A review and bibliometric analysis of utilizing building information modeling (BIM) on effective operation and maintenance (O&M)

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Abstract. Developments in information technology can facilitate the planning and implementation of sustainable development. Building Information Modeling (BIM) is one such technology that can be utilized to achieve this goal. BIM has now reached dimensions of 6D and even 7D, with 6D BIM being used for energy analysis and 7D BIM for facility management during the operational and maintenance period of a building. This paper aims to discuss patterns, gaps, and trends in the utilization of BIM for effective building operation and maintenance. Bibliometric data mapping was conducted using VOSviewer® software, and 219 scholarly bibliographic records from the Scopus database between 2009 and 2023 were analyzed. The results showed that the highest publication growth was in 2021, with 36 publications (16.44%). China published the most articles, with 74 (29.84%). Recent research reviews indicate that BIM can facilitate the O&M process of a facility, including maintenance and repair, energy management, and security. However, there are still many challenges related to the BIM 7D function, such as data interoperability issues and the need for a framework for using BIM. The study also examines the application of BIM 7D in Indonesia. Further research is needed to balance the utilization of BIM for facility management with its application for asset management.

1 Introduction

Sustainable Development Goals (SDGs) are development that maintains sustainable improvement of people's economic welfare, development that maintains the sustainability of people's social life, development that maintains the quality of the environment, and development that ensures justice and the implementation of governance that is able to maintain the improvement of the quality of life from one generation to the next. The SDGs consist of 17 goals and 169 targets for the period 2015-2030 [1]. Implementing sustainable construction is one of the efforts that can be made to achieve these goals. Developments in information technology, particularly in the construction sector, can help facilitate the planning and implementation of sustainable development. One way to achieve this is through the utilization of Building Information Modeling (BIM).

Building Information Modeling (BIM) has gained widespread usage in the construction industry in recent years. In essence, BIM serves to integrate all systems within a building, enabling multiple parties to work simultaneously without interference. BIM has made significant contributions to the Architectural, Engineering, and Construction (AEC) industry. It enables three-dimensional (3D) modeling of projects, facilitates project schedule management throughout the lifecycle, serves as a communication platform for all stakeholders, assists in cost estimation and calculation, detects clashes, and empowers stakeholders to inspect and manage buildings throughout their lifecycle [2].

1.1 Definition of building information modeling (BIM)

Building Information Modeling (BIM) is a promising development in the AEC industry [3]. It can be defined as a methodology that supports collaborative efforts by creating an application environment that can accommodate all disciplines involved in a construction project with a large amount of information applicable to different stages of the project [4]. BIM can also integrate many of the functions needed to model the lifecycle of a building, providing a foundation for new design and construction, as well as changing roles and relationships among project teams. If properly adopted, BIM can facilitate a more integrated design and construction process, resulting in better quality buildings, at a lower cost, and shorter project duration [3].

The scope of BIM directly or indirectly affects all stakeholders involved in a construction project. BIM provides various methods for creating, utilizing, and sharing data throughout the building lifecycle [3]. BIM can assist stakeholders in exchanging data and information about building construction throughout the life cycle of the building [5]. The National Building

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Information Modeling Standard (NBIMS) divides BIM categories into three, which are [3]:

a) As a product;
b) As an open standards-based process enabled by IT, and a collaborative process;
c) As a facility lifecycle management requirement.

BIM models can be used for specific, predefined purposes, usually referred to as use cases. Based on the project's needs and complexity in each phase, certain parameters are added to the existing information in the BIM. These predefined use cases can be referred to as BIM dimensions. BIM is not limited to creating a 3D model of a building. It can also facilitate the addition of information related to the design, construction, and maintenance phases of a building. Each BIM dimension has its purpose, depending on the user's needs, such as estimating project costs, implementing schedules, and identifying the project's future sustainability. BIM dimensions continue to evolve along with the advancement of information technology. The function of each BIM dimension is described in Table 1.

Table 1. Dimensions of BIM [6].

Dimensions of development	Descriptions	Stakeholder impact
3D	Consists of two and three dimensional model data to represent the building design	Design team, supplier
4D (3D + time)	Links scheduling/time related information to the 3D model's object in order to sequence the construction project over time	Contractor, sub-contractor
5D (4D + cost)	Adds cost related information to the 3D model's element	Quantity surveyor
6D (5D + self-sustainable & energy efficient)	Allows an exhaustive analysis in terms of sustainability (environmental, energy, etc) of the building model	Facility manager, building owner
7D (6D + facility management information)	Integrates facility management and building life cycle information	Facility manager, building owner
nD	Other possible dimensions associated with the BIM model	Can relate to any specified stakeholder

1.2 BIM 6D and 7D functions

The dimensions of BIM continue to expand over time, starting from the previous 3D dimension and now reaching up to 6D and 7D. BIM dimensions encompass all aspects and information that contribute to the construction digitization process. In addition to representing the building model graphically in 2D or 3D, BIM can also depict other aspects of the model. The 6D BIM, also known as integrated BIM or energy analysis in buildings, aims to determine the amount of energy usage in a building plan through a digital model. On the other hand, BIM 7D serves for facility management (FM). This BIM dimension is generally used when the building has entered the operational and maintenance phase. The use of BIM 7D facilitates coordination in the routine maintenance of assets in the building since all 3D model data, including buildings and assets, are consolidated on one platform, and stored in the cloud.

1.3 Scope and structure of the paper

The operation and maintenance phase incurs the highest cost in the lifecycle of a facility [7]. The life cycle cost of a property is estimated to be 5-7 times higher than the initial investment cost [8]. The design and construction phase costs less than 15% of the total life cycle cost of the building [9]. Meanwhile, the operation and maintenance phase, which is the longest phase in the life cycle, consumes more than 60% of the total cost [10]. BIM serves as the best data collector and an effective database for information management in the AEC industry, including the operation (O) and maintenance (M) phases [5], which can be utilized for facility management (FM) [11].

This paper uses the Scopus database as a source for data collection. The main objective of this paper is to identify patterns, trends, and gaps related to the utilization of BIM for the O&M phase of buildings by using bibliometric analysis using VOSviewer and reviewing a number of related articles. This paper will also explore the application of BIM 7D for facility management in Indonesia.

