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DECISION-MAKING APPROACHES IN BUILDING MAINTENANCE: A BIBLIOMETRIC REVIEW OF GLOBAL TRENDS AND METHODS

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Abstract:

The growing complexity of building assets and infrastructure has intensified the need for structured and data-driven decision-making approaches in maintenance management. Despite increasing research attention, the literature on how decision-making methods are applied in building maintenance remains fragmented and lacks a comprehensive synthesis of global trends and thematic directions. This bibliometric analysis aims to map and evaluate the research landscape of decision-making approaches in building maintenance using a systematic data-driven methodology. A total of 532 relevant documents published between year 2000 until October 2025 were retrieved from the Scopus database using keyword searches including "decision making," "multi-criteria decision making (MCDM)," "building maintenance," and "infrastructure maintenance." The data was analyzed using Scopus analyzer to identify publication trends, top contributing countries, authors, and journals. OpenRefine was utilized to clean and standardize the data, ensuring consistency in author names, keywords, and affiliations. VOSviewer software was employed to visualize co-authorship networks, keyword co-occurrence, and country collaborations, generating comprehensive knowledge maps that reveal the intellectual and thematic structure of the

field. The findings indicate a significant increase in research output over the last decade, with notable contributions from countries such as the United States, China, and the United Kingdom. Key thematic clusters identified include multi-criteria decision models, digital technologies such as BIM and digital twins, and sustainability-driven maintenance strategies. This study contributes to the body of knowledge by highlighting research hotspots, influential contributors, and emerging themes, offering valuable insights for academics, practitioners, and policymakers seeking to enhance decision-making in building maintenance through structured and technology-supported approaches.

Introduction

Building maintenance is a critical aspect of facility management, ensuring the longevity, safety, and efficiency of structures. Effective maintenance strategies are essential to mitigate the risks of structural failures, reduce operational costs, and enhance the overall performance of buildings (Besiktepe et al., 2020). Decision-making in building maintenance involves selecting appropriate strategies that balance cost, reliability, and sustainability. It is also a multifaceted process influenced by various factors, including the condition of building components, user preferences, and economic considerations. Various decision-making approaches have been developed to address the complexities and uncertainties in maintenance planning.

MCDM methods are widely recognized for their ability to handle complex decision problems involving multiple attributes. The Analytic Hierarchy Process (AHP) is among of the popular MCDM methods that has been applied to model subjective decision problems in maintenance planning. A study proposed a decision model based on AHP for the maintenance of reinforced concrete structures under corrosion risk, demonstrating its effectiveness in selecting the best maintenance alternative (Benítez et al., 2020). Similarly, the Reliability-Centered Maintenance (RCM) method has been introduced to improve decision-making by evaluating the failure risk of key building facilities, resulting in significant cost reductions (Ma et al., 2020).

The selection of appropriate MCDM methods for specific maintenance problems remains a challenge. A comprehensive review of MCDM applications in facility management and building maintenance identified key trends and developed a contextual MCDM Method Selection Matrix to guide the selection process (Anbari Moghadam & Besiktepe, 2025). This matrix links specific maintenance problems to suitable MCDM methods, addressing challenges such as subjectivity, uncertainty, and expert qualifications. The study highlighted the growing adoption of hybrid MCDM methods and the need for structured guidance to achieve consistent, data-driven decision-making.

Subjective motivations, such as personal preferences and aesthetic considerations, often influence maintenance decisions. Combining objective indicators of building degradation with subjective user perceptions can help prioritize maintenance actions and allocate resources effectively (Valença et al., 2023). In the construction industry, MCDM methods have been used to design optimal maintenance strategies for heavy machinery, such as boom placers, by assessing and ranking various approaches based on criteria like cost, reliability, and ease of

implementation (Farwaha et al., 2025). This structured approach helps companies identify balanced maintenance strategies that align with operational goals and budget constraints.

