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A Critical Review of Barriers Hindering BIM Integration of Operation and Maintenance Phase in Existing Buildings

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Abstract
Presently, researchers have made clear justices to Building Information Modelling (BIM) capability in new building production and management. Researchers' findings have proven that BIM plays a significant role in building facilities' operation and maintenance (O&M) phase, using information generated during the construction process in the BIM database. However, over 90% of existing residential buildings do not have a functioning BIM. Recently, there has been a growing consideration for BIM implementation in existing residential buildings. Through the critical review of this study, 18 barriers hindering BIM implementation in the existing residential building were identified and systematically grouped under six groups: Documentation Factor, Technical Factor, Personnel Factor, Professional Management Factor, Financial Factor, and Security Factor. The "Data interoperability problem" was identified as the primary barrier hindering BIM adoption in existing buildings that already use FM tools for their management.

Keywords
Existing Building, implementation, BIM, Barriers, operation, and maintenance.

1. Introduction

Don (2017) described facilities operations and maintenance (O&M) as a broad-spectrum encompassing services, competencies, processes, and tools required to assure the built environment will perform the functions for which a facility was designed and constructed. Also, "O&M typically includes the day-to-day activities necessary for the building/built structures, its systems and equipment, and occupants/users to perform their intended function". However, Operations and maintenance are combined into the common term O&M because a facility cannot operate at peak efficiency without being maintained; therefore, the two are discussed as one (Don, 2017).

In this paper, existing buildings could be seen as habitable property (private or commercial buildings) which has been 100% completed, wherein has been occupied or previously occupied.

The BIM model's adoption, implementation, and application were initially designed for new buildings. The tremendous contributions of BIM to the built environment industry have called for its consideration for existing buildings. Loeh et al. (2021) affirmed that the way the BIM model was created and adopted from the design phase. However, it can also be created and implemented from the grassroots for existing buildings.

Decades ago, the idea of Building Information Modeling (BIM) started during the 3rd industrial revolution stage. The focus initially started from the planning and design phase. Wherein advanced to the cost, procurement, and construction phase. It started gaining more attention in the 4th Industrial revolution stage. The further use and adoption of BIM around the lifecycle (LC) of the building could be traced to the benefit acquired in the previous phases in which it has been successfully used (Volk et al., 2014).

Over the years, BIM as an information model has become the central platform for information management in the built environment industry (Hossain & Yeoh, 2018). It has been proven as a platform that grants stakeholders the medium to manage and exchange information throughout the lifecycle of a building concerning its components (Motawa & Almarshad, 2013).

Even though there is a rising trend in BIM adoption within the built environment industries, its use has only been for some new projects in recent years towards O&M of the building phase (NBS, 2016). However, it was noted that most buildings currently existing do not have a functional BIM model. Designing a BIM platform to accommodate existing building data and promote the O&M phase is essential (Hossain & Yeoh, 2018). Moreover, it has been reported by numerous researchers that BIM can function in the O&M phase, which can be used for renovation, defect detection, energy usage analyses, installation and monitoring of firefighting equipment, safety in facility management, demolition, and so on (Hossain & Yeoh, 2018; Wetzel, 2015). Over the years, the adoption of BIM in the design and built environment has received a substantial establishment and has received growing attention for FM and O&M (Cheng et al., 2017; Love et al., 2014; Pärn et al., 2017). FacilitiesNet (2021) reported that for "facility managers, Building Information Modeling database can be a powerful new tool to enhance building's performance and manage operations more efficiently throughout a building's life". Nevertheless, claims have been made frequently since BIM's inception. However, most of the recorded, measurable advantages of BIM are still connected to building design and construction, with little empirical evidence of BIM's benefits in the operations and maintenance phase (Becerik-Gerber et al., 2012; Kiviniemi & Codinhoto, 2014). BIM could be seen as a suitable platform that can handle more extensive and more complicated buildings and can be used in all categories of building types (Becerik-Gerber & Rice, 2010; Kiviniemi & Codinhoto, 2014). Since BIM is seen as a platform for managing reliable building information throughout a building's lifecycle (LIU et al., 2012), it is appropriate to include maintenance and project closeup procedures data information. Information is an essential driving power that supports day-to-day efficient and productive O&M of building facilities (Atkin & Brooks, 2009; Gu et al., 2008; Teicholz, 2013). Yet, the facility management sector is still struggling with information management, primarily due to information's uniqueness and division (Codinhoto et al., 2013; Eastman et al., 2011). Within the built professionals and owner-operated industry, those two fundamental issues are the principal causes of knowledge loss in the construction environment (Kamara et al., 2002). Computerization improves asset means of information capturing and retrieval. However, automated analysis of data and knowledge capturing is inadequate within computer-aided facilities management (Becerik-Gerber et al., 2012; Brian & Brooks, 2009).