There are several previous studies that share similarities with this research. Zhao [12] conducted a scientometric review using bibliographic data from the Web of Science on global research on BIM. Cao et al. [13] conducted a systematic review on the use of BIM for the operation and maintenance phase of Green Buildings, utilizing data sources from Web of Science and Scopus from January 2022 to April 2022.

This paper is divided into five main sections. Section 1 serves as an introduction, providing an overview of the topic and explaining the fundamental concepts. Section 2 describes the methodology used for collecting and analyzing the bibliometric data. In Section 3, the obtained results will be discussed. Section 4 presents a review of relevant studies closely related to the topic. Finally, Section 5 concludes the paper and provides suggestions for future research.

2 Research method

This study aims to conduct a systematic literature review on the benefits of BIM in achieving effective building operation and maintenance processes. The paper utilizes a combination of quantitative and qualitative methods to analyze articles related to BIM and Operation & Maintenance (O&M). Bibliometric analysis is employed to explore and analyze relevant bibliographic data from the selected articles.

The study conducted a quantitative analysis to examine the distribution of BIM publications over time, authors, countries, research institutions, subject categories, and journals. Additionally, a qualitative analysis was performed by importing bibliometric records into a bibliometric tool for visualization analysis, including co-authorship networks, country/region and institution networks, co-occurring subject category networks, co-occurring keyword networks, journal co-citation networks, author co-citation networks, and document co-citation networks. Furthermore, a discussion on the application areas of BIM was conducted to provide comprehensive insights into the benefits of 6D and 7D BIM in Operation & Maintenance, as well as suggestions for future research in this field.

The preparation of this paper involved three stages. Firstly, data collection was conducted to gather articles and publications related to BIM applications in Operation and Maintenance. Secondly, a bibliometric analysis was performed on the collected data. Lastly, a comprehensive discussion of the obtained results was conducted. The stages are outlined as follows:

2.1 Data collection

Data collection was carried out using the Scopus database, which was chosen for its extensive collection of peer-reviewed literature and publications [14]. The search was conducted using the keywords "Building Information Modeling" OR "BIM" OR "Building Information Modeling" AND "Operation and Maintenance" OR "OM". The publications analyzed in this study were those published between 2009 and 2023, up until February 10. The initial search yielded 242 research publications. To provide a comprehensive overview of the existing research, the selected document types included articles, conference papers, and reviews [15]. Only English documents were selected, as VOSviewer, the analysis tool used, is limited to English documents [16]. Additionally, subject areas unrelated to BIM, such as medicine and arts and humanities, were excluded. Consequently, 219 research publications were obtained and will be used for the subsequent analysis stage.

2.2 Bibliometric analysis

Bibliometric analysis is a quantitative method used to explore and analyze bibliographic data of scientific articles. It provides an overview of the literature on a specific topic, allowing for the examination of research performance and patterns across authors, journals, countries, and institutions. Moreover, it helps to identify and observe the relationships between these studies [17]. In this study, bibliometric analysis was conducted using the VOSviewer software. VOSviewer is a visualization application that facilitates large-scale network analysis through natural language processing methods and text mining techniques [15]. It is a valuable tool for presenting large-scale bibliometric maps in an easily interpretable manner [18]. The software encompasses various bibliometric techniques, including co-authorship, co-occurrence, citations, bibliographic coupling, and co-citation analysis.

The main objective of this study is to examine the relationship between BIM and Operation and Maintenance by conducting bibliometric mapping and conducting a comprehensive review of related articles. The data obtained from the Scopus database in CSV format was imported into the VOSviewer software to construct a publication network based on direct citations. This network map utilizes distance-based visualization, where the proximity of nodes reflects their level of connection. The color scheme of the network map indicates the concentration of citations, with red representing the highest concentration [16]. The bibliometric analysis was performed based on the resulting network map.

2.3 Qualitative method

A qualitative analysis was conducted to gain a comprehensive understanding of the application of BIM in achieving effective Operation and Maintenance. The objective of this qualitative analysis was not to develop new theories but to identify the findings of various studies and existing gaps [19]. A review of relevant published articles was carried out to establish a general understanding of how BIM contributes to effective operation and maintenance. This review aimed to identify barriers and challenges encountered in implementing BIM in this context, as well as opportunities for future research.

3 Results

3.1 Development of publications

The analysis of publication growth in the field of BIM, and operation and maintenance, based on data collected from the Scopus database spanning from 2009 to 2023, reveals a notable increase in publications from 2016 to 2017. During this period, the number of publication articles rose from 6 to 19. The highest surge in publication growth, as indexed by Scopus, was observed in 2021, with 36 publications accounting for 16.44% of the total. Further details regarding the growth of international publications can be found in Fig. 1 and Table 2.

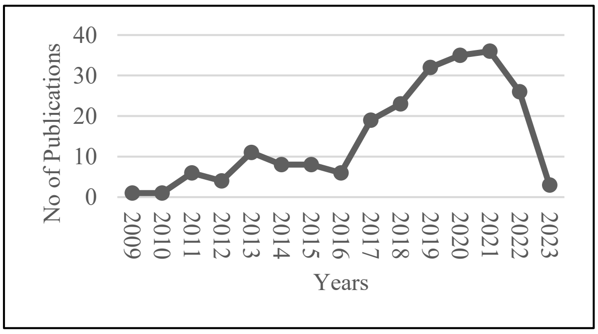

Fig. 1. The number of articles published each year regarding BIM and O&M from 2009 to 2023.

Table 2. Publication development, scopus article data sources.

Year	No of publication	Percentage
2009	1	0.46%
2010	1	0.46%
2011	6	2.74%
2012	4	1.83%
2013	11	5.02%
2014	8	3.65%
2015	8	3.65%
2016	6	2.74%
2017	19	8.68%
2018	23	10.50%
2019	32	14.61%
2020	35	15.98%
2021	36	16.44%
2022	26	11.87%
2023	3	1.37%
TOTAL	**219**	**100%**

3.2 Co-author analysis

The bibliographic records obtained from the Scopus database include information about the authors, such as their identities, institutions, and countries where they conducted their research. Co-citation analysis is employed to establish connections between items, such as authors or countries/institutions, based on the number of co-authored documents. The VOSviewer application is utilized to create a co-authorship network and a network of co-authors' countries/regions.

3.2.1 Co-authorship network

By examining the co-authorship network, we can identify the most productive authors based on the number of publications they have contributed. The top three authors in terms of the number of documents they have published are Raja R.A. Issa, Rui Liu, and Xinrong Liu.