The integration of advanced technologies, such as machine learning (ML) and deep learning (DL), offers new opportunities for predictive maintenance (PdM). ML techniques, including Logistic Regression (LR), Support Vector Machine (SVM), and Convolutional Neural Network (CNN), enable real-time monitoring and prediction of structural problems, enhancing the accuracy and efficiency of maintenance activities (Jin, 2024). However, the complexity of data collection, processing, and analysis poses challenges to the practical application of these techniques. Despite these challenges, ML-based PdM methods have shown potential in reducing maintenance costs and improving building health monitoring.
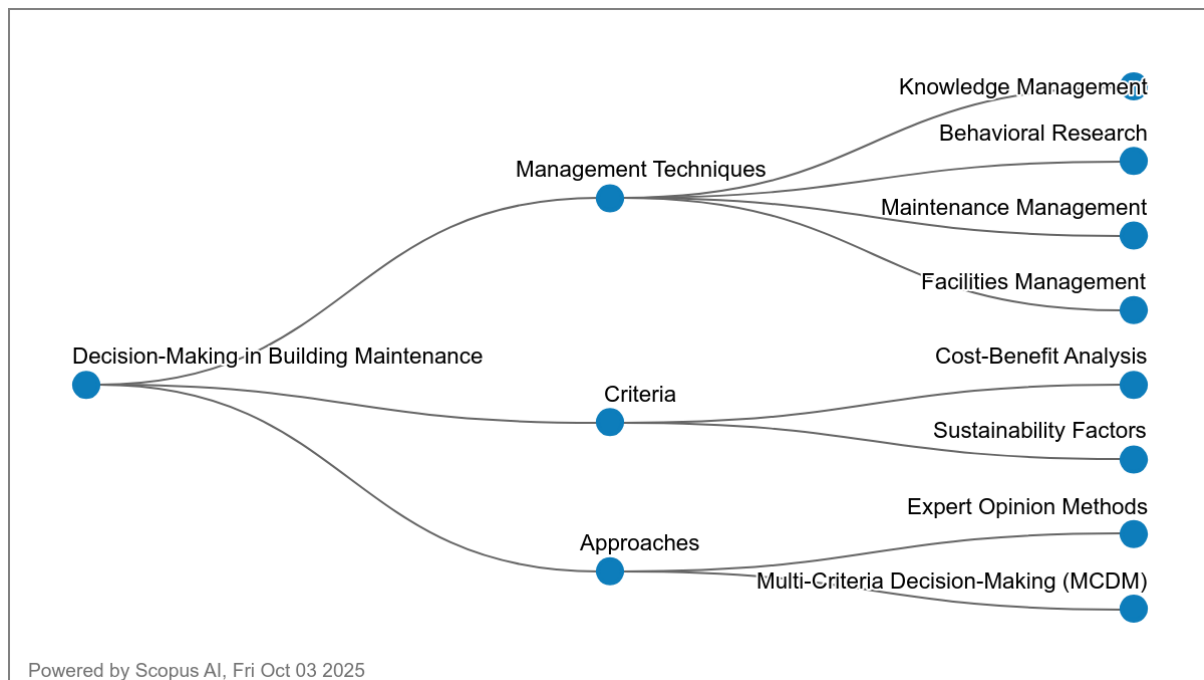

Figure 1: Mind Map for Decision-Making Approaches in Building Maintenance

Figure 1 illustrates a framework for understanding decision-making in building maintenance, consisting of three major themes: Management Techniques, Decision Criteria, and Approaches. The Management Techniques theme includes Knowledge Management, Behavioral Research, Maintenance Management, and Facilities Management, reflecting the organizational, psychological, and operational strategies that support effective decision-making processes in maintenance planning and execution. These techniques influence how maintenance data is managed, how teams behave under decision uncertainty, and how maintenance systems are governed at both strategic and operational levels. The second theme, Decision Criteria, comprises Cost-Benefit Analysis and Sustainability Factors. These serve as the primary evaluative parameters used to prioritize maintenance actions, balance short- and long-term benefits, and ensure alignment with environmental and financial performance goals. Finally, the Approaches theme features MCDM and Expert Opinion Methods, which represent the structured methodological tools often applied to evaluate complex alternatives. These approaches enhance decision quality by combining quantitative models with expert judgement. Collectively, the three themes and their subcomponents demonstrate that building maintenance

decision-making is a multidimensional process that integrates management practices, sustainability-focused criteria, and formal analytical techniques.

