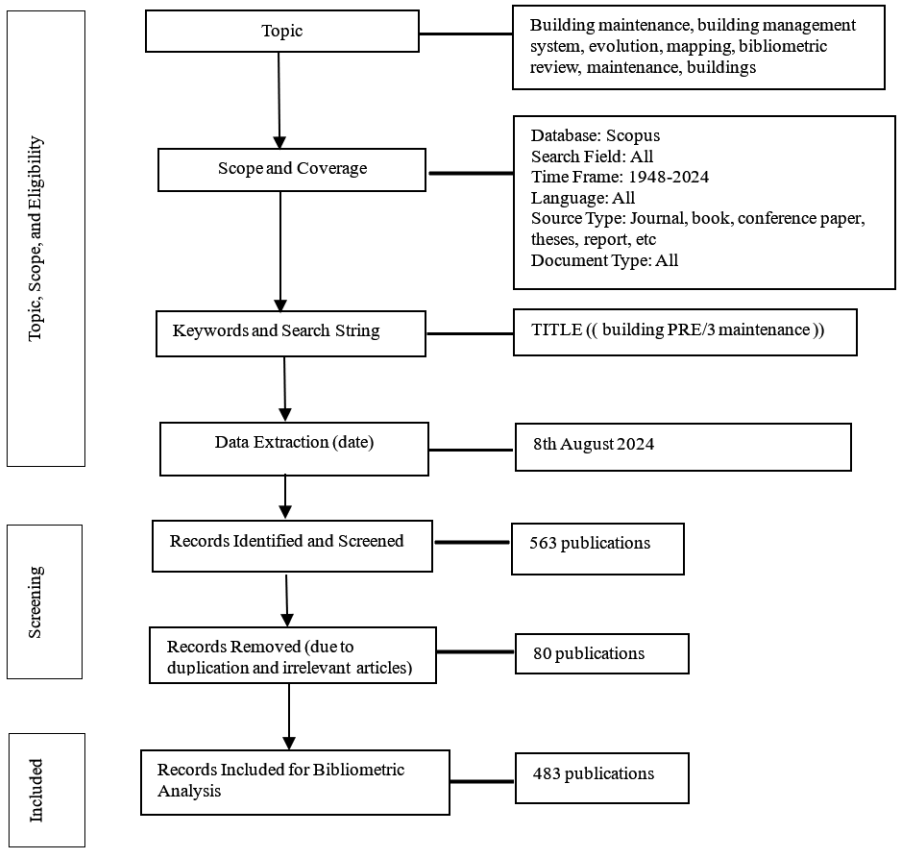

Figure 1. The flowchart of the search approach

Table 3. Data information summary of the examined BM-related studies (source: Generated by the author(s) using biblioMagika®)

Data information	Data
Period	1948–2024
Source (journal and book)	267
Reference	12119
Article	275
Average years sing publication	12.7
Average citations per publication	12.63
Publication content	
Author's keywords (DE)	898
Keywords plus (ID)	1838
Author	
Author	1042
Author of multi-authored publications	955
Author of single-authored publications	87
Collaboration between authors	
Single-authored publication	116
Collaboration index	2.60
Co-authors per publication	2.86
Authors per publication	2.15

4. Data analysis, results, and discussion

4.1. Publishing pattern and citation trend

Table 4 indicates the predominant BM-related studies, which are research articles in 275 publications (56.94%). Conference papers followed this outcome at 158 publications (32.71%), review documents at 19 publications (3.93%), and book chapters at 18 publications (3.73%). Table 5 reveals that the publication source mainly comprises journal articles (60.87%). This finding was followed by conference proceedings (28.99%), book series (4.97%), books (3.11%), and reports (0.41%). Table 6 depicts the distribution of publications by language. Most publications [94% of the total publications (TP)] were in English. In contrast, alternative language publications were relatively infrequent, each representing below 1% of the TP. Table 7 illustrates the publication distribution by subject area, offering information on the interdisciplinary characteristics of BM-related studies. The publication distribution by subject area in descending order was engineering (336, 69.57%), computer sciences (84, 17.39%), business, management, and accounting (73, 15.11%), social sciences (62, 12.84%), and environmental science (56, 11.59%). Consequently, this evolution exhibited the interdisciplinary character of BM, incorporating elements from environmental science, engineering, management, business, and computer science.

Table 4. Summary of the publication metrics by publication type (source: Generated by the author(s) using biblioMagika®)

Document type	TP	Percentage (%)
Article	275	56.94
Conference paper	158	32.71
Review	19	3.93
Book chapter	18	3.73
Book	3	0.62
Note	3	0.62
Conference review	2	0.41
Report	2	0.41
Short survey	2	0.41
Editorial	1	0.21
Total	483	100.00

Notes: TP – total number of publications.

Table 5. Summary of the publication distribution metrics by source type (source: Generated by the author(s) using biblioMagika®)

Source type	TP	Percentage (%)
Journals	294	60.87
Conference proceedings	140	28.99
Book series	24	4.97
Books	15	3.11
Trade journal	8	1.66
Report	2	0.41
Total	483	100.00

Notes: TP – total number of publications.

Table 6. Summary of the publication metrics by language type (source: Generated by the author(s) using biblioMagika®)

Language	TP	Percentage (%)
English	454	94.00
Chinese	4	0.83
Croatian	4	0.83
German	4	0.83
Portuguese	4	0.83
Japanese	3	0.62
Spanish	3	0.62
Finnish	1	0.21
French	1	0.21
Greek	1	0.21
Italian	1	0.21
Korean	1	0.21
Polish	1	0.21
Serbian	1	0.21
Total	483	100.00

Notes: TP – total number of publications.

Table 7. Summary of the publication metric by subject area (source: Generated by the author(s) using biblioMagika®)

Subject area	TP	Percentage (%)
Engineering	336	69.57
Computer sciences	84	17.39
Business, management and accounting	73	15.11
Social sciences	62	12.84
Environmental science	56	11.59
Earth and planetary sciences	27	5.59
Energy	24	4.97
Arts and humanities	22	4.55
Materials science	21	4.35
Medicine	20	4.14
Mathematics	18	3.73
Decision sciences	15	3.11
Economics, econometrics and finance	13	2.69
Physics and astronomy	12	2.48
Chemical engineering	11	2.28
Multidisciplinary	7	1.45
Chemistry	5	1.04
Agricultural and biological sciences	4	0.83
Biochemistry, genetics and molecular biology	4	0.83
Health professions	1	0.21
Pharmacology, toxicology and pharmaceutics	1	0.21

Notes: TP – total number of publications.

