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RESEARCH ARTICLE

Challenges in Implementation of 7D-BIM for Infrastructure Asset Management: A Systematic Review

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Abstract

Infrastructure Asset Management (InfraAM)/Facilities Management (FM) which deals with infrastructure maintenance, repair, and rehabilitation needs an urgent focus on technology-based solutions. This can be done by implementing digital technologies, like Building Information Modelling (BIM), that can help in 3D visualization, 4D scheduling, 5D costing, 6D sustainability, and 7D FM throughout the service life of the project. However, BIM's implementation undergoes various challenges and to understand the critical challenges, a systematic literature review (SLR) was conducted using 89 peer-reviewed papers from three databases, and quantitative and qualitative analyses were performed. The literature revealed the critical challenges (CCs) and success factors (SFs) that influence BIM implementation for FM but lacks an interrelationship between them. Hence, the current study linked various CCs and SFs through a theoretical approach. The study found that the role of government and contractual frameworks can help to eliminate the majority of the challenges. This novel approach could provide significant contributions by helping practitioners and policymakers understand the connections between CCs and the role of SFs as potential solutions for enhancing BIM implementation for FM.

Keywords

BIM; Critical Challenges; InfraAM; FM; SLR; Success Factors

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Introduction

Infrastructure construction and management is critical for the country's development, economic growth, competitiveness, and social improvement (Prakash and Ambekar, 2020). As a result, infrastructure asset management (InfraAM) has gained more prominence in recent times on account of the renewed emphasis on infrastructure development. InfraAM is defined as "an act of maintaining demanded service level of the asset (such as water treatment facilities, roads, utility grids, bridges, railways, etc.) for present and future customers based on most economically effective management (IPWEA, 2015). This helps in operating, maintaining, upgrading, and expanding physical assets effectively throughout their lifecycle (Akofio-Sowah, et al., 2014). This aspect of the management of infrastructure assets has also been the focus of facility management (FM). The International Facility Management Association (IFMA) defines FM as something that encompasses multiple disciplines to ensure functionality, comfort, safety, and efficiency of the built environment (such as real estate property, buildings, technical infrastructure, HVAC, etc.) by integrating people, process, and technology. As per the above definitions, though infrastructure assets and facilities include varying structures with different requirements and applications, there exist studies that have considered them under the same category of either facility/asset while discussing and analysing the role of facility/asset managers in utilizing BIM (Ikediashi, Ogunlana and O. Ujene, 2014; Volk, Stengel and Schultmann, 2014; Park, Park and Lee, 2016; Parn, et al., 2019; Munir, et al., 2020b; Falcão Silva and Couto, 2021; Kong, Kapogiannis and Cheshmehzangi, 2022; Sadeghineko and Kumar, 2022). This is because the BIM tools/software that are used for designing and constructing an infrastructure asset or facility remain the same (Munir, et al., 2020b), whereas there exist challenges in utilizing as-built BIM models for FM purposes. Also, BIM initially was seen as a project-specific approach which has now moved to an enterprise InfraAM perspective (Godager, Onstein and Huang, 2021) and hence for the current study, the terms InfraAM and FM are used interchangeably.

Once the infrastructure is built, the biggest challenge is ensuring their delivery and management during the operating period. This requires meticulous management of FM expenses as overall management accounts for 85% of the total lifetime cost of the facility (Love, et al., 2015) while the design and building phase results in less than 15% of the total project cost (Lewis, Riley and