The race for efficient and sustainable production in the construction industries has been corroborated in developed and developing countries towards a well-developed and contributory information modeling structure – BIM (Codinhoto et al., 2013; Toyin & Mewomo, 2021a). McGraw-Hill (2008) researched and found out that there is an increase in successful BIM implementation cases in the design and construction phase. Also noted is that the adoption rate of BIM in Europe increased significantly eighteen (18) years ago.

The valuable contribution of the successful implementation of BIM in the construction industry cannot be overemphasized. This has called the attention of prospective clients (Government and Private), who are basically on the ladder to benefit more from the successful adoption of BIM, hence forming part of the fundamental role influencing change in the construction industry (Eastman et al., 2011)

Currently, BIM experts and built professionals are working tremendously to integrate the BIM model into existing buildings' operation and maintenance phases. Thereby allowing existing buildings and facility managers to enjoy the accruable benefit of BIM (Sun et al., 2017).

2. Research methodology

This study adopts a critical systematic review of published articles in conference proceedings, books, thesis, and academic journals on the state-of-art of BIM in an existing building O&M phase. A systematic review enables the researcher to gain more understanding and trends about the topic working on (Faisal Shehzad et al., 2020; Toyin & Mewomo, 2021b; Zhu et al., 2019). The research involves three (3) steps, as shown in figure 1. Step 1: Formulating the research questions: what is the start-of-the-art of BIM in existing buildings? What are the barriers hindering BIM adoption in the Existing building O&M phase?. Those questions were used to formulate the search keywords.; Step 2: article search approach using keywords for drawing out related studies from the databases. The following search condition keywords: BIM FM O&M barriers", "BIM for facility manage", "BIM-FM implementation in old building", 'BIM for the existing building to locate different articles" were repeated in the following databases: DUT online Library A-Z database, Elsevier (Scopus and Science direct), Springer and Google Scholar. The search brought about 157 published papers (n = 157), exclusion of duplicated articles From Endnote database (n= 90), Applied exclusion and Inclusion criteria (Relevance, Missing year of publication and Authors name, etc.) (n=36); Step 3: additional article search using contacted paper references were used to get 20 more relevant papers; Step 4: This is the last step. It involves findings, discussion, analysis of results, conclusion, and suggestions to improve BIM adoption in an existing building.