Figure 2 portrays the TP and total citations (TC) for the BM-related studies between 1948 and 2024. These BM-related studies attracted considerable interest from researchers in 2011, with publications in 2015 achieving the highest TC (676). The advancement pathway of this field was also exhibited, demonstrating an accelerating trend in publications and higher TC. Likewise, the number of contributing authors (NCA) revealed a positive trajectory, signifying a growing and dynamic research community.

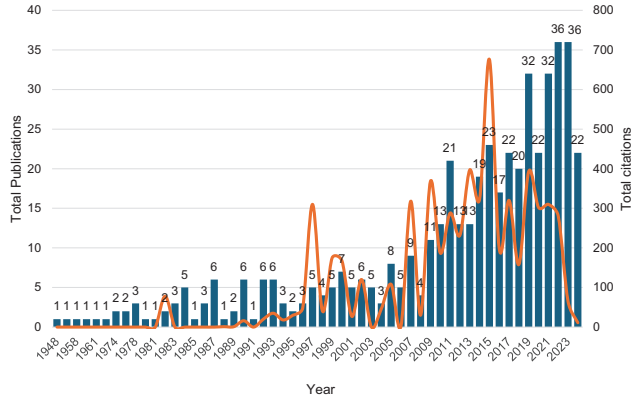

Figure 2. The TP and TC for the BM-related studies between 1948 and 2024 (source: Generated by the author(s) using biblioMagika®)

Table 8. Summary of the publication metrics by publication year (source: Generated by the author(s) using biblioMagika®)

Year	TP	NCA	NCP	TC	C/P	C/CP	h	g
1948	1	1	0	0	0.00	0.00	0	0
1952	1	0	0	0	0.00	0.00	0	0
1958	1	1	0	0	0.00	0.00	0	0
1960	1	0	0	0	0.00	0.00	0	0
1961	1	1	0	0	0.00	0.00	0	0
1970	1	0	0	0	0.00	0.00	0	0
1974	2	2	0	0	0.00	0.00	0	0
1977	2	3	0	0	0.00	0.00	0	0
1978	3	3	0	0	0.00	0.00	0	0
1979	1	1	0	0	0.00	0.00	0	0
1981	1	1	0	0	0.00	0.00	0	0
1982	2	2	1	78	39.00	78.00	1	2
1983	3	3	0	0	0.00	0.00	0	0
1984	5	4	0	0	0.00	0.00	0	0
1985	1	2	0	0	0.00	0.00	0	0
1986	3	4	0	0	0.00	0.00	0	0
1987	6	5	0	0	0.00	0.00	0	0
1988	1	1	1	1	1.00	1.00	1	1
1989	2	2	1	1	0.50	1.00	1	1
1990	6	9	2	16	2.67	8.00	1	4
1991	1	0	0	0	0.00	0.00	0	0
1992	6	12	5	20	3.33	4.00	3	4
1993	6	9	6	35	5.83	5.83	2	5
1994	3	5	2	18	6.00	9.00	2	3
1995	2	4	1	30	15.00	30.00	1	2
1996	3	9	2	48	16.00	24.00	2	3
1997	5	10	5	310	62.00	62.00	5	5
1998	4	5	3	41	10.25	13.67	2	4
1999	5	8	2	175	35.00	87.50	2	5
2000	7	12	4	167	23.86	41.75	4	7
2001	5	6	3	27	5.40	9.00	3	5
2002	6	13	5	120	20.00	24.00	4	6
2003	5	8	0	0	0.00	0.00	0	0
2004	3	9	3	46	15.33	15.33	2	3
2005	8	23	6	108	13.50	18.00	4	8
2006	5	12	2	2	0.40	1.00	1	1
2007	9	21	8	318	35.33	39.75	5	9
2008	4	7	3	30	7.50	10.00	3	4
2009	11	20	8	368	33.45	46.00	7	11
2010	13	29	12	187	14.38	15.58	7	13
2011	21	69	17	288	13.71	16.94	9	16
2012	13	34	12	232	17.85	19.33	7	13
2013	13	50	12	397	30.54	33.08	7	13
2014	19	62	17	323	17.00	19.00	10	17
2015	23	72	21	676	29.39	32.19	13	23
2016	17	59	16	198	11.65	12.38	8	13
2017	22	62	19	320	14.55	16.84	10	17
2018	20	75	17	158	7.90	9.29	7	12
2019	32	95	20	393	12.28	19.65	10	19
2020	22	68	20	302	13.73	15.10	7	17
2021	32	104	27	310	9.69	11.48	9	17
2022	36	142	26	281	7.81	10.81	8	16
2023	36	138	18	65	1.81	3.61	4	7
2024	22	66	5	11	0.50	2.20	1	3
TOTAL	483	1363	332	6100	12.63	18.37	42	63

Notes: TP – total number of publications; NCA – number of contributing authors; NCP – number of cited publications; TC – total citations; C/P – average citations per publication; C/CP – average citations per cited publication; h – h-index; and g – g-index.

Table 9. Summary of the publication metrics by the top-performing source titles (source: Generated by the author(s) using biblioMagika®)

Source title	TP	NCA	NCP	TC	C/P	C/CP	h	g	m
Facilities	22	40	16	336	15.27	21.0	12	18	0.293
IOP Conference Series: Earth and Environmental Science	18	50	10	28	1.56	2.80	3	4	0.500
Structural Survey	11	16	7	209	19.00	29.86	4	11	0.114
Journal of Building Engineering	10	34	9	317	31.70	35.22	8	10	1.143
Automation in Construction	10	27	10	620	62.00	62.00	8	10	0.320
Building Research and Information	8	25	7	169	21.13	24.14	6	8	0.207
International Journal of Building Pathology and Adaptation	8	25	6	76	9.50	12.67	4	8	0.667
Property Management	8	9	7	107	13.38	15.29	4	8	0.108
Buildings	7	24	7	120	17.14	17.14	5	7	0.556
Jurnal Teknologi	7	22	6	79	11.29	13.17	5	7	0.500
AIP Conference Proceedings	7	31	1	1	0.14	1.00	1	1	0.125
Journal of Facilities Management	6	19	6	216	36.00	36.00	6	6	0.375
Journal of Performance of Constructed Facilities	6	19	6	115	19.17	19.17	4	6	0.138
Procedia Engineering	5	13	5	303	60.60	60.60	5	5	0.357
Engineering, Construction and Architectural	5	18	5	40	8.00	8.00	4	5	0.286
Sustainability (Switzerland)	5	19	4	12	2.40	3.00	2	3	0.500
Journal of Building Appraisal	5	8	5	236	47.20	4720	5	5	0.278

Notes: TP – total number of publications; NCA – number of contributing authors; NCP – number of cited publications; TC – total citations; C/P – average citations per publication; C/CP – average citations per cited publication; h – h-index; g – g-index; m – m-index.