The co-authorship network, depicted in Fig. 2, illustrates the connections established between authors through co-authoring articles. Out of the 568 authors identified in the 219 collected documents, the co-authorship network reveals that only 113 authors are interconnected. The network consists of 128 clusters and 1018 links. Moreover, by examining the co-authorship network, it is apparent that many authors collaborate with one or two highly productive authors.

3.2.2 Network of countries/regions

The network of countries/regions, illustrated in Fig. 3, demonstrates the connections among countries/regions contributing to articles related to BIM and Operation and Maintenance. The network consists of 20 clusters and 32 links, with a total link strength of 43. By examining the network, it is evident that out of the 40 countries/regions mentioned in the documents, only 27 are interconnected.

According to the international publication data obtained from Scopus regarding the topic of BIM and operation and maintenance, China emerged as the country with the highest number of articles published on the use of BIM for operation and maintenance activities, accounting for 74 articles (29.84%). It was followed by the United States (US) with 53 articles and the United Kingdom (UK) with 25 articles. These findings indicate that research on BIM applications in operation and maintenance has been undertaken in various countries worldwide. Table 3 provides data on the top 10 countries with the most published articles, highlighting the significant number of journal publications in these countries/regions and indicating the advancements in research related to BIM and operation and maintenance.

Furthermore, developed countries such as the United States and China have engaged in collaborations with researchers from other countries, including Australia, Thailand, Italy, and Finland. The country/region network also reveals that a substantial amount of research has been conducted between 2020 and 2022, indicating widespread interest from various countries in studying BIM and its potential for future growth.

3.3 Co-occurrence analysis

Recently, many research topics are related to BIM and operation maintenance, for which co-occurrence analysis is performed to identify the relationship between related keywords based on the number of documents in which the keywords appear together.

Keywords describe the core content of the article and show the development of the research topic over time [12]. In data visualization using VOSviewer, there are three keyword options to be displayed, namely, author keywords, index keywords, and all keywords. All keywords is selected to build a network of keywords that appear together.

The co-occurrence network of keywords is illustrated in Fig. 4. The size of each circle and its corresponding label indicates the weight of the keyword. The distance between two keywords reflects their degree of correlation, with closer proximity indicating a stronger relationship. Conversely, greater distance signifies a weaker association between keywords [18]. Moreover, the colors of the circles in the network represent clusters of related keywords, highlighting distinct thematic groupings within the dataset [15].

The keyword co-occurrence network reveals strong associations between four main terms and BIM and O&M: facilities management, information management, asset management, and architectural design. Out of the 1639 keywords analyzed, 100 keywords meet the criteria of having at least 5 co-occurrences. The resulting network comprises 5 clusters, encompassing a total of 2273 links. Table 4 displays the top 10 keywords with the highest frequency of occurrence.

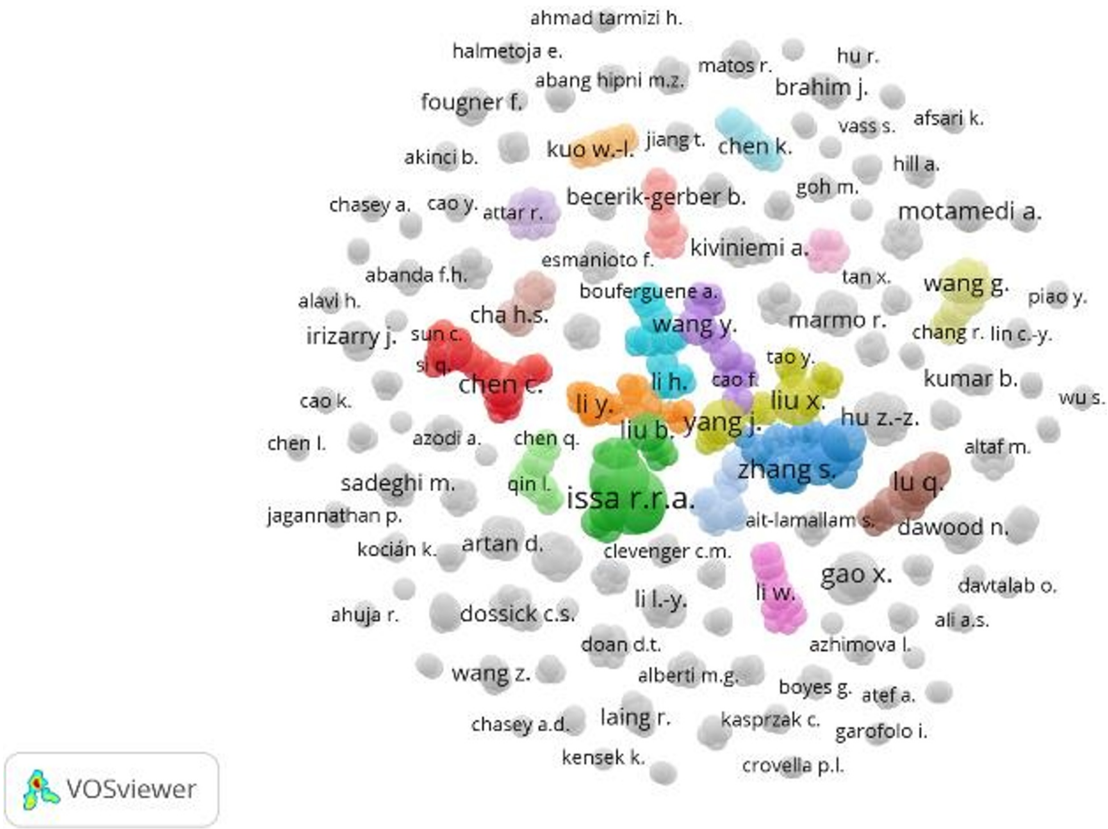

Fig. 2. Co-authorship network.