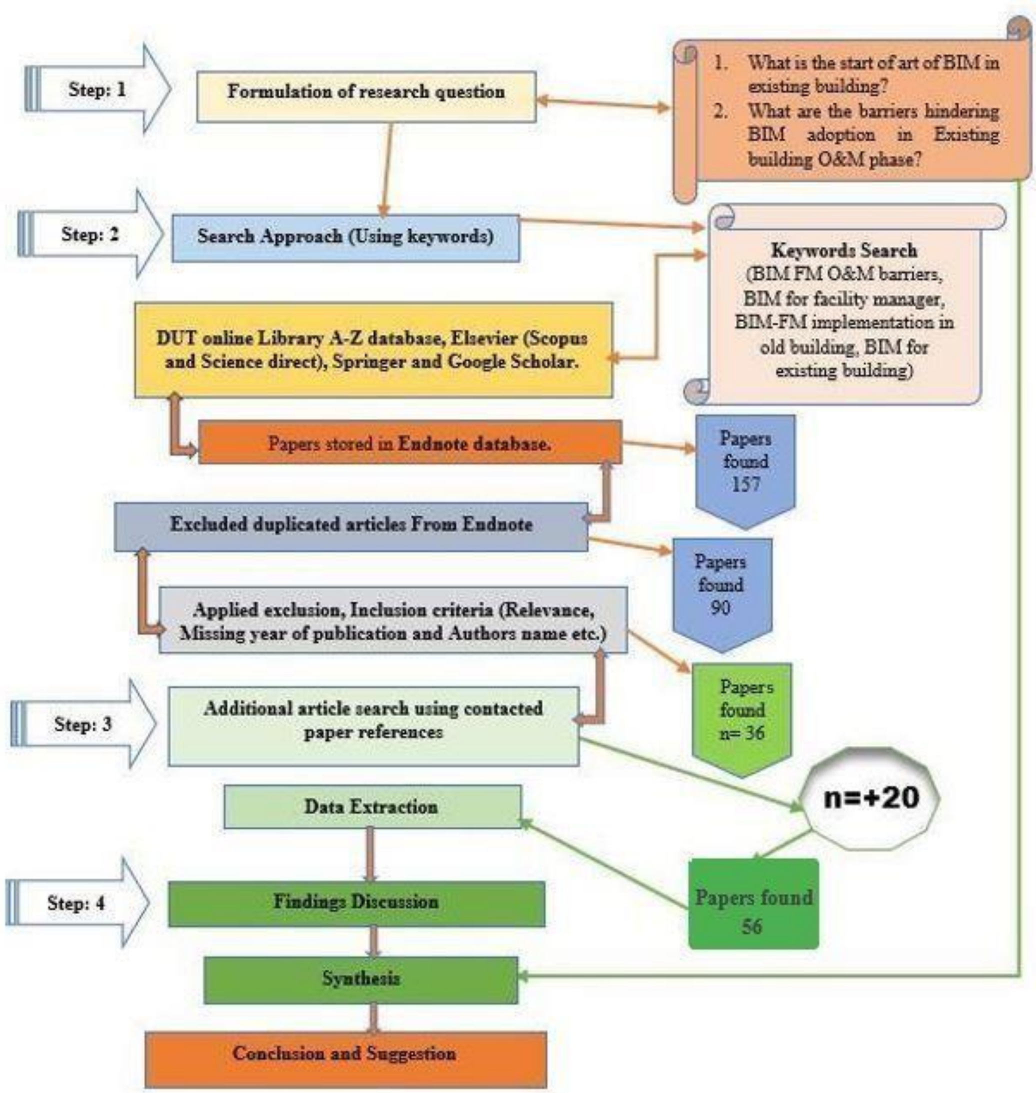


Fig. 17. Review framework

3. Research findings

3. 1 Need for BIM in an existing building

BIM is a revolutionary technology that can improve the construction industry's process and product, owing to its ability to manage information, integration of design, and flexible construction management features (Naghshbandi, 2016; Pniewski, 2011). Moreover, BIM technology aims to create an interactive model of a building facility that the stakeholders or clients could use throughout the project lifecycle (LC). BIM is seen as digital modeling which contains comprehensive virtual information in the representation of a building structure and its component. The required information that could be consulted at any stage of the building LC is contained in the model (Azhar, 2011). Furthermore, Haines (2016) noted that "lifecycle BIM is the practice of creating, maintaining and utilizing building information to manage operations and maintenance of buildings throughout their operational lifecycles". The integration of BIM in an existing building cannot be overemphasized. The use has been justified to some extent in recently completed buildings. Wherein, BIM was adopted throughout its LC (Dixit et al., 2019; Pavón et al., 2021; Zhu et al., 2019). However, various scholars were able to document some vital use of BIM in the O&M phase: Used to store inspections and repairs information history (LIU et al., 2012), help to facilitate locating building elements and components during inspection and management (McArthur, 2015), help to facilitate the incorporation of building facility data into BIM databases and display the drawing of such components (Pärn et al., 2017), BIM enable easy means of scheduling Maintenance work orders (Cheng et al., 2020), to plan maintenance routes (Predictive and Preventive) (Cheng et al., 2020; Wetzel, 2015), used to ease maintenance work processes and effective asset management (Altohami et al., 2021; Loeh et al., 2021).