Table 8 presents data demonstrating the substantial increase in BM-related studies between 1948 and 2024. Even though the data implied that studies were minimal from 1948 to 1983, interest increased significantly from 2008 onwards. The volume of published studies then exhibited a consistent increase until 2013. Specifically, a notable surge in research outputs from 2009 was observed, achieving a peak in 2022 and 2023. These publications in 2022 and 2023 constituted 7.45% of the total research output, while 2021 accounted for 6.63%. The increasing h-index and g-index values also demonstrated the rising significance and relevance of BM-related studies over time.

Table 9 presents the journals with the highest productivity, each containing a minimum of five BM-related publications. The significant impact and scope of the research Facilities accommodated was distinguished by its four excellent publication metrics: TP (22), TC (336), h-index (51), and g-index (18). The Journal of Building Engineering (TP = 10) and Automation in Construction (TP = 10) also played a crucial role in disseminating BM-related information. Although the Journal of Building Engineering possessed lower TP than Facilities, a constant citation rate and significant impact were observed due to its stable C/P and C/CP metrics. On the contrary, the significant C/P (62.00) and C/CP (62.00) of Automation in Construction signified a substantial impact per published article. Notable contributions were then presented by the IOP Conference Series: Earth and Environmental Science owing to its solid TP. This journal also exhibited lower TC, suggesting that its publications were cited less often than the other journals above. Nevertheless, the contributions of this journal remained significant, as its active involvement enhanced the diversity of source titles in this sector. This review concluded that Facilities, IOP Conference Series: Earth and Environmental Science, and Structural Survey were pivotal centres for innovative research. Concurrently, various journals and conferences significantly enhanced the knowledge base of the field.

4.2. Demographic distribution and country productivity

Table 10 provides a comprehensive analysis of global contributions to BM-related studies, highlighting the leading countries with over 10 publications on authors' affiliations. The publication metrics for Malaysia were the most significant (TP = 86, TC = 1058, and h-index = 20) compared to other nations, indicating the notable influence and research quality. Aside from Malaysia, the United Kingdom (TP = 44 and h-index = 12) and Hong Kong (TP = 37 and h-index = 16) significantly contributed to BM-related studies. The United States (TP = 34) and Italy (TP = 31) were also significant contributors to BM-related studies compared to Hong Kong, China, Australia, South Korea, Canada, Portugal, South Africa, Spain, Taiwan, and Japan (h-index range = 5–9). It is crucial to categorise the leading BM articles by geographical region to identify the countries that have made significant contributions to the concept. Contextual evaluations can assist national researchers in gaining a deeper understanding of BM by enabling more reliable comparisons and conclusions, ultimately identifying knowledge gaps that warrant further research.

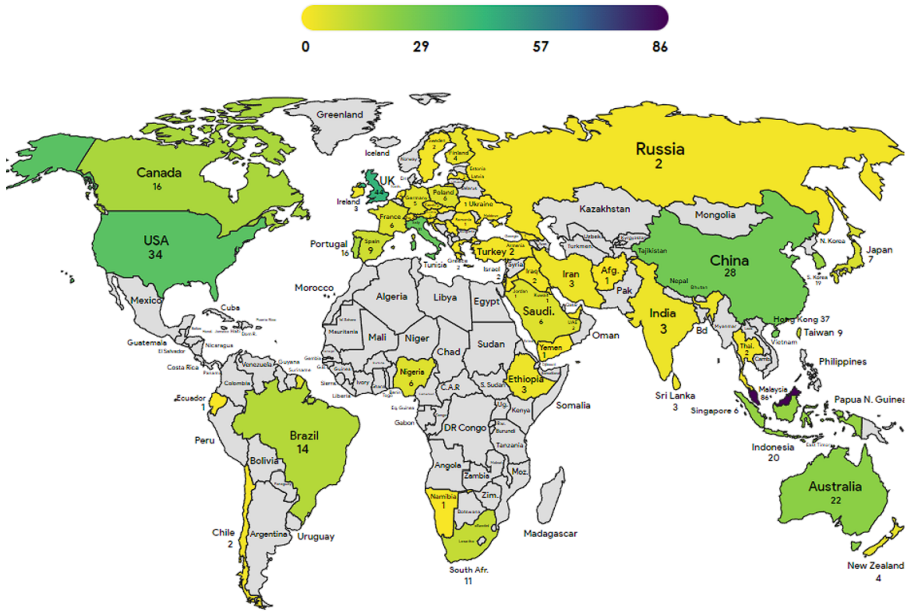

Figure 3. The global scientific production of BM-related studies indexed by Scopus (source: India in Pixels, n.d.)

Table 10. Summary of the publication metrics by the top nations with over 10 publications (source: Generated by the author(s) using biblioMagika®)

Country	TP	NCA	NCP	TC	C/P	C/CP	h	g	m
Malaysia	86	279	69	1058	12.30	15.33	20	32	1.111
United Kingdom	44	86	39	951	21.61	24.38	12	30	0.279
Hong Kong	37	87	36	830	22.43	23.06	16	28	0.640
United States	34	77	22	449	13.21	20.41	10	21	0.196
Italy	31	83	26	462	14.90	17.77	7	21	0.179
China	28	95	19	424	15.14	22.32	9	20	0.643
Australia	22	45	17	245	11.14	14.41	8	15	0.186
Indonesia	20	64	9	31	1.55	3.44	3	5	0.300
South Korea	19	69	14	159	8.37	11.36	5	12	0.357
Canada	16	41	12	454	28.38	37.83	5	16	0.104
Portugal	16	45	13	144	9.00	11.08	7	12	0.438
Brazil	14	44	10	42	3.00	4.20	4	6	0.308
South Africa	11	27	9	73	6.64	8.11	5	8	0.556

Figure 3 illustrates the scientific output of different countries in the field of supply chain management (SC), with a range from 0 to 86 publications. The blue countries in Figure 3 have engaged in BM research, while the darker blue countries have significantly outperformed the yellow countries in terms of BM publications. Notably, there are no BM research articles from the nations represented with grey backgrounds. Consequently, out of the 195 countries worldwide, the study found that 61 have produced research on BM from 1974 to 2023. This indicates that at least one research publication on BM exists from 31% of the countries globally. Figure 3 effectively visualises the global distribution of BM-related publications through a map format.