Research Questions

Given the increasing research interest in decision-making approaches within building maintenance, this study employs a bibliometric analysis to examine the publication trends, influential literature, thematic directions, and international collaboration in this domain. Bibliometric analysis offers a structured methodology to assess the body of knowledge by identifying key publications, dominant themes, contributing countries, and co-authorship networks. The following research questions guide the bibliometric investigation:

What are the research trends in decision-making studies in building maintenance according to the year of publication?
1. What are the top 10 most cited articles in the field?
2. Which countries are the top 10 contributors based on the number of publications?
3. What are the most popular keywords associated with decision-making in building maintenance?
4. What are the patterns of co-authorship and international collaboration among countries?

Methodology

Bibliometric analysis entails the systematic collection, organization, and evaluation of bibliographic data derived from scholarly literature (Alves et al., 2021; Assyakur & Rosa, 2022; Verbeek et al., 2002). In addition to generating basic metrics such as identifying core journals, publication timelines, and prolific authors (Wu & Wu, 2017), this method also encompasses advanced techniques, including document co-citation analysis. A robust literature review demands a rigorous and iterative process of keyword selection, literature retrieval, and critical examination. Such a methodology facilitates the development of an exhaustive bibliography and ensures the credibility of findings (Fahimnia et al., 2015).

Accordingly, this study prioritized high-impact publications, recognising their value in revealing the theoretical underpinnings of the research domain. For the sake of data reliability, the Scopus database was employed as the principal source for data acquisition (Al-Khoury et al., 2022; di Stefano et al., 2010; Khiste & Paithankar, 2017). Furthermore, to uphold scholarly integrity, the analysis was confined to peer-reviewed journal articles, intentionally omitting books and lecture notes (Gu et al., 2019). All bibliographic records were retrieved from Elsevier's Scopus database, covering publications dated from 2000 to October 2025.

Data Search Strategy

The bibliometric analysis in this study is grounded in a structured and refined search strategy, designed to capture the evolution of decision-making approaches in building maintenance from the year 2000 up to October 2025. The Scopus database was selected as the primary data source due to its broad coverage of peer-reviewed literature in engineering, management, and applied sciences. The search string was constructed using a combination of Boolean operators and wildcard symbols to ensure comprehensive retrieval. As shown in Table 1, the search targeted article titles, abstracts, and keywords (TITLE-ABS-KEY) using terms related to various types of maintenance (e.g., building*, facilit*, propert*, asset*, infrastructure*) and decision-making concepts (e.g., decision-making, DSS, MCDM, MADM). The search was limited to English-language publications to maintain consistency and accuracy in keyword analysis.

As presented in Table 2, articles published before the year 2000 and those written in non-English languages were excluded. The search initially yielded 555 documents. After applying inclusion and exclusion criteria and removing non-relevant or duplicate records, a total of 532 articles were retained for bibliometric analysis.

Table 1: Scopus Search String

Scopus	(TITLE-ABS-KEY ("building* maintenance" OR "facilit* maintenance" OR "propert* maintenance" OR "asset* maintenance" OR "infrastructure* maintenance") AND TITLE-ABS-KEY ("decision-making" OR "decision making" OR "decision model*" OR "decision approach*" OR "decision support system*" OR "DSS" OR "multi-criteria decision making" OR "multi attribute decision making" OR "MCDM" OR "MADM")) AND (LIMIT-TO LANGUAGE, "English"))

Access Date: October 2025

Table 2: The Selection Criteria

Criterion	Inclusion	Exclusion
Language	English	Non-English
Time line	2000 – 2025	< 2000

Data Analysis

VOSviewer, developed by Nees Jan van Eck and Ludo Waltman at Leiden University, Netherlands (van Eck & Waltman, 2010, 2017), has emerged as one of the most widely adopted tools for bibliometric mapping and visualization. Renowned for its intuitive interface and powerful analytical capabilities, the software enables researchers to explore the structural dynamics of scientific knowledge through sophisticated visual representations. VOSviewer excels in constructing network maps that depict co-authorship, co-citation, and keyword co-occurrence relationships, thereby offering comprehensive insights into the intellectual structure and thematic evolution of research domains. Its continual development and user-centric design have made it a preferred platform for scholars seeking to decode complex bibliographic data efficiently.