3.2 BIM for FM: Area of application.

The area where BIM technology is applicable in FM practices, according to Nicał and Wodyński (2016) findings, is linked to: “mobile localization of building resources, Digital asset with real-time data access, space management, Renovation/retrofit planning, and feasibility studies, Maintainability studies, Energy analysis and control, Safety/emergency management” (Becerik-Gerber et al., 2012; Love et al., 2014; Volk et al., 2014). The finding shows that BIM has a promising and crucial role in the O&M phase of building, which invariably will benefit the existing building. The full potential could be realized in the existing building if it is successfully integrated (Toyin & Mewomo, 2021a).

3.3 BIM for existing buildings O&M phase.

Barbosa et al. (2016) find out that “The usage of BIM has been suggested for the documentation of existing buildings in a cultural heritage context”. The building modeling is usually grounded on on-site surveys and historical documents (Pauwels et al., 2008). Revit and ArchiCAD, known as Architectural BIM technology software, was adopted in the architectural heritage framework (Fai et al., 2011; Pauwels et al., 2008). This could be used to generate the likely 3D design of the building. Barbosa et al. (2016) reported that “in many cases, these historical BIMs are mainly constructed with a more theoretical purpose, namely, to study the historical value of any particular building”. (Hossain & Yeoh, 2018) study fundamental that BIM technology software can perform a vital function in existing building O&M phase to project closeup mainly if the existing building O&M phase has been managed using FM tools. The connection of the information in the FM tools to the BIM technology database should be reasonably simple than building managed without FM tools (Fai et al., 2011). In the first scenario, in a BIM database model application, a new building will be designed based on the available historical information generated from the FM application using a BIM application. In the second case, where the FM application is not used to manage the building, A typical in-depth survey would be performed before planning to design the O&M schedule. While carrying out the “survey, the geometrical, constructive, functional, and spatial characteristics of a building are registered” (Barbosa et al., 2016). This could be active through the use of traditional methods, which involves sketches and drawings, photos, manual surveys, written and descriptive analysis, and manual surveys, or “using more technological means, such as terrestrial laser scanning (TLS) and automatic digital photogrammetry (ADP)” (Barbosa et al., 2016; Mateus et al., 2008). Mikhail et al. (2001) explain TLS and ADP: “TSL is a technology that uses laser light to obtain the coordinates of many points in an almost continuous and nearly real-time fashion. ADP allows to accurately relate the geometrical information of an object with a digital image through measurements performed on photographs”. However, 3D points clouds result from TLSand ADP surveys. The likelihood of relying on point clouds models in the BIM database may enable more efficient and high-quality development of reliable building information that may be subsequently used to design a renovation or rehabilitation intervention. “The products of TLS and ADP surveys are 3D point clouds. The possibility to rely on point clouds models (PCMs) in a BIM software environment may allow more efficient and qualitative production of the first layer of building information” (Barbosa et al., 2016). wherein could help plan rehabilitation and refurbishment intervention (Barbosa et al., 2016). In addition, “PCMs allow the capturing of the existing situation in greater geometric detail than what is typically included in a BIM model”. These features attributed to PCMs make it easier to use them for tracking likely hazards in the existing buildings (deformations, cracks, bends). After identifying those hazards and recording them, those characteristics attributed to PCM are critically needed to be integrated into the BIM package, which benefits existing buildings. However, good documentation of those geometric hazards during the O&M phase of the building facility management will aid the planning of an improved renovation plan for the existing building within the lifecycle management schedule of the building. “Likewise, non-geometric components should be documented from the point cloud to the BIM database, as well as the presence of asbestos materials or other hazardous materials, and including potentially dangerous situations (confined spaces, restricted access areas)” (Barbosa et al., 2016).

Despite all the promising advantages of BIM technology for an existing building, the integration and adoption in the existing building O&M phase come with some barriers.