4.3. Trending topics

Figure 4 illustrates the trending topics in BM-related studies over the past 20 years. Specifically, the blue circle filled with colours on the right side of the graphic represents subjects ranked from 20 to 60; the larger the circle, the more frequently a topic is mentioned. In contrast, topics on the left side of the image have been recognised as trending in BM since 2004. Future researchers in BM are encouraged to investigate these prominent themes. Regarding the analysis of trending topics, frequently occurring themes within the discipline of BM encompass maintenance, BIM, facilities management, operation and maintenance, BMM, buildings, critical success factors, construction, and maintenance strategies.

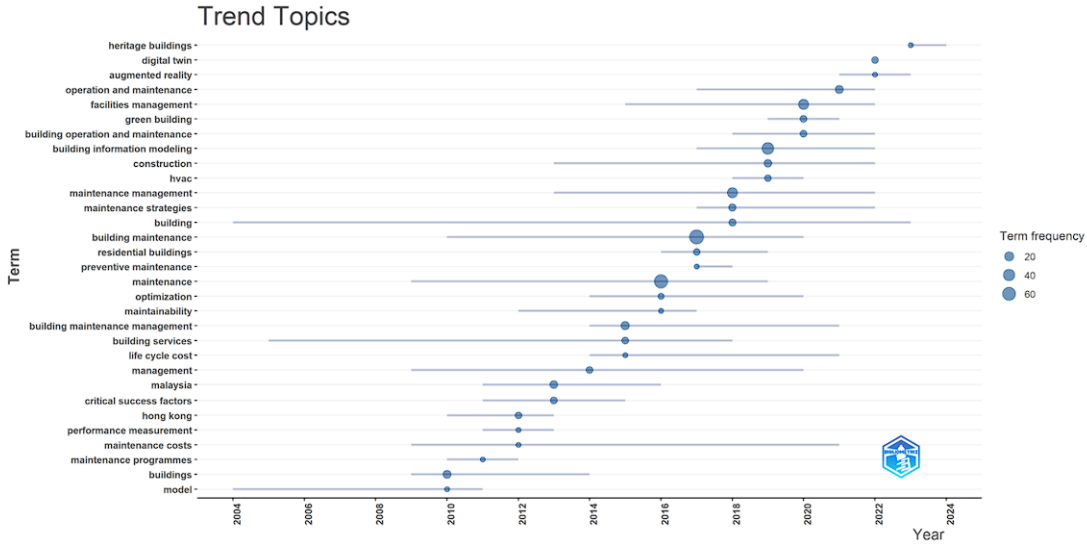

Figure 4. The trending topics for BM-related studies over the last 20 years (source: Generated by the author(s) using Biblioshiny)

4.4. Factorial analysis based on keywords

Table 11 reveals the authors' primary keywords categorised based on TP and the respective percentages. The most frequently occurring keywords in the top three ranks were maintenance, BM, and buildings. Figure 5 illustrates a word cloud that represents the keywords associated with BM. A word cloud visually depicts the frequency of words appearing in the dataset of documents examined for the BM index. In the word cloud shown in Figure 5, there are various words of varying sizes. Each word's size corresponds to its occurrence frequency in existing research. The placement of words within the cloud is random, with no specific intention behind their arrangement; however, the most prominent words typically occupy the centre. This study's keywords that stand out most prominently include BM, maintenance, Building Information Modeling (BIM), maintenance management, facilities management, operation and maintenance, building operation and maintenance, maintenance strategies, and constructions and buildings.

This review collected and examined the co-occurring indexed keywords employed by authors, which generated 1838 keywords with 121 co-occurrences. Figure 6 illustrates that keywords with at least five occurrences are analysed. These keywords were categorised into eight coloured clusters based on similarities in research areas. Consequently, the 15 most frequently occurring keywords in descending order were maintenance (198 occurrences), BM (144 occurrences), building (130 occurrences), architectural design (57 occurrences), maintenance management (37 occurrences), office building (32 occurrences), decision makings (32 occurrences), BIM (29 occurrences), life cycle (27 occurrences), operation and maintenance (27 occurrences), construction (26 occurrences), repair (25 occurrences), facilities management (24 occurrences), survey (23 occurrences), and sustainable development (22 occurrences).

Table 11. Summary of the publication metrics by the top author's keywords (source: Generated by the author(s) using biblioMagika®)

Author keywords	TP	Percentage (%)
Maintenance	204	4.98
BM	145	3.54
Buildings	114	2.78
Architectural design	57	1.39
Maintenance management	36	0.88
Decision making	34	0.83
Office buildings	32	0.78
Information management	29	0.71
Construction	27	0.66
Life cycle	27	0.66
Construction industry	26	0.63
Repair	25	0.61
Surveys	23	0.56
Sustainable development	22	0.54
Building operations	21	0.51
Intelligent buildings	21	0.51

The co-occurrence network between maintenance and building (li strength = 21.75) was the most significant among all the co-occurrence networks. This outcome was closely followed by the co-occurrence network between maintenance and BM (link strength = 21.19). The analysis

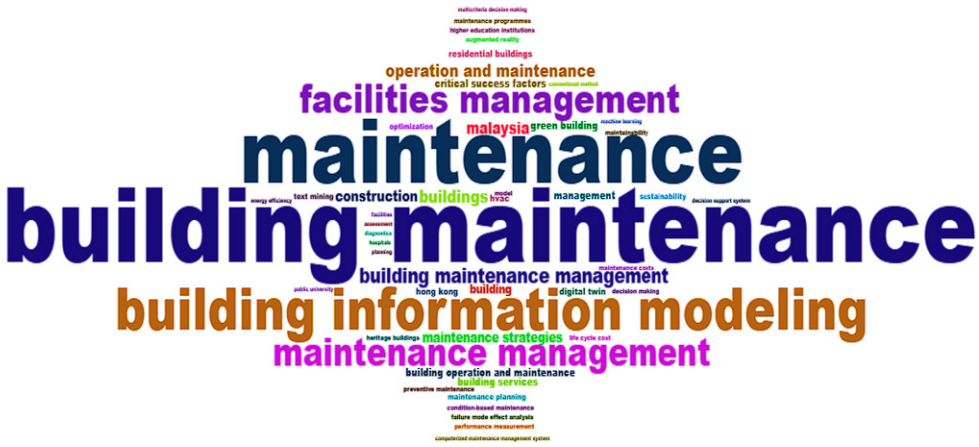

Figure 5. The cloud diagram representing the indexed keywords (source: Generated by the author(s) using Biblioshiny)