Among its most notable features is the ability to convert voluminous and intricate bibliometric datasets into accessible, visually engaging maps and density plots. By focusing on network visualization, the software facilitates the identification of research clusters, emerging themes, and influential publications. Its compatibility with major bibliometric databases and capacity for customized metrics computation significantly enhance its analytical flexibility. Furthermore, VOSviewer supports both novice and expert users in generating meaningful interpretations of vast scientific landscapes, positioning it as an indispensable instrument in bibliometric and scientometric research.

For this study, bibliometric data comprising publication year, article title, author information, journal source, citations, and author keywords were extracted from the Scopus database in PlainText format, covering the period from 2004 through December 2024. Analysis was conducted using VOSviewer version 1.6.19, which facilitated the generation of bibliometric maps and cluster visualizations. The software employs its proprietary VOS (Visualization of Similarities) mapping technique as an alternative to traditional Multidimensional Scaling (MDS), enabling the spatial placement of items in a low-dimensional layout where the distance between any two elements directly reflects their degree of relatedness (van Eck & Waltman, 2010). While VOS shares conceptual underpinnings with MDS (Appio et al., 2014), it diverges methodologically by applying the association strength (AS_{ij}) normalization technique, a more robust metric for co-occurrence data, as opposed to conventional similarity indices such as cosine or Jaccard coefficients (Van Eck & Waltman, 2007).

$$AS_{ij} = \frac{C_{ij}}{w_i w_j}$$

which is "proportional to the ratio between on the one hand the observed number of co-occurrences of i and j and on the other hand the expected number of co-occurrences of i and j under the assumption that co-occurrences of i and j are statistically independent" (Van Eck & Waltman, 2007).

Findings And Discussion

This section outlines the main findings of the bibliometric analysis on decision-making approaches in building maintenance, guided by five research questions. It first reviews publication trends to show how the field has developed over time, then highlights the top 10 most cited articles that shaped the research area. The analysis also identifies the leading countries in terms of publication output and examines popular keywords to reveal key themes and methods. Finally, international collaboration is explored through co-authorship networks, showing global research connections in the field.

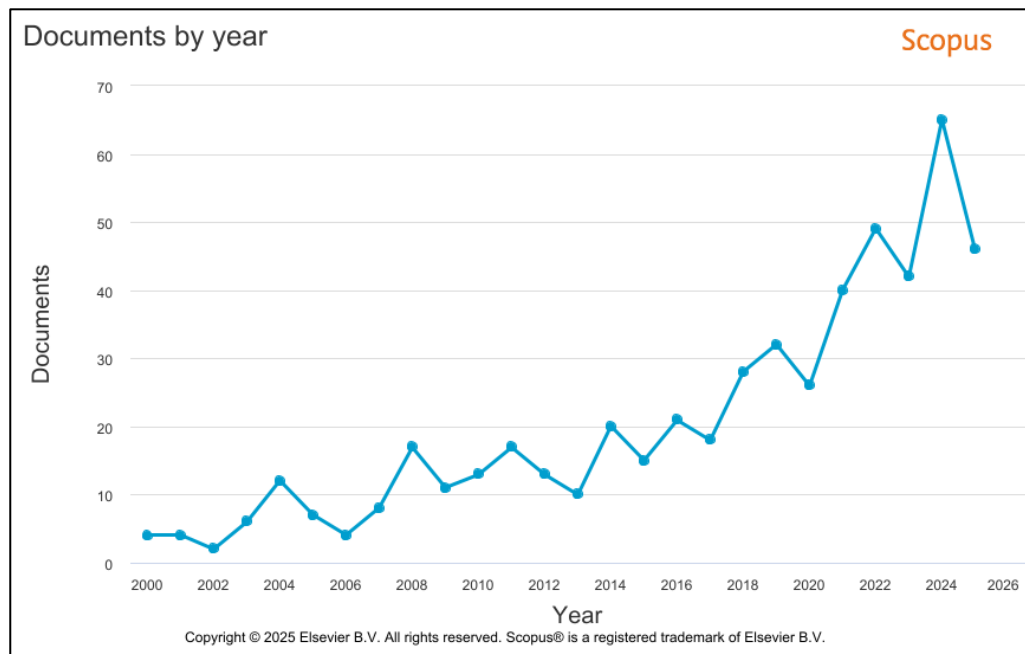*Research Trends According to the Year of Publication*