3.4 BIM State-of-art in existing buildings.

The evolutionary progress of BIM technology in new buildings throughout its lifecycle has shown its efficiency in promoting and enhancing construction projects in all areas. Decades ago, its integration of cultural heritage buildings' O&M phase started (Pauwels et al., 2008). This could be traced to the ineffective traditional means used in maintaining those buildings, wherein a large amount of information is lost every year due to improper information documentation. More sophisticated technology such as BIM, which enhances information documentation, was adopted to curb the loss of such historical memories in our society. This act has made “the world heritage virtually accessible for historical research. Numerous disappeared monuments have been reconstructed and digitized under their impulse”(Quintero, 2003). Recently, there has been an increasing interest in adopting BIM for existing buildings (Hossain & Yeoh, 2018). This shows there has been an advancement over the year as to what (Volk et al., 2014) reported.
Barbosa et al. (2016)Outlined how the existing BIM guidelines and standards can be adopted in existing building projects. The lack of proper adoption in this phase is relatively rare due to the limited use of BIM in the O&M phase of the existing building. This could be traced to barriers encountered during its integration. Over the years, researchers have been able to identify some barriers. This study critically reviews those barriers.

3.5 Barriers were limiting the adoption of BIM in an existing building.

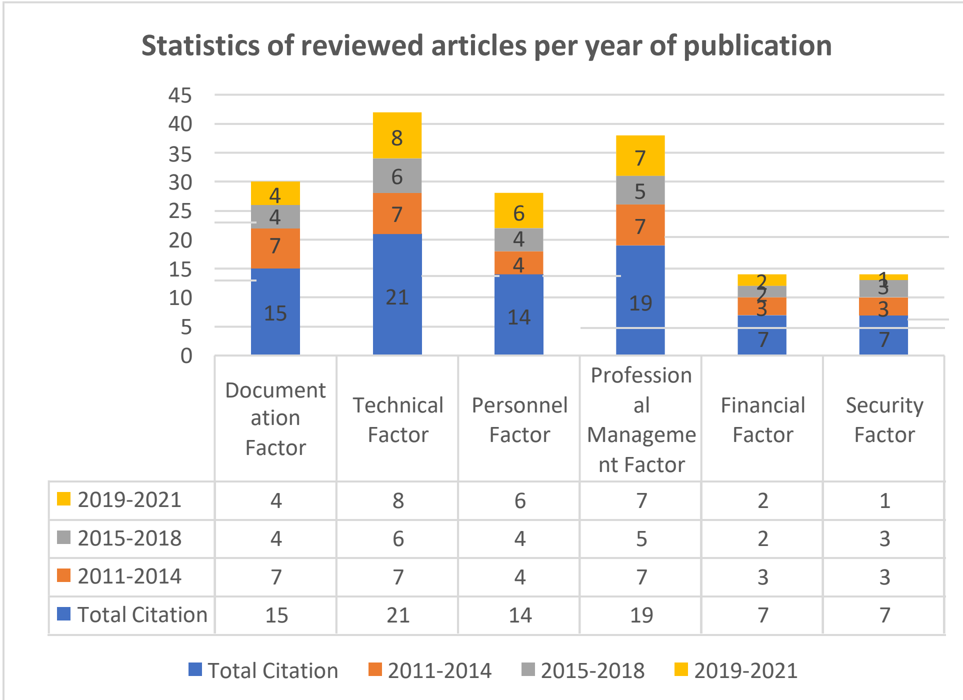
This study critically reviews published articles in the area of BIM for an existing building, looking at the barriers hindering its fast adoption. Below are the barriers found in the reviewed articles.

Table 17. Barriers hindering BIM integration in the existing building.