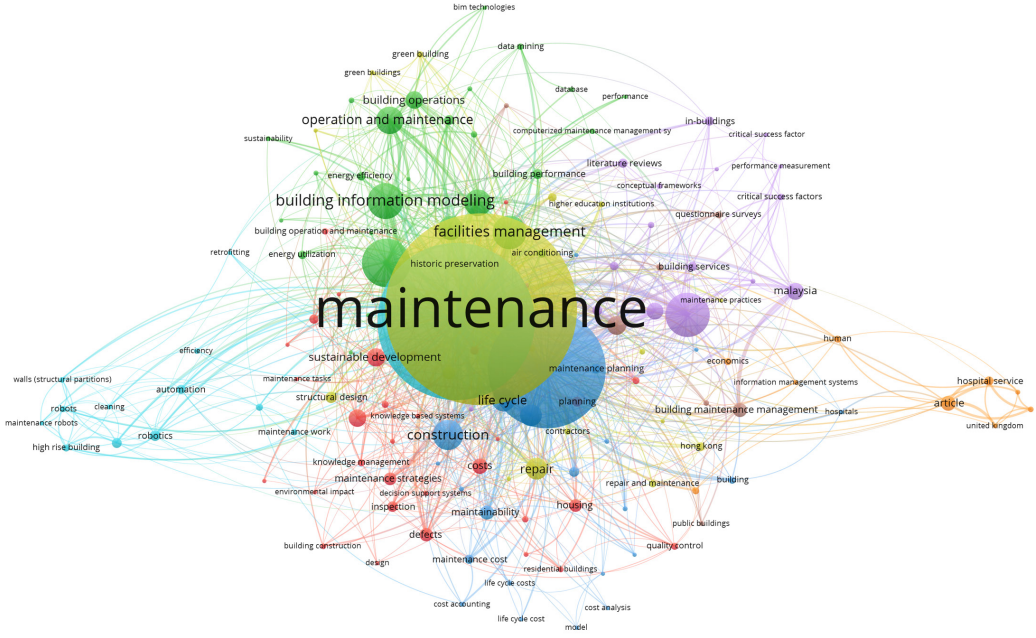

Figure 6. The network of indexed keywords with five or more co-occurrences on BM-related studies (source: Van Eck & Waltman, 2010)

of keyword occurrences also suggested BM-related studies encompass areas such as building, maintenance, operation and maintenance, life cycle, repair, maintenance management, sustainable development, and intelligent building. Thus, this study demonstrated global awareness and continuous efforts towards sustainable development and energy efficiency, resulting in the more prominent application of BM. Questionnaires were also the most frequently researched BM. This study also revealed that the questionnaire has been the most used research tool in BM-related studies.

4.5. Treemap analysis by authors' keywords, title, and abstract

The treemap by authors' keywords illustrated that specific concepts were prevalent in the analysed publications (see Figure 7). These concepts included BM [frequency (N) = 77, 15%], maintenance (N = 66, 12%), BIM (N = 43, 8%), facilities management (N = 29, 5%), and maintenance management (N = 28, 5%). Likewise, the treemap by title and abstract revealed several prevalent specific concepts (see Figure 8). These concepts were maintenance (N = 205, 5%), BM (N = 146, 11%), buildings (N = 134, 10%), architectural design (N = 57, 4%), and maintenance management (N = 37, 3%). N is frequency.

Figure 7. The treemap by authors' keywords (source: Generated by the author(s) using Biblioshiny)

4.6. Cluster analysis and MCA of high-frequency keywords

4.6.1. Thematic evolution

Figure 9 portrays the thematic evolution of authors related to BM (1948–2024). The existing four themes (1948–2011) expanded to 10 themes (2012–2019), which further increased to 12 themes (2020–2024). Over the past decade, several prominent themes have emerged, including BM, maintenance strategies, building operation and maintenance, and failure mode effect analysis. Seven additional themes have also been identified from 2022 to the present. These themes have been broadened to encompass failure mode effect analysis, sustainability, operation and maintenance, decision support systems, energy efficiency, and preventive maintenance.

Figure 8. The treemap by title and abstract

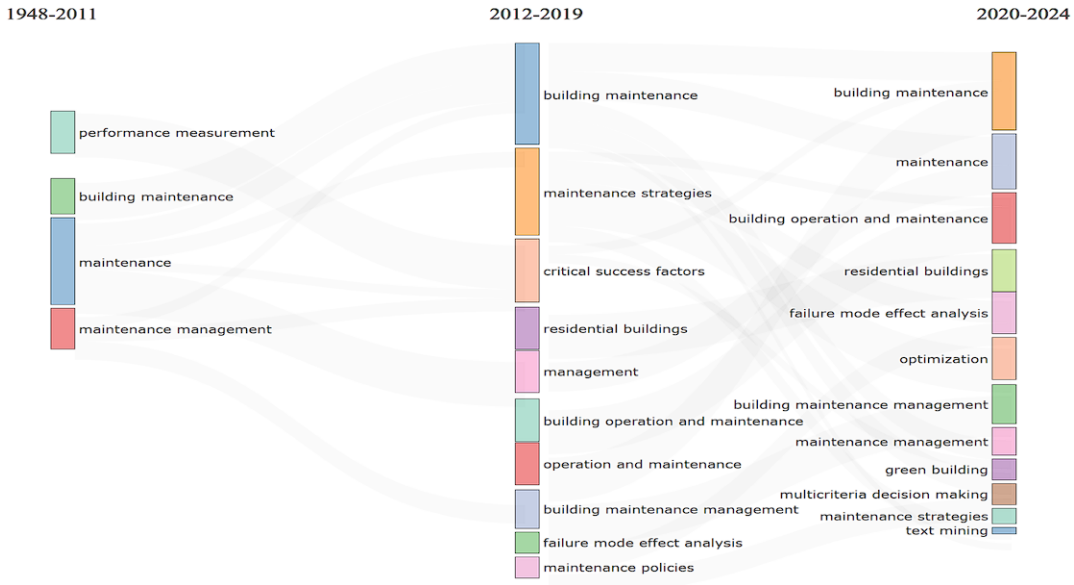

Figure 9. The thematic evolution by authors' keywords (source: Generated by the author(s) using Biblioshiny)

4.6.2. Thematic mapping

The thematic analysis usually facilitates identifying and examining the thematic area evolution within a scientific field. Subsequently, determining scientific gaps necessitates additional consideration in future studies and forecasting trends in advancing a specific field. This outcome involves developing strategic and subject-matter maps within a domain, which can be achieved using two prevalent techniques: citation and lexical examinations. The concurrent application of these two techniques also facilitates the comparison of citation and lexical patterns. Therefore, a novel perspective on scientific studies may be developed by addressing the limitations inherent in each approach. The lexical examination of the science map is often performed using thematic maps through keyword cluster derivation. These clusters are also regarded as themes. Two parameters (density and centre) characterise each research theme generated from this process, representing the two meanings and the average values of each cluster. Consequently, four sections are produced from these themes.