Figure 2: Research Trends by Years

The publication trend from 2000 to 2025 on the topic "Decision-Making Approaches in Building Maintenance" reveals a significant upward trajectory, particularly from 2015 onward. Between 2000 and 2014, the number of publications remained relatively modest, fluctuating between 2 and 20 documents per year. This reflects a nascent stage in which research on maintenance-related decision-making was still developing, often focused on traditional maintenance practices without integration of structured decision tools. However, starting from 2015, a steady increase is observed—rising from 15 papers in 2015 to 32 by 2019—indicating growing awareness of the importance of systematic decision-making in facility and asset management. This period likely marks the emergence of Multi-Criteria Decision-Making (MCDM) methods such as AHP, TOPSIS, and PROMETHEE being applied to maintenance prioritization and planning.

The surge becomes more pronounced from 2020 to 2024, peaking at 65 publications in 2024, before slightly dropping to 46 in 2025 (likely due to indexing lag). This sharp growth corresponds with the global push toward digital transformation in maintenance practices, driven by the adoption of smart building technologies, IoT sensors, Building Information Modelling (BIM), and predictive analytics. Additionally, sustainability imperatives and cost-optimization pressures in both public and private sectors have led to increased academic and industry attention on decision-support tools. The spike also coincides with the post-COVID-19 era, where asset resilience, remote monitoring, and data-driven maintenance strategies became critical priorities. Therefore, the rising trend reflects a maturing research field responding to practical demands for smarter, justifiable, and risk-aware maintenance decisions in the built environment.

Analysis of Most Cited Articles

Table 3 : The Most Cited Articles

Authors	Year	Source title	Cited by
Wang et al., 2020	2020	Neuro computing	269
Maekawa et al., 2008	2008	-	221
Chen et al., 2018	2018	Automation in Construction	202
Noonan et al., 2012	2012	European Journal of Neuroscience	150
Cholasuke et al., 2004	2004	Journal of Quality in Maintenance Engineering	139
Zhao et al., 2022	2022	Journal of Building Engineering	137
Chemweno et al., 2015	2015	International Journal of Production Economics	126
Lu et al., 2019	2019	-	121
Ighravwe & Oke, 2019	2019	Journal of Building Engineering	113
Yu et al., 2021	2021	Tunnelling and Underground Space Technology	112

The analysis of the top 10 most cited articles related to "Decision-Making Approaches in Building Maintenance" reveals a strong orientation toward digital technologies, predictive modelling, and structured decision frameworks. The most cited article by Wang et al. (2020) with 269 citations demonstrates the growing importance of machine learning and neural networks in predicting machinery life, a critical component of predictive maintenance. Similarly, articles by Chen et al. (2018) on BIM-based scheduling and Zhao et al. (2022) on digital twins reflect the integration of digital engineering tools to improve maintenance operations. These papers highlight the transition from manual and reactive approaches to data-driven, automated decision-support systems. The inclusion of works like Maekawa et al. (2008) also suggests that foundational studies in structural modelling remain influential, particularly when linked to performance and deterioration assessment in built assets.

Additionally, the presence of structured decision-making models such as MCDM, Analytic Network Processes (ANP), and risk assessment frameworks (e.g., Chemweno et al., 2015; Ighravwe & Oke, 2019) reflects the field's emphasis on rational and quantifiable decision support. The prominence of digital twin-related studies (Zhao et al., Yu et al., Lu et al.) shows a recent surge in interest, aligning with industry trends in Industry 4.0, smart buildings, and asset digitization. These articles are cited frequently because they offer practical frameworks, empirical validation, and technological relevance, serving as foundational references for both academic researchers and industry practitioners. The variety of journals, ranging from Automation in Construction to Journal of Production Economics, demonstrates the

interdisciplinary appeal of maintenance decision-making research across engineering, computer science, and operations domains.