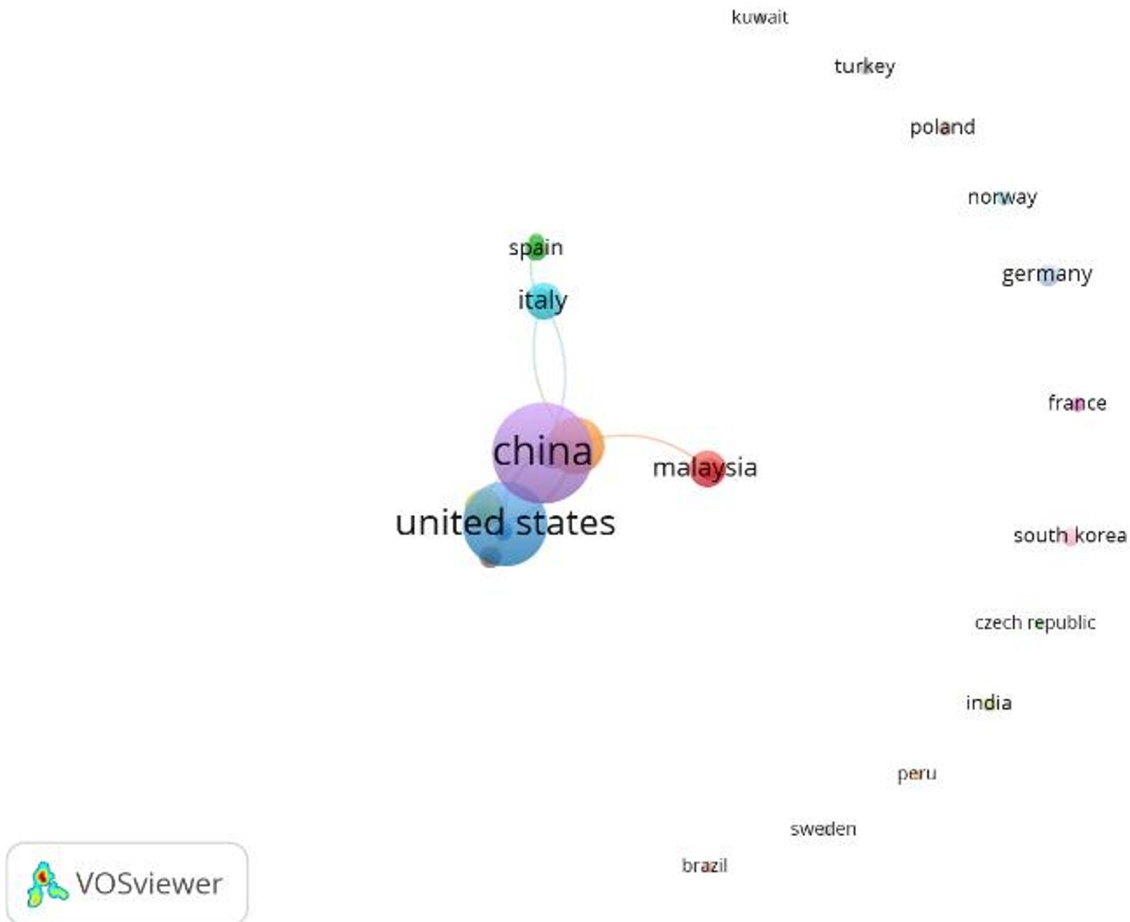

Fig. 3. Network of countries/regions.

Table 3. The top 10 most productive countries/regions.

Country	Count	Percent of Publications
China	74	29.84%
United States	53	21.37%
United Kingdom	25	10.08%
Canada	12	4.84%
Malaysia	11	4.44%
Italy	10	4.03%
Hong Kong	9	3.63%
Taiwan	4	1.61%
Australia	4	1.61%
Germany	4	1.61%
Finland	4	1.61%

In the bibliometric mapping conducted with the VOSviewer application, a density visualization feature is utilized alongside the network visualization. The density visualization assigns a color to each point on the map based on the density of items in that location [18]. Keywords with high density are represented by vibrant colors, indicating extensive research on those topics. Conversely, keywords with lower density are represented by dimmer colors, indicating less frequency within the analyzed set of documents.

The density visualization of the 219 documents collected from the Scopus database is shown in Fig. 5. In the figure, it can be seen that the dots for the keywords building information modeling and operation and maintenance are rather dense in color, indicating that there are many documents that discuss these keywords, while the dots for the keyword facility management, which is the topic of discussion in this paper, have a rather dim color, indicating that this keyword has not been widely discussed and is one of the reasons for the author to raise this research topic.

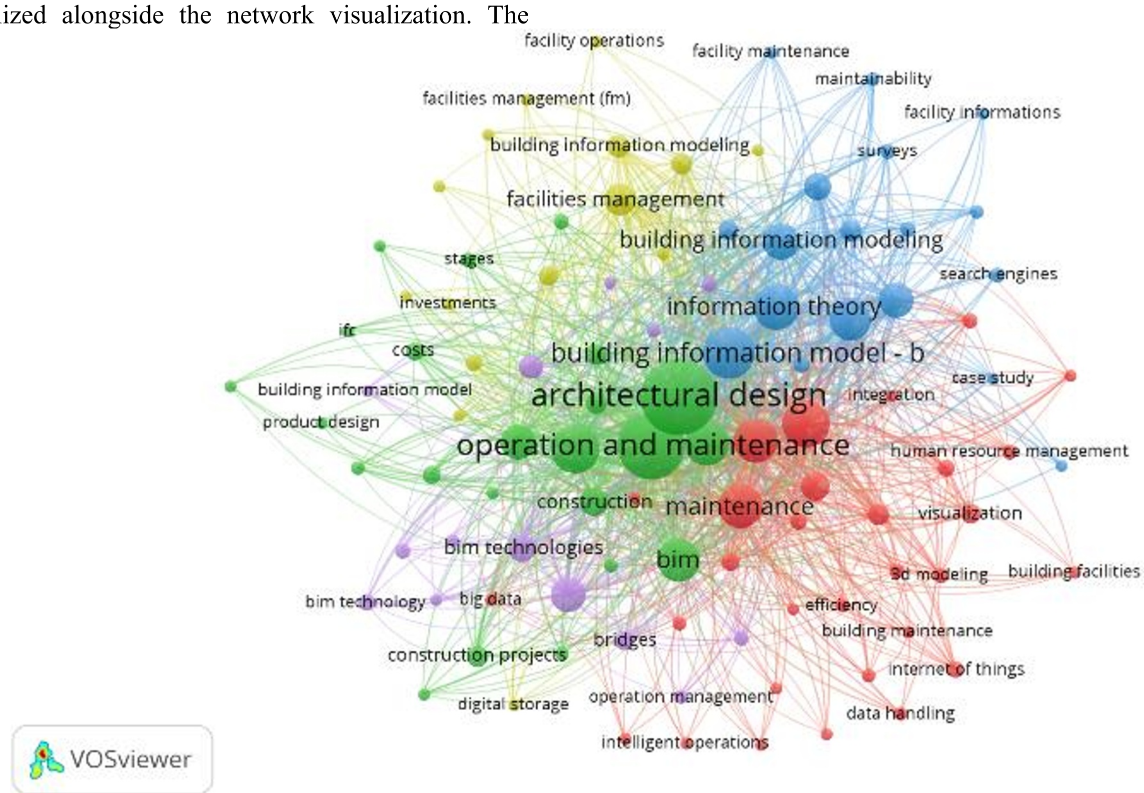

Fig. 4. Network of keyword co-occurrence (all keywords).