A network graph (thematic network) is formed by a theme associated with a keyword and its internal communications. Every tributary network is assigned a significant and relevant term related to the corresponding theme. Hence, a thematic map provides an effective visual representation, enabling the analysis of themes according to their respective quadrants as follows:

1. Q1 (top right quadrant): This quadrant contains motor themes to determine effective themes and their significance for the research framework.
2. Q2 (top left quadrant): This quadrant contains poorly developed and marginal niche themes.
3. Q3 (bottom left quadrant): This quadrant contains emerging themes that are significant to the research topic but remain underdeveloped.
4. Q4 (bottom right quadrant): This quadrant contains basic themes that have been thoroughly developed with internal relationships. Nonetheless, external relations are minimal and only marginally relevant to the topic.

Figure 10 presents information regarding the associations and significance of various topics within the BM or through a thematic map produced by the Bibliometrix R-package. The theme distribution related to BM-related studies was illustrated through 16 clusters, in which three primary dominant clusters were observed (BM, construction, and buildings). Alternatively, various emerging themes were indicated in Q3 (building operation and maintenance, condition-based maintenance, augmented reality, failure mode effect analysis, service quality, and public university). The ongoing core and comprehensive themes of BM-related studies also included construction, operation and maintenance, BMM, and heating, ventilation and air conditions HVAC. Likewise, the central themes in BM-related studies included building services, BM, building, and green building. Despite multiple niche themes (decision support system, performance measurement, and multicriteria decision making) being specialised within the BM sectors, they exerted less influence across the more comprehensive research domain.

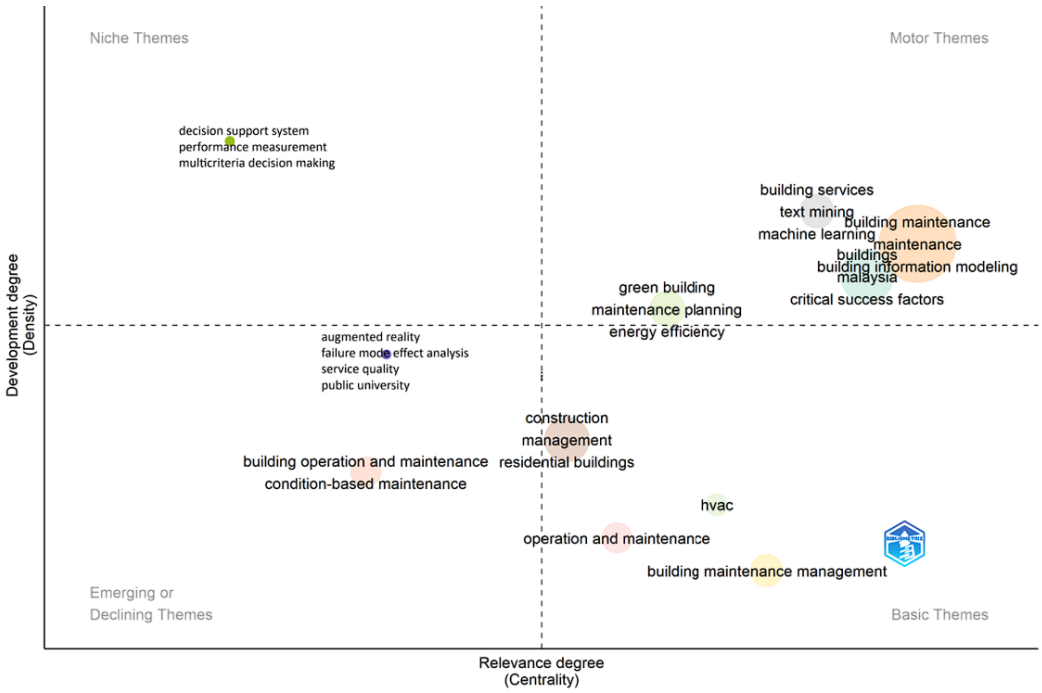

Figure 10. The thematic map based on authors' keywords (source: Generated by the author(s) using Biblioshiny)

4.6.3. Factor analysis

This review performed the MCA of the keywords for the dataset. Figure 11 displays the conceptual structure of the keywords related to the resilience publications. The analysis typically reduces large datasets with numerous variables into a lower-dimensional space. An intuitive two-dimensional (2D) [or three-dimensional (3D)] plot is created that utilises plane distance to represent the similarity among keywords. Hence, keywords near the centre point suggest they have garnered significant interest recently. The outcomes are then examined using the relative point locations and the distribution across the dimensions, and words that exhibit higher distribution similarity are observed closer together on the map (B. P. et al., 2021). Consequently, MCA is advantageous in bibliometrics, as it analyses multiple categorical variables

Figure 11. The factorial analysis (MCA) based on authors' keywords for the BM-related studies

(authors, institutions, or subject categories). This method determines associations and trends that standard co-occurrence analysis may overlook (Iman et al., 2023).

The MCA employed in this review offered a 2D data representation (see Figure 11). Every point corresponded to a keyword, and the distance between points indicated the degree of associations among keywords. Closely related keywords were positioned near each other on the map, whereas those with weaker associations were situated further apart. This analysis then allowed for additional understanding of the word map produced using MCA. Consequently, numerous critical observations were demonstrated from the word map. The central cluster (Cluster 1, indicated by purple) denoted a comprehensive perspective on BM-related studies, highlighting fundamental maintenance-related concepts and practices. This cluster encompassed various keywords: maintenance management, buildings, construction, maintenance strategies, operation and maintenance, critical success factors, green building, residential, and management. The terms indicated a significant emphasis on maintainability practices involving decision support systems, condition-based maintenance, and failure mode effect analysis for multicriteria decision-making as strategies for maintenance. Additionally, the ongoing attention to the influence of technology, techniques, factors, and management practices on enhancing the maintainability of BM was demonstrated by a few keywords, such as maintenance planning, augmented reality, life cycle cost, service quality, and critical success factors.