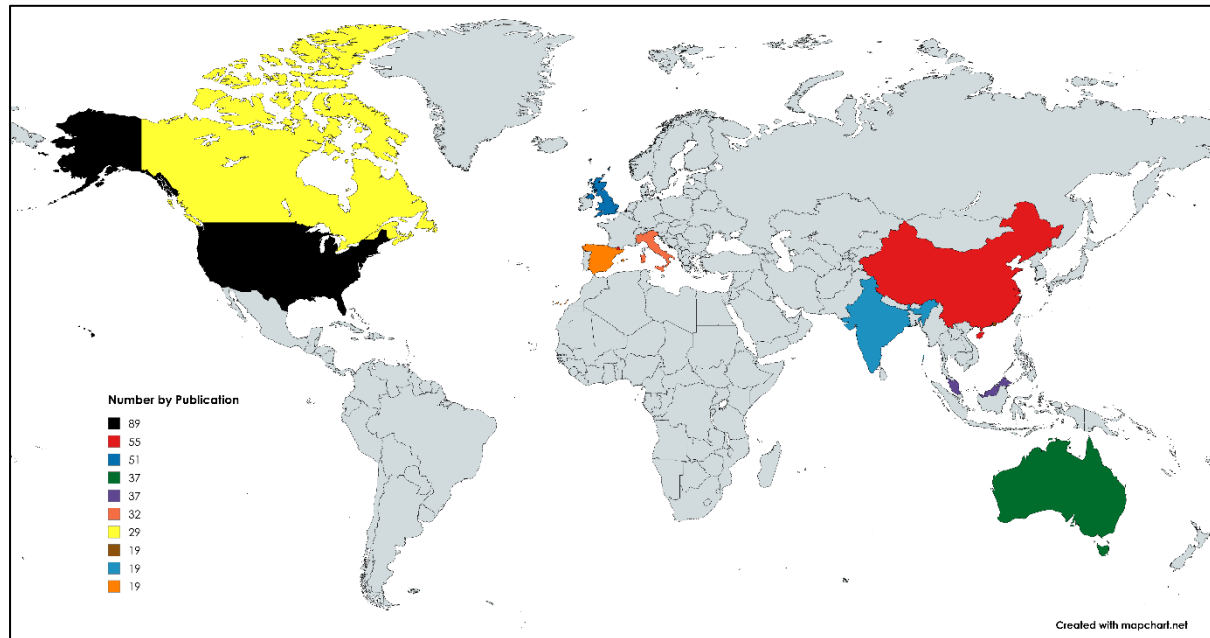*Top 10 Countries Based on The Number of Publications*

Figure 3: Top 10 Countries Mapping Based on the Number of Publication

Table 4: Top 10 Countries Based on Publications

Country	No of Publication	Percentages (%)
United States	89	23.00
China	55	14.21
United Kingdom	51	13.18
Australia	37	9.56
Malaysia	37	9.56
Italy	32	8.27
Canada	29	7.49
Hong Kong	19	4.91
India	19	4.91
Spain	19	4.91

The distribution of publications by country on the topic "Decision-Making Approaches in Building Maintenance" highlights the global engagement in this research domain, with notable dominance by developed nations. The United States leads significantly with 89 publications representing 23% of the total scholarly output in this field, reflecting its strong research infrastructure, well-established facilities management industry, and longstanding investment in engineering and decision sciences. Following the U.S., China, with 55 publications (14.21%) and the United Kingdom, with 51 publications (13.18%) also show high output, likely due to rapid urbanization, infrastructure expansion, and policy-driven emphasis on sustainable construction and smart cities. Countries such as Australia with 37 publications (9.65%) and

Italy, with 32 publications (8.27%), are similarly active, benefiting from strong academic–industry linkages and government-led innovation in building technologies.