Table 4. The top 10 high-occurrence keywords.

Keyword	Occurrences	Total link strength
Architectural design	192	1626
Operation and maintenance	151	1204
Building information model	91	790
Life cycle	81	724
Information management	76	705
Information theory	69	669
Maintenance	68	595
Office building	56	560
Facility management	43	399
Construction industry	43	397

3.4 Co-citation analysis

Co-citation refers to the frequency with which two documents are cited together [19] and serves as an indicator of their correlation [12]. Co-citation analysis is employed to identify connections between items, such as references, authors, and sources, based on the number of times they are cited together.

3.4.1 Source co-citation network

Source co-citation analysis aims to identify the journals cited in the 219 documents collected from the Scopus database. The citations from the 219 documents were analyzed using VOSviewer, resulting in a co-citation network of cited sources (Fig. 6). The network consists of 4 clusters and 1221 links. To generate the network, a minimum threshold of 10 citations to a source was applied, resulting in 70 sources meeting the criteria out of a total of 3433 sources.

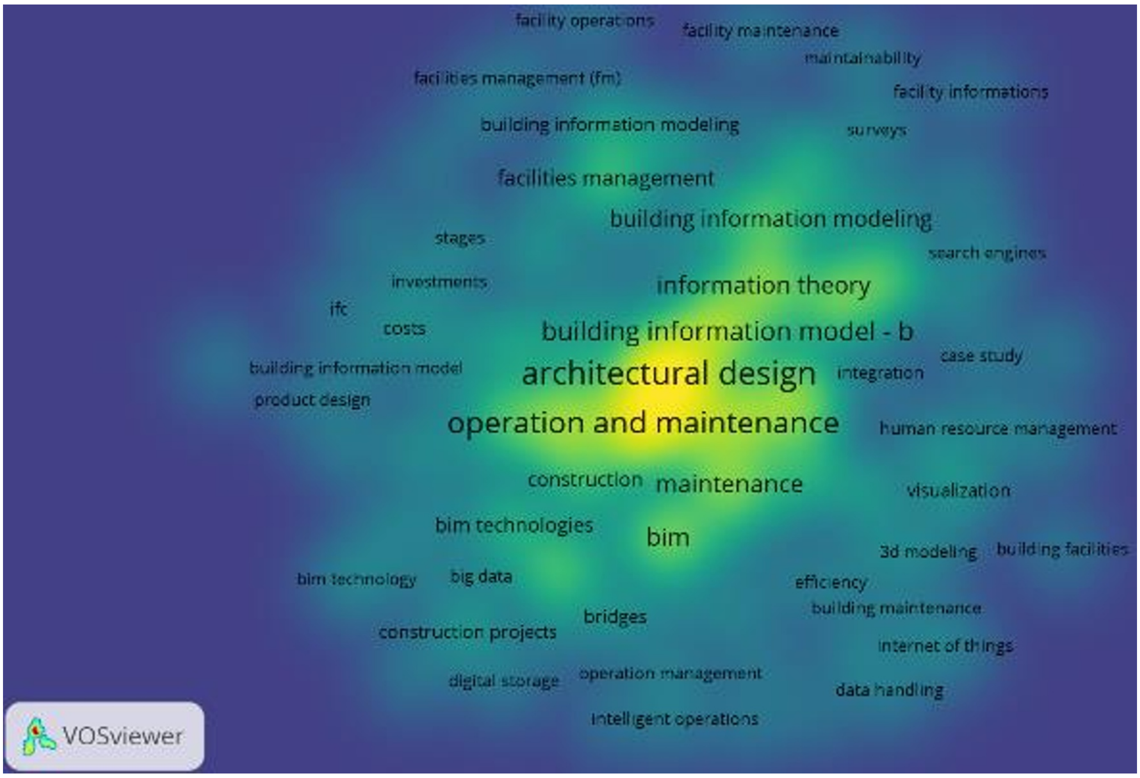

Fig. 5. Density visualization of keywords co-occurrence.