Cluster 2 (red) emphasised the application of BIM in BM for addressing facilities management, operation and maintenance, building services, energy efficiency, computerised maintenance management systems, and sustainability. This statement focused on modernising BM through computerised sustainability and energy conservation maintenance practices. The significance of technological innovation in meeting sustainability objectives was also exhibited by the intersection of technological developments (IoT and energy efficiency). Therefore, this cluster indicated that future studies should focus on novel technologies (machine learning) to improve building sustainability. Cluster 3 (green) was defined by keywords associated with BMM, including maintenance programmes, performance measurement, and preventive maintenance and facilities, emphasising Malaysian public institutions. The focus on BMM procedures also suggested a notable transition towards enhanced efficiency. Thus, this cluster signified a trend towards BMM concerning preventive maintenance and measuring performance in facilities.

4.6.4. Top 10 highly cited publications

Table 12 tabulates the publication metrics involving the top 10 highly cited publications. Horner et al. (1997) published an article with 159 citations, averaging 5.68 citations annually. The study presented the necessity of minimising total life cycle costs by establishing a systematic framework for choosing maintenance approaches for specific building components. Motawa and Almarshad (2013) documented the most cited article that sought to develop an integrated case-based reasoning BIM system for BM. This system could aid the transition from BIM to building knowledge modelling. Pulselli et al. (2007) also produced a significant article with 231 citations, averaging 12.83 citations annually. The study offered substantial information regarding building technologies and their environmental effects by utilising an emergy analysis to explore the energy and material inputs associated with building manufacturing, maintenance, and usage.

Table 12. Summary of the publication metrics involving the top 10 highly cited publications (source: Generated by the author(s) using biblioMagika®)

No.	Authors	Title	Source title	Cites	Cites per year
1	Motawa and Almarshad (2013)	A knowledge-based BIM system for BM	Automation in Construction	276	23.00
2	Pulselli et al. (2007)	Emergy analysis of building manufacturing, maintenance and use: Em-building indices to evaluate housing sustainability	Energy and Buildings	231	12.83
3	Horner et al. (1997)	BM strategy: A new management approach	Journal of Quality in Maintenance Engineering	159	5.68
4	McArthur (2015)	A Building Information Management (BIM) Framework and Supporting Case Study for Existing Building Operations, Maintenance and Sustainability	Procedia Engineering	155	15.50
5	Ilter and Ergen (2015)	BIM for building refurbishment and maintenance: current status and research directions	Structural Survey	134	13.40
6	Duchaine et al. (2000)	Influence of BM, environmental factors, and seasons on airborne contaminants of swine confinement buildings	American Industrial Hygiene Association Journal	99	3.96

End of Table 12

No.	Authors	Title	Source title	Cites	Cites per year
7	Hon et al. (2014)	Relationships between safety climate and safety performance of building repair, maintenance, minor alteration, and addition (RMAA) works	Safety Science	98	8.91
8	Ko (2009)	RFID-based BM system	Automation in Construction	92	5.75
9	Arditi and Nawakorawit (1999a)	Designing buildings for maintenance: Designers' perspective	Journal of Architectural Engineering	91	3.50
10	Peng et al. (2017)	A hybrid data mining approach on BIM-based building operation and maintenance	Building and Environment	87	10.88
11	Arditi and Nawakorawit (1999b)	Issues in BM: Property managers' perspective	Journal of Architectural Engineering	84	3.23
12	Chen and Tang (2019)	BIM-based integrated management workflow design for schedule and cost planning of building fabric maintenance	Automation in Construction	80	13.33
13	Lee and Scott (2009)	Overview of maintenance strategy, acceptable maintenance standard and resources from a BM operation perspective	Journal of Building Appraisal	78	4.88
14	Christer (1982)	Modelling inspection policies for BM	Journal of the Operational Research Society	78	1.81
15	Gunay et al. (2019)	Text-mining BM work orders for component fault frequency	Building Research and Information	76	12.67
16	Al-Hammad et al. (1997)	The effect of faulty design on BM	Journal of Quality in Maintenance Engineering	76	2.71
17	Shohet et al. (2002)	Deterioration patterns of building cladding components for maintenance management	Construction Management and Economics	75	3.26
18	Olanrewaju and Abdul-Aziz (2015)	BM processes and practices: The case of a fast developing country	BM Processes and Practices: The Case of a Fast Developing Country	71	7.10
19	Zhao et al. (2022)	Developing a conceptual framework for the application of digital twin technologies to revamp building operation and maintenance processes	Journal of Building Engineering	70	23.33
20	Puķīte and Geipele (2017)	Different Approaches to Building Management and Maintenance Meaning Explanation	Procedia Engineering	67	8.38

McArthur (2015) incorporated a BIM model with multiple systems to enhance the development of a 7D (a BIM model for facilities management/operations) BIM framework, establishing a unified information source encompassing the entire spectrum of campus CF&S (Campus Facilities & Sustainability) systems. The study streamlined the input format for energy management and sustainability data using a rich room data schedule (RRDS) format, facilitating the assessment of potential energy before finalising the complete as-built model. Even though the study possessed a lower annual citation count, the publication remained significant due to its average of 15.50 citations per year. Overall, these publications profoundly shaped the discourse and direction of BM-related studies. Each publication generated distinct contributions to this field, demonstrating information into various crucial sectors. These sectors included building manufacturing, BMM strategy, knowledge-based BIM systems, and 7D BIM for the operations, maintenance, and sustainability of existing buildings. Table 13 summarise the research question, analysis and outcome.