No.	Barriers limiting the adoption of BIM in the existing building.	Reference	Frequency
1.	Lack of comprehensive as-built drawing document.	(Cheng et al., 2020; Fai et al., 2011; Kelly et al., 2013; Kiviniemi & Codinhoto, 2014; Pärn et al., 2017; Teicholz, 2013; Zhu et al., 2019)	7
2.	Unavailability of real cases validating integration of BIM in existing buildings.	(Altohami et al., 2021; Fai et al., 2011; Kelly et al., 2013; Kiviniemi & Codinhoto, 2014; Marocco & Garofolo, 2021; Motawa & Almarshad, 2013; Nicał & Wodyński, 2016; Pärn et al., 2017; Pniewski, 2011; Teicholz, 2013)	10
3.	Data interoperability problem.	(Alvanchi et al., 2021; Barbosa et al., 2016; Becerik-Gerber et al., 2012; Deng et al., 2020; Dixit et al., 2019; Durdyev et al., 2021; Gao & Pishdad-Bozorgi, 2019; Hossain & Yeoh, 2018; Kelly et al., 2013; Kiviniemi & Codinhoto, 2014; Loeh et al., 2021; Motawa & Almarshad, 2013; Naghshbandi, 2016; Nicał & Wodyński, 2016; Pärn et al., 2017; Pavón et al., 2021; Teicholz, 2013; Wetzel, 2015; Zhu et al., 2019)	19
4.	Lack of BIM knowledge, technical skills, and experience among the facility manager.	(Altohami et al., 2021; Becerik-Gerber et al., 2012; Cheng et al., 2020; Dixit et al., 2019; Durdyev et al., 2021; Fai et al., 2011; Kiviniemi & Codinhoto, 2014; Marocco & Garofolo, 2021; Nicał & Wodyński, 2016; Pniewski, 2011)	10

5.	Inadequate compatibility between BIM and existing FM technologies.	(Dixit et al., 2019; Hossain & Yeoh, 2018; Kiviniemi & Codinhoto, 2014; Marocco & Garofolo, 2021; Pniewski, 2011; Volk et al., 2014; Wetzel, 2015)	7
6.	Failure to identify critical information for sustainable operation.	(Cheng et al., 2020; Kiviniemi & Codinhoto, 2014; McArthur, 2015; Pärn et al., 2017; Wetzel, 2015)	5
7.	Handling of uncertainty where building documentation is incomplete.	(Barbosa et al., 2016; Kiviniemi & Codinhoto, 2014; McArthur, 2015; Volk et al., 2014)	4
8.	Lack of best practices and guidelines.	(Fai et al., 2011; Kiviniemi & Codinhoto, 2014; Naghshbandi, 2016; Wetzel, 2015)	4
9.	Lack of effective collaboration between project stakeholders for modeling and model utilization	(Cheng et al., 2020; Deng et al., 2020; Kiviniemi & Codinhoto, 2014; Loeh et al., 2021; Naghshbandi, 2016; Pärn et al., 2017; Pniewski, 2011)	7
10.	Uncertainty of required data.	(Becerik-Gerber et al., 2012; Fai et al., 2011; Kiviniemi & Codinhoto, 2014; LIU et al., 2012; Nicał & Wodyński, 2016; Teicholz, 2013)	6
11.	General lack of Knowledge of software required to use BIM.	(Al-Yami & Sanni-Anibire, 2019; Dixit et al., 2019; Durdyev et al., 2021; Fai et al., 2011; Loeh et al., 2021)	5
12.	Lack of demand and interest by stakeholders and clients.	(Al-Yami & Sanni-Anibire, 2019; Dixit et al., 2019; Fai et al., 2011; Teicholz, 2013)	4
13.	Hardware and software costs.	(Barbosa et al., 2016; Durdyev et al., 2021)	2
14.	Lack of competent BIM experts.	(Becerik-Gerber et al., 2012; Codinhoto et al., 2013; Fai et al., 2011; Hossain & Yeoh, 2018; Kiviniemi & Codinhoto, 2014; Teicholz, 2013; Wetzel, 2015)	7
15.	Lack of clear maintenance policy.	(Alvanchi et al., 2021; Becerik-Gerber et al., 2012; Codinhoto et al., 2013; Kiviniemi & Codinhoto, 2014; LIU et al., 2012; Teicholz, 2013)	6
16.	High cost of training facility managers.	(Becerik-Gerber et al., 2012; Codinhoto et al., 2013; Deng et al., 2020; Durdyev et al., 2021; Hossain & Yeoh, 2018; Kiviniemi & Codinhoto, 2014)	6
17.	Lack of interest/reluctance to change from existing method of maintenance.	(Codinhoto et al., 2013; Durdyev et al., 2021; Kiviniemi & Codinhoto, 2014; Teicholz, 2013)	4
18.	Cyber security/data ownership.	(Becerik-Gerber et al., 2012; Chien et al., 2014; Ghaffarianhoseini et al., 2017; Loeh et al., 2021; Solihin & Eastman, 2015; Sun et al., 2017; Volk et al., 2014)	7

Fig. 2. Classification of barriers hindering BIM integration in existing buildings.