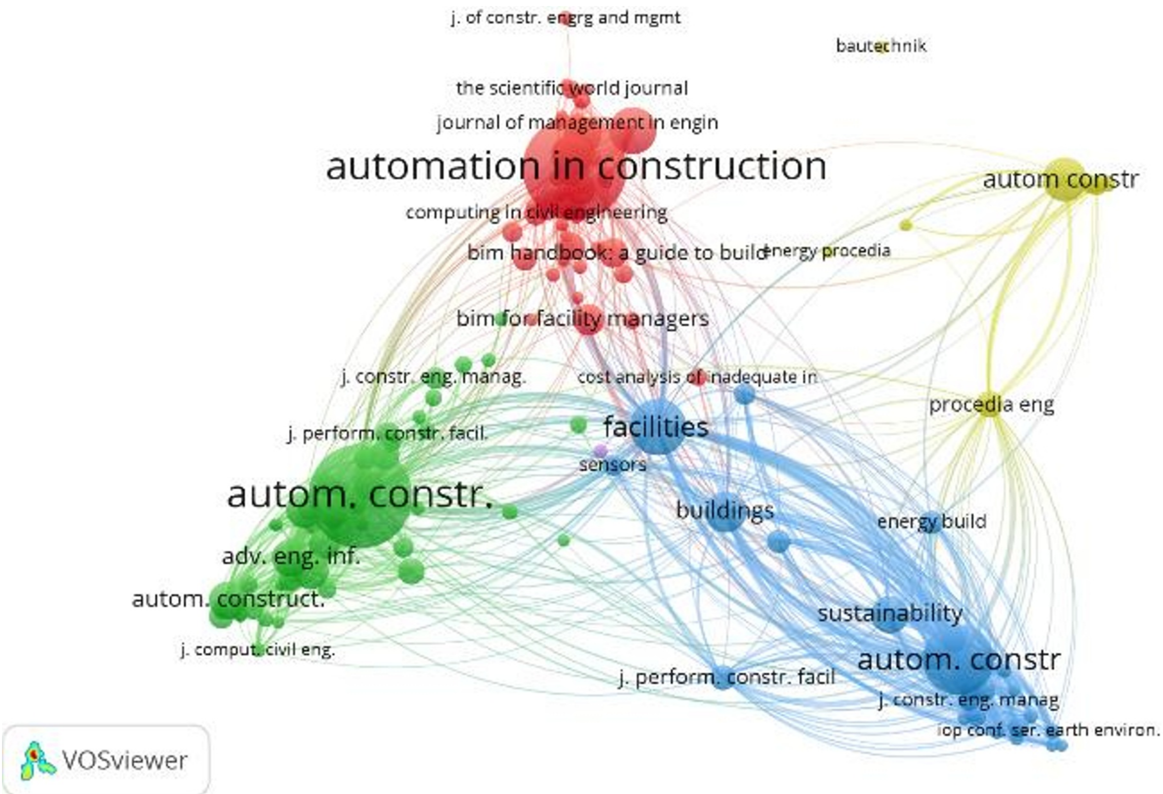

Fig. 6. Source co-citation network.

The analysis of co-citations reveals the five most influential sources in the field of BIM and O&M. These sources, based on the frequency of co-citations, are Automation in Construction (327 citations), Facilities (101 citations), Advanced Engineering Informatics (69 citations), Buildings (52 citations), and Journal of Construction Engineering and Management (52 these citations). The high number of citations indicates that sources have published a significant number of articles on the topic of BIM and O&M.

3.4.2 Author co-citation network

Author co-citation analysis reveals the relationships between authors whose publications are cited together in the same articles [12]. The author co-citation network, as shown in Fig. 7, consists of 159 items, 4 clusters, and 11,678 links. To generate this network, out of 8,466 authors, 159 authors meet the minimum citation criteria of 15 citations from other authors. By analyzing this author co-citation network, we can identify the authors whose articles are most frequently cited. These highly cited authors include Burcu Akinci (100 citations), Burcin Becerik-Gerber (95 citations), Charles Eastman (88 citations), Rafael Sacks (75 citations), and Paul Teicholz (71 citations). It is worth noting that many of the highly cited authors are from the United States, which indicates the significant development of BIM research in this country and the influence of these authors in the field, as they are referenced by researchers worldwide.

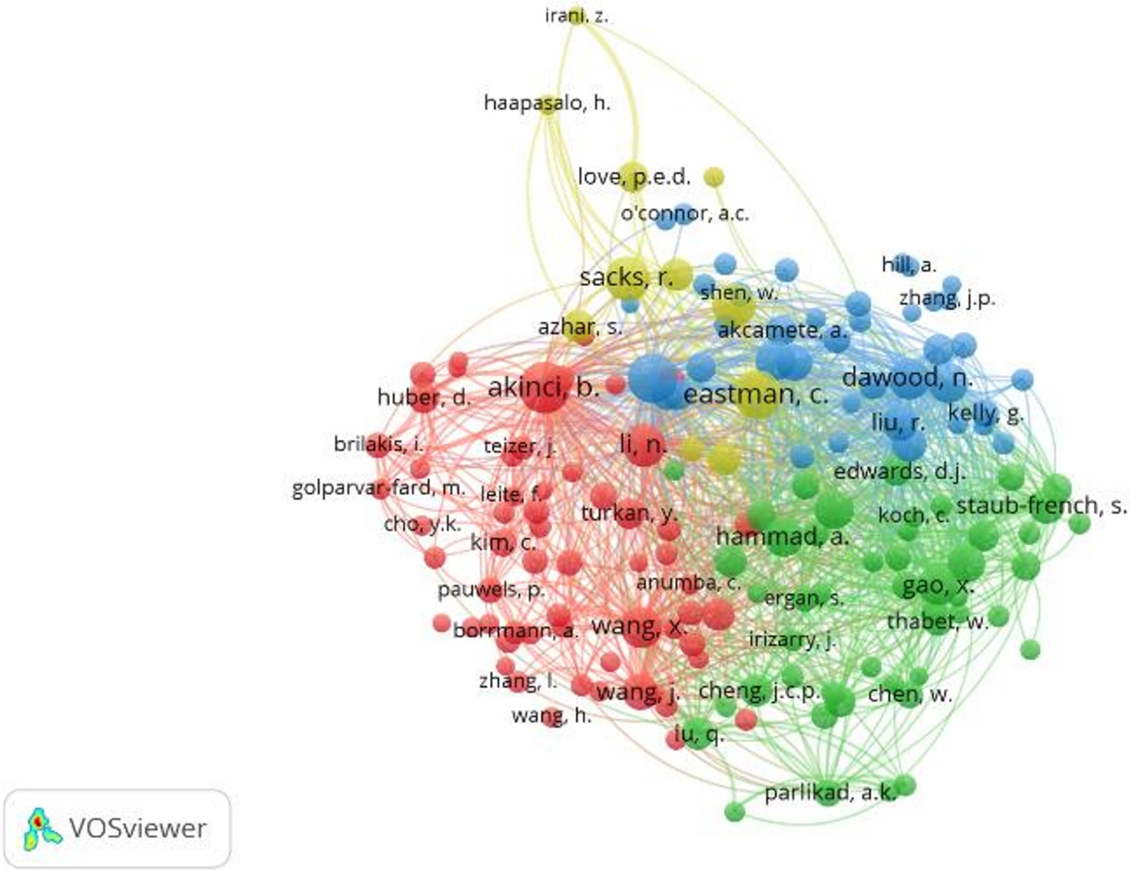

Fig. 7. Author co-citation network.

3.4.3 Reference co-citation network

Reference co-citation analysis examines the relationships between articles that are cited together. The reference co-citation network, displayed in Fig. 8, reveals these connections. Out of all the references cited in the 219 documents, 61 references meet the minimum citation threshold of 3. Among these references, 59 of them are linked to each other in the network. The resulting network consists of 5 clusters and 364 links, indicating the interconnections between the cited references.