Table 13. Summary of research question, analysis and outcome

Research questions	Analysis	Output
What are the recent emerging trends in BM-related studies?	Bibliomagika a) publication type b) source type c) language type d) subject area e) TP & TC for BM (1948–2024) f) publication year g) Trend topics	English articles and conference papers published in journals and conference proceedings within the engineering field are the most sought-after publications for BM. The peak in publication volume occurred in both 2022 and 2023, with 36 publications each year. The highest number of citations was recorded in 2015. Current trending topics include building maintenance, maintenance management, building information modeling, and facilities management
Which journals and publications are crucial to pioneering BM-related studies in BM by country?	Bibliomagika a) source titles (journal) b) country production c) Highly Cited publications iipmaps a) demographic distribution	BM's top-performing publications include Facilities, IOP Conference Series: Earth and Environmental Science, Structural Survey. Journal of Building Engineering, and Automation in Construction. Malaysia, the United Kingdom, Hong Kong, the United States, and Italy are the leading countries, each contributing more than 10 publications. "A knowledge-based BIM system for BM" by Motawa and Almarhsad is highly cited paper
Which principal research themes facilitate the progression and growth of the BM sector?	Factorial Analysis Based on Keywords a) Biblioshiny b) VOSviewer c) Treemap Analysis by Authors' Keywords, Title, and Abstract Cluster Analysis and MCA a) Thematic mapping b) Factor analysis	Maintenance, building maintenance, buildings, architectural design, maintenance management, decision making, office buildings, information management, construction and life cycle the top author's keywords, emerging themes were building operation and maintenance, condition-based maintenance, augmented reality, failure mode effect analysis, service quality, and public university, ongoing core and comprehensive themes of BM-related studies also included construction, operation and maintenance. BMM and heating, ventilation and air conditions HVAC. Future studies should focus on novel technologies (machine learning) to improve building sustainability, a trend towards BMM concerning preventive maintenance and measuring performance in facilities

5. Discussion

This review indicated that the BM sector was extensive and interdisciplinary, involving various disciplines (engineering, computer science, and business management). Most BM-related studies were predominantly featured in publications concerning facilities, environmental science, building engineering, and automation in construction. These publications were also disseminated in English through articles and journals. Meanwhile, an expanding influence and significance were observed from the consistent increase of BM-related studies. These publications were characterised by a varied cohort of authors from regions marked by high population density and significant urban development [specifically in Southeast Asia (Malaysia)]. Nonetheless, additional investigation into citation practices and quality control within the BM sector was necessary due to the fluctuations in citation rates. The trends obtained in this review also underscored the increasing significance of BM in resolving building sustainability concerns and the application of technology. Therefore, examining scientific contributions from different institutions was essential for comprehending active research domains, investigating opportunities for future partnerships, and facilitating strategic development.

The importance of BM as an issue in developing and developed nations was demonstrated in this review. The word map based on MCA visualised various interconnections among different keywords in BM-related studies. This data revealed the essential concepts, targeted focus areas, and emerging trends in the discipline. Cluster 1 indicated a growing trend towards the ongoing upkeep of buildings to preserve their value by highlighting the importance of maintaining green buildings, hospitals, residential structures, institutes of higher learning, school facilities, and heritage sites. Cluster 2 emphasised the evolution of sustainable business model practices by integrating sustainability principles with technological innovations. Cluster 3 underscored the significance of implementing BMM in public institutions with established performance metrics.

All these clusters collectively presented a multidimensional view of the BM research domain.

This review delineated the existing research literature, determining key themes, identifying evolving trends, and pinpointing areas mature for exploration and innovation to improve the theoretical framework of BM-related studies. The complex interrelations, historical development, and emerging cutting-edge technologies of the clusters exhibited the dynamic and diverse characteristics of sustainable BM. Several vital themes also demonstrated a significant relationship with BM, including maintenance, architectural design, building, maintenance management, buildings, information management, construction, and facilities management. Hence, future studies should pinpoint unexamined domains and explore future research avenues in BM based on the findings of this review. Given that LCCs and maintenance procedures (key performance indicators) have only been investigated, other BM-related fields can be examined (maintenance allocation, public housing, commercial buildings, maintenance expenses, and cost analysis).

This review presented the emerging themes that highlighted the potential of technologies (machine learning, digital, IoT, and computerised maintenance management systems) to improve BM sustainability. Therefore, the findings can provide the sector with directives for technological implementation while emphasising the importance of factoring BM during the architectural design and planning phases. This information can also provide policymakers with data about the worldwide research domain in BM, facilitating the creation of efficient and context-specific sustainability policies. Moreover, this review indicated the necessity of transitioning to energy efficiency, enhancing comprehension of societal sustainability. The outcomes can influence educational curricula and public discussions, promoting a culture of sustainability and encouraging future generations to engage in this important field. Overall, this review demonstrated the broad theoretical, methodological, practical, and societal implications of BM-related studies. This research area is significant and directs future studies, promoting the ongoing advancement of BM-related studies.

6. Conclusions

This review successfully performed a bibliometric analysis utilising R software to examine the evolution of BM trends between 1948 and 2024. The analysis involved a detailed examination of the publications (publication years, article types, sources, and content). This bibliometric analysis also yielded significant insights into the annual publication trends, most productive authors, most cited papers, most productive countries and institutions, most productive source titles, top keywords used, co-authorship and co-occurrence analyses, collaboration analysis, thematic evolution analysis, and thematic mapping.

The examination of publishing trends and citation patterns has revealed new developments in building maintenance (BM) research, analysing publication types, sources, languages, and subject areas from 1984 to 2024, as chronicled by biblioMagika. Journal articles in English are the predominant publication format in BM, with "Facilities" emerging as the top journal. Significantly, the years 2022 and 2023 saw the highest publication counts, both totalling 36. Keyword analysis has highlighted key topics such as building maintenance, maintenance, building information modeling, facilities management, and operation and maintenance. The leading countries in BM publications are Malaysia, the United Kingdom, Hong Kong, and the United States. The most cited work in this discipline is "A Knowledge-Based BIM System for BM" by Motawa and Almarshad from the United Kingdom.

Through factorial analysis, treemap analysis, cluster analysis, and multiple correspondence analysis (MCA) of high-frequency keywords, several key areas have been identified, such as maintenance, BM, buildings, architectural design, maintenance management, decision-making, office buildings, sustainable development, building operations, construction, life cycle, operation and maintenance, and facilities management. Furthermore, thematic map analysis has revealed important emerging themes related to the research topic, including augmented reality, failure mode effects analysis, service quality, public universities, building operation and maintenance, and condition-based maintenance, which are still largely unexplored. The MCA suggests that future research should prioritise innovative technologies aimed at improving building sustainability and trends in building maintenance management, especially concerning preventive maintenance and performance measurement in facilities.

Despite the theoretical understanding of BM and key areas for future research being presented, several constraints were observed for this review (reliance on keywords for article retrieval concerning BM). The search process was also constrained by over-relying on the Scopus online database as the main source. Therefore, future studies should involve other databases while exploring BM during the design phase in commercial structures. Information can also be obtained from future studies involving user behaviour assessment in BM implementation and practices while exploring recent technological developments in managing BM (digital maintenance tools and defect detection).

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Author contributions

Ong conceived this review and managed the data analysis, collection, and interpretation design and development. Hasniyati and Yasmin contributed to supervision, review, and editing.

Disclosure statement

The authors declare there is no conflict of interest.

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