	Documentation Factor	Technical Factor	Personnel Factor	Professional Management Factor	Financial Factor	Security Factor
2019-2021	4	8	6	7	2	1
2015-2018	4	6	4	5	2	3
2011-2014	7	7	4	7	3	3
Total Citation	15	21	14	19	7	7

Fig. 3. Statistics of reviewed articles per year of publication.

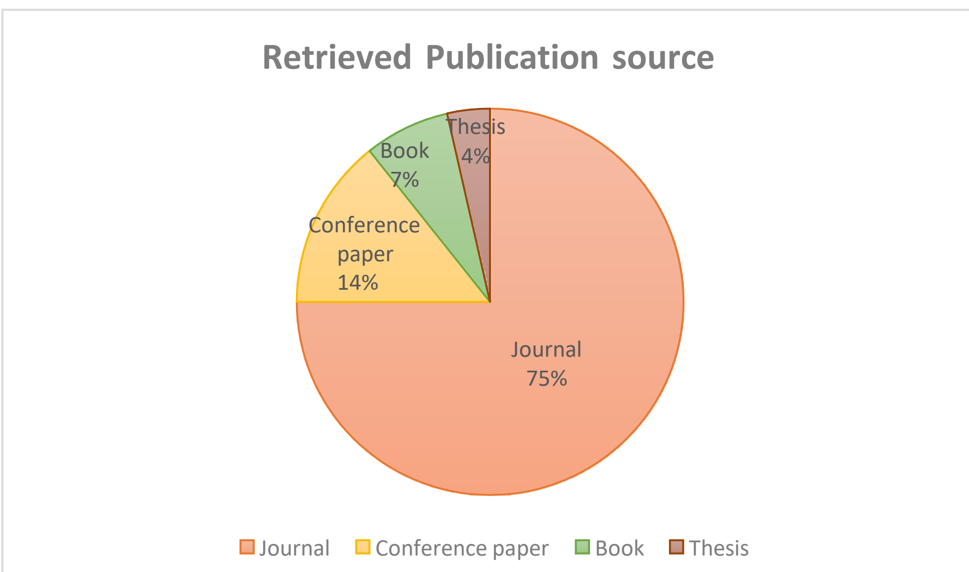


Fig. 4. Retrieved Publication source.

4. Discussion

Fig. 2. shows the systematic grouping of the identified barriers according to their corresponding factors. Al-Al-Yami and Sanni-Anibire (2019); Toyin and Mewomo (2021b) also adopt this grouping in their study. The authors systematically grouped the potential BIM benefit into five groups. Fig. 3. Shows the statistics of reviewed articles per year of publication. Fig. 4. This shows the source which the papers reviewed were retrieved from. The Journal article

used was 75%, and conference paper was 14%, the book was 7%, and the thesis was 4%. All the documents were saved in an endnote.

4.1 Documentation Factors.

Those are the barriers encountered due to improper O&M record-keeping, unavailability of reliable data that provides reliable information or evidence or serves as a record. The following were grouped under this heading: Lack of comprehensive as-built drawing document; Unavailability of real cases validating integration of BIM in existing buildings and Handling of uncertainty where building documentation is incomplete.