Based on the formed network, several highly cited references can be identified, including Becerik-Gerber et al. [21] (7 citations), Pishdad-Bozorgi et al.[22] (7 citations), dan Shen et al.[23] (7 citations). Becerik-Gerber et al. [21] conducted research on the utilization of BIM in FM practices through surveys and interviews, highlighting application areas and data requirements for BIM-enabled FM. Pishdad-Bozorgi et al. [22] explored the implementation of BIM-enabled FM in a pilot project, addressing challenges and proposing a research framework for building knowledge on BIM in the FM field. Shen et al. [23] provided a comprehensive review of system integration and collaboration in AEC/FM. The links in the network indicate that these references are cited in multiple articles, suggesting their significant influence and frequent use as sources by researchers studying the use of BIM in the O&M phase of buildings.

4 Discussion

After conducting the bibliometric analysis using the VOSviewer application, this study proceeded with a review of several articles closely related to the research topic. The analysis revealed that research on this topic is primarily conducted in developed countries such as China and the United States. However, there is still a need for more information regarding the utilization of BIM in other countries and regions. In this section, the study will outline several theories and research findings from the collected articles on the utilization of BIM for facility management during the operation and maintenance phase of buildings. Additionally, the application of BIM 7D in Indonesia will also be discussed.

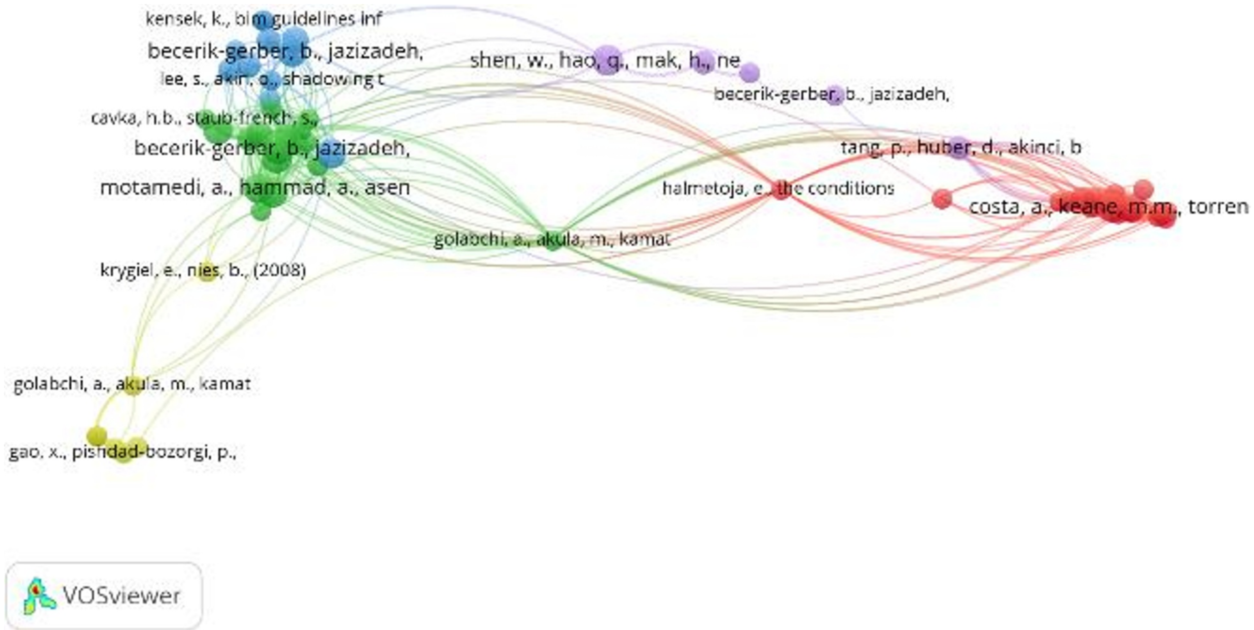

Fig. 8. Reference co-citation network.

4.1 BIM usage for facility management in O&M phase

Building Information Modeling (BIM) has revolutionized the development, sharing, and management of project information. While the application of BIM in the design and construction phase has been extensively researched and widely adopted, its utilization for facility management (FM) in the operation and maintenance (O&M) phase is still in its early stages [22]. BIM has the potential to enhance facility operations and maintenance by providing a platform for facility managers to access, analyze, and utilize digitized building information in in 3D [24]. Most of the research on BIM for O&M is still in its infancy and focuses on energy management [24]. Considering the prolonged duration of the FM phase compared to the design and construction phases, adopting BIM can potentially improve the efficiency and cost-effectiveness of the overall process [10].

Facility owners generally find it difficult to sort through a large number of documents to obtain the information required for the facility management system, which is caused by the mismatch between the FM information system and the fragmentation of the required data, and as a result can cost a lot of time and money. Recently, FM has become an important factor in the environment. FM is defined as "a profession that encompasses a wide range of disciplines to ensure the functionality of the built environment by integrating people, places, processes, and technology" [25]. The application of BIM can effectively address these issues and FM can be facilitated because BIM is able to reduce communication gaps and facilitate the exchange and interoperability of information in digital form [10].

BIM can support FM functions, both for new and existing buildings [26]. The application of BIM can generally be seen throughout the facility lifecycle, with functions such as design visualization, site planning and utilization, scheduling, cost estimation, layout and site work as well as operation and maintenance [27]. Hoang et al. [27] summarized the operational areas facilitated by BIM in O&M works, including:

1. Daily operation of the building,
2. Energy management,
3. Hazardous waste management and recycling,
4. Real estate management,
5. Relocation management,
6. Wired and wireless communication management,
7. Emergency preparedness and business continuity,
8. Maintenance and repair,
9. Security management, and
10. Many administrative functions related to organizational support and building.

4.2 The benefits and challenges of BIM implementation for FM in O&M phase

BIM offers numerous benefits to stakeholders, particularly in facilitating data and information exchange throughout the lifecycle of a building construction project [5]. BIM has great benefits in O&M and facility management, especially for facility owners and managers by presenting a huge database to capture information from virtual models for facility management [28]. According to Hoang et al. [27], the benefits of BIM for FM in the O&M phase include: collaborative improvement, more accurate information from a data-rich asset, automatically updated model, improved interoperability, increased employees' productivity and efficiency, easier data retrieval, reduced response time in operations, more proactive maintenance, increased level of emergency preparedness, workforce engagement, evaluate energy efficiency, reduce operational cost, better customer service, clearer FM requirement definition for design and construction.