Interestingly, Malaysia ranks equally with Australia at 37 publications (9.56%) marking a significant presence for a developing country. This suggests Malaysia's increasing focus on infrastructure modernization, particularly in the public and defence sectors, where decision-making in maintenance has become essential due to budget constraints and aging assets. The involvement of countries like Canada with 29 publications (7.49%), Hong Kong, India and Spain share 19 publications (4.91%), indicates a growing interest in localized approaches to facility management and the adoption of decision support tools in both academic and practical contexts. Collectively, the spread of publications across continents reflects a shared global challenge, optimizing building maintenance strategies and highlights the varying degrees of technological adoption, policy influence, and research funding that shape national contributions to this field.

Popular Keywords Related to the Study

Figure 4: Popular Keywords Related to the Study

The co-occurrence analysis of author keywords using VOSviewer identifies how frequently keywords appear together within the same documents, revealing relationships between research themes and helping to uncover the intellectual structure of the field. In this study, full counting was applied, meaning every occurrence of a keyword in a document is counted

equally. With a minimum threshold of 5 occurrences, the system analyzed 2,573 keywords, of which 267 met the threshold, and further filtered using a minimum cluster size of 5, resulting in 9 distinct keyword clusters. These clusters represent thematic groupings based on similarity and co-occurrence patterns, allowing researchers to understand major research streams and emerging trends. The most dominant keywords, such as "decision making" (326 occurrences), "maintenance" (283), and "building maintenance" (118) anchor the central research focus and show strong total link strengths, highlighting their frequent co-mentioning with other terms.

The findings from this network contribute significantly to the body of knowledge in building maintenance and decision-making research. The presence of clusters around terms like "decision support systems," "digital twin," "sustainable development," and "artificial intelligence" suggests an evolving paradigm that integrates digital technologies, optimization techniques, and sustainability into maintenance decision-making processes. Emerging keywords such as "predictive maintenance," "Internet of Things," "risk assessment," and "machine learning" reveal how modern infrastructure maintenance is increasingly data-driven and risk-aware. This co-occurrence map not only visualizes how the field has matured from basic maintenance models to intelligent and integrated systems but also informs future research directions by highlighting underexplored intersections and thematic gaps. Ultimately, it strengthens scholarly understanding of the interdisciplinary nature of building maintenance decision-making, combining engineering, data science, and management perspectives.

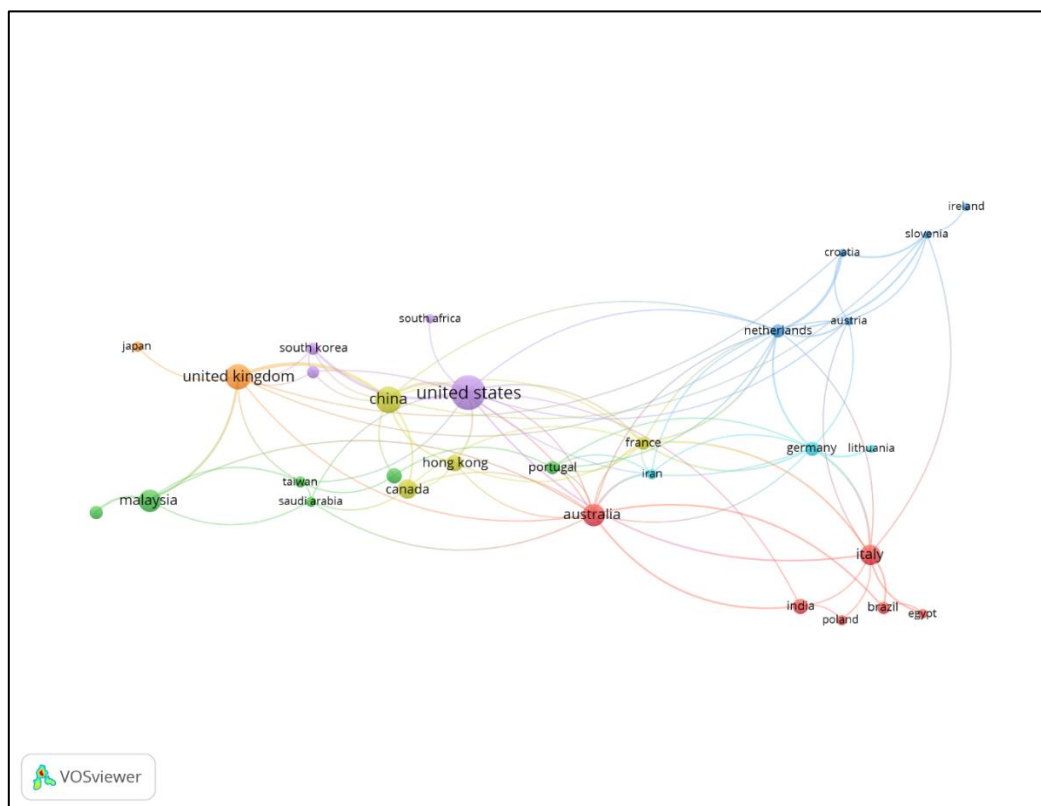*Co-Authorship by Countries Collaboration*

Figure 5: Co-Authorship Based on Countries' Collaboration

The co-authorship analysis by countries using VOSviewer is a bibliometric method that maps international collaboration patterns based on shared authorship across published documents. This technique identifies which countries tend to co-author papers together, providing insights into global research networks and the degree of scientific cooperation in a specific field, in this case, decision-making approaches in building maintenance. Using the full counting method, every co-authorship is equally weighted regardless of how many times a country appears. Out of 74 countries, a minimum threshold of 5 publications was applied, resulting in 30 countries meeting the threshold. A minimum cluster size of 5 was also set, producing 7 clusters, each representing a collaborative subgroup of countries that are more tightly linked based on co-authored publications.

The network reveals that leading contributors like the United States (88 documents, 1317 citations) and China (54 documents, 817 citations) exhibit the strongest collaborative ties (total link strength of 24 each), indicating they play central roles in global knowledge exchange. Countries such as the United Kingdom, Australia, and the Netherlands also appear as influential nodes, both in terms of publications and international collaboration. Interestingly, Malaysia (37 documents, 399 citations) has a notable publication volume but a relatively lower link strength (9), suggesting more domestic or regional research output. These findings contribute to the academic landscape by highlighting where research leadership and partnerships are emerging, and they emphasize the importance of cross-border collaborations in addressing complex challenges in building maintenance. Understanding these collaboration patterns can help researchers identify potential international partners and funding opportunities, and support efforts to enhance the global impact and visibility of research in this field.

Conclusion

Based on the bibliometric analysis conducted on the topic of "Decision-Making Approaches in Building Maintenance", the primary aim was to systematically map research development, identify key thematic clusters, and evaluate global trends and collaboration patterns in this domain. The study focused on uncovering the intellectual structure and evolution of decision-making methodologies applied in the context of building maintenance. Using data retrieved from the Scopus database between 2000 and 2025, the research revealed a substantial increase in scholarly attention in the last decade, particularly after 2015, driven by the integration of digital technologies and the rising complexity of infrastructure systems.

The findings show that the most frequently occurring keywords and cited articles relate to multi-criteria decision-making (MCDM), decision support systems, and digital solutions such as BIM and digital twins. Leading contributors include the United States, China, and the United Kingdom, with Malaysia emerging as a notable contributor in the Southeast Asian context. The study contributes to the existing body of literature by offering a comprehensive knowledge structure of how decision-making in building maintenance has evolved, especially in relation to sustainability, predictive modeling, and structured evaluation criteria. Practically, these insights may support more informed development of decision-support tools for building management in real-world applications. However, limitations include reliance on a single database and language filter, potentially excluding relevant non-English works or grey literature. Future research could explore citation content analysis or thematic evolution using multiple databases to further enrich the findings. Overall, this bibliometric study underscores the value of data-driven review methods in synthesizing fragmented knowledge, guiding

strategic research directions, and informing policy and practice in infrastructure maintenance and facility management domains.

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