4.2 Technical Factors.

BIM technical factors are the challenges faced by or using the BIM software packages. These factors are called BIM limiting factors emanating through inappropriate software use or standard of data available during the integration of BIM in the O&M phase of the existing building. The technical barriers encountered during the integration of BIM in the existing building include data interoperability problems and inadequate compatibility between BIM and existing FM technologies. Interoperability "was defined in the IEEE (1990) glossary as the ability of two or more systems or components to exchange information and use the information exchanged". Kelly et al. (2013) noted the findings of (Lee et al., 2012), which observed that interoperability inefficiencies had caused over a $15.8 billion loss. Wherein $10.6 billion could be traced to the O&M phase. Parallel disintegration between stakeholders in a specific project phase (e.g., building plan, construction, O&M phase) could be affected by the variety of software programs used, contributing to interoperability problems (Howard et al., 1989). Nevertheless, Young et al. (2008) reported that BIM experts are trying to improve interoperability issues. Recently, standards have been put in place to solve the interoperability issues (Marocco & Garofolo, 2021; Pavón et al., 2021). Yet interoperability issue still stands as a top barrier hindering the integration of BIM in the existing building.

4.3 Personnel Factors.

This category of barrier factors involves the whole building production team, including the client. This could be seen as the team member's actions towards BIM integration in the existing building, which are: Lack of BIM knowledge, technical skills, and experience among the facility manager; Failure to identify critical information for sustainable operation; Lack of demand and interest by stakeholders and clients; Lack of interest/reluctance to change from the existing method of maintenance. BIM breaks the conventional method used for building production between multiple built stakeholders and enables the exchange of project information in a single model (Deng et al., 2020). This will directly result in changes in the work process, from conceptual design, data management to the project closeup phase. As a result, the building professionals and construction industry companies will require sufficient time to adjust to the modifications (Sun et al., 2017).

4.4 Professional Management Factors.

Those are the barriers that can be traced to the slackness of the O&M team members in control of BIM integration in the existing building. This could result in the loss of vital information during the documentation. The following barriers were reported: "Lack of best practices and guidelines"; "Lack of effective collaboration between project stakeholders for modeling and model utilization"; "Uncertainty of required data"; "General lack of Knowledge of software required to use BIM"; "Lack of competent BIM experts".

4.5 Financial Factors.

Financial factors are the barriers discouraging BIM implementation, which are cost related. They are mainly cost-incurred during the BIM implementation process for the O&M phase of an existing building. This comprises hardware and software costs and the cost of training facility managers.

4.6 Security Factors.

This is one of the limiting barriers hindering BIM implementation in the existing building. Cyber security and data ownership of BIM data cannot be overlooked in BIM progression (Solihin & Eastman, 2015). Because sharing information allows team members to access project data, cyber security is a problem due to the risk of illegal internet access and copyright breach (Chien et al., 2014).

5. Conclusions, Suggestions, and future research.

The use of BIM in new buildings from the conceptual design phase to construction has been well documented in developed countries. At the same time, its uses for post-construction phase have also gained significant attention. The advancement and benefit of BIM in the new building lifecycle have attracted and drawn the attention of the built professionals and clients to look inward on how to implement this novel technology in an existing building. Limited research has been published in this area of study. Therefore, this study juxtaposes the findings of numerous researchers on the current BIM state-of-art in existing buildings. Basically, this research focuses on a critical review of published articles on the barriers delaying BIM implementation in the existing buildings. The findings show that BIM implementation was first proposed in early 2000 for the Heritage building M&O phase, wherein, a design was generated according to the available structures; this was done in other to retain memories in the society. Also, it was proposed to be used for Residential buildings recently. However, those operations and processes usually come with delays or barriers, which likely discourage the continuous implementation of BIM in the O&M phase of the existing building.

In this study, it was seen that publications on BIM for existing buildings started evolving in 2011. Wherein, 18 barriers were identified. Understanding those barriers made it possible for the author to systematically group them under Six (1) groups: Documentation Factors; Technical Factors; Personnel Factors; Professional Factors; Financial Factors, and Security Factors.

It is recommended that those barriers should be critically investigated and treated accordingly without leaving anyone unattended. This will ease the smooth running and encourage BIM implementation in an existing building.

For further research, this study was limited to highlighting the barriers and discussing the finding. It can be further researched in different regions in other to know more about the barriers peculiar to each region and find a better way of solving them.

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