Besides the benefits described above, there are also challenges in implementing BIM in the O&M phase. According to Parn et al. [6], significant challenges faced by the FM sector include the need for: long-term strategic considerations; improved data integration/interoperability issues; improved knowledge management; improved performance measurement; and enriched training and competency development for facility managers to better handle the range of intangible services covered by FM. Gao and Pishdad-Bozorgi [24] found that interoperability in BIM for O&M is still a challenge, and one potential solution to overcome it is to adopt the Cyber-Physical Systems (CPS) Framework from the National Institute of Standards and Technology (NIST).

The application of BIM in the FM industry has demonstrated numerous benefits for FM and the building lifecycle [21]. Data and information collected by BIM users throughout the building lifecycle can shorten the time and reduce the cost of building FM systems [5].

4.3 BIM for facility management in Indonesia

While the use of BIM for construction is already widespread in some developing countries, it is relatively new in Indonesia [29]. The concept of BIM was formally introduced in Indonesia in 2017 by the Ministry of Public Works and Public Housing (PUPR) [30]. The introduction of BIM is also accompanied by the issuance of a roadmap for the application of BIM in Indonesia or the Indonesian digital construction roadmap. The Indonesian government has also developed various tools to implement BIM, namely the issuance of the Minister of PUPR Regulation No. 22/PRT/M/2018 concerning the construction of state buildings [30]. This regulation requires the implementation of BIM in every government building with an area of more than 2,000 m^2 and has more than two floors [31].

Hatmoko et al. [29] conducted a study to investigate the level of company readiness towards BIM implementation in Indonesia. Company readiness index (CRI) was developed to measure company readiness, followed by gap analysis. Four main elements of readiness consist of organizational process, management, people, and technology, which are divided into 11 categories and 28 readiness criteria. Based on the results of the survey questionnaire and interviews with 4 companies consisting of contractors, engineering consultants and EPCI (Engineering, Procurement, Construction and Installation), a CRI value of 76.19% was obtained, which means that they are ready for BIM implementation.

Khasani and Hidayat [32] conducted research on the implementation of BIM in the construction of high-rise buildings in Indonesia. Important-Performance Analysis of BIM Implementation (IPABIM) is used to map the level of achievement of BIM implementation. IPABIM analysis uses a Cartesian diagram divided into four quadrants, namely quadrant A (area of improvement), quadrant B (excellent work), quadrant C (low priority), and quadrant D (disproportionate), which explains the level of achievement. The results show that located in quadrant C, which indicates a low priority in BIM implementation, is the implementation of BIM for facility operations and maintenance. This result shows that the implementation of BIM in the O&M phase of a facility has not been a concern for practitioners in the construction industry.

On the other hand, although the application of BIM in Indonesia, especially BIM 7D for facility management in the O&M phase of buildings is still lacking, there have been researchers who have tried to implement BIM for facility management needs. Suwardhi et al. [33] implemented BIM on the new campus building of the Bandung Institute of Technology (ITB), located in Jatinagor, Sumedang. Since BIM cannot perform certain functions, such as spatial analysis with geographic coordinates, other technologies are also used to complement the needs, in this case by using a Geographic Information System (GIS). The integration between GIS and BIM produces more complete and user-friendly information, both for macro and micro level representation. In applying the integration of BIM and GIS, researchers also used an opensource application, OpenMAINT, for property and facility management.

5 Conclusion

A facility's operation and maintenance phase incur the highest costs throughout its lifecycle. This phase, being the longest, accounts for over 60% of the total lifecycle costs. With the rapid development and widespread adoption of BIM technology in the AEC industry, BIM has emerged as an effective tool for the facility management (FM) during the O&M phase.

A total of 219 scholarly bibliographic records were retrieved from the Scopus database covering the period from 2009 to 2023. The data was processed using VOSviewer, revealing a consistent increase in publications related to the topics of BIM and O&M, with the most significant growth occurring from 2016 to 2017. The highest publication output was observed in 2021, with 36 publications (16.44%). China emerged as the leading contributor with 74 articles (29.84%), followed by the United States and the United Kingdom. In terms of co-citation analysis, it was found that the most cited authors were from the United States, suggesting that BIM and O&M research has flourished in developed countries like the US, China, and the UK and serves as a reference for researchers worldwide. Collaborating and partnering with established researchers in this area can be beneficial for researchers interested in studying BIM and O&M. Facility managers, especially in countries that have not yet implemented BIM for facility management like Indonesia, can refer to countries that have successfully implemented BIM to gain insights and guidance. However, when considering co-occurrence analysis, it is evident that the keyword "facility management," which is the main focus of this paper, has received relatively less attention based on its frequency of occurrence in the collected documents.

Based on a review of several previous studies, it is well-established that BIM can effectively support various operational areas in the O&M phase. These areas include (1) daily building operations, (2) energy management, (3) hazardous waste management and recycling, (4) real estate management, (5) relocation management, (6) wired and wireless communication management, (7) emergency preparedness and business continuity, (8) maintenance and repair, (9) security management, and (10) various administrative functions related to organizational support and building operations. The application of BIM in the O&M phase provides numerous benefits, particularly for facility owners and managers, by facilitating the exchange of data and information throughout the building's life cycle. BIM simplifies the O&M process of a facility, including maintenance and repair, emergency management, energy management, change/relocation management, and security. To effectively manage the O&M process using BIM, it is essential to ensure the completeness of data, such as models, drawings, and other supporting information. Regular updates are necessary to ensure that the stored data aligns with the actual conditions of the facility.

In addition to the aforementioned benefits, several challenges are associated with utilizing the 7D BIM function, specifically for facility management. These challenges include the need to improve data integration and interoperability issues, as well as the requirement for a robust framework for implementing BIM effectively.

In Indonesia, BIM has gained significant traction in the construction sector, particularly since its formal introduction by the Ministry of Public Works and Public Housing (PUPR) in 2017. However, the predominant use of BIM in Indonesia has been focused on the design and construction stages, with relatively less attention given to the O&M phase. Nonetheless, there have been researchers who have explored the application of BIM for facility management purposes. For instance, BIM has been successfully implemented in the construction of the new ITB campus building in Jatinagor, Sumedang, through its integration with GIS.

For future research, there is a need to explore the utilization of BIM for asset management in order to achieve a balance between its use for facility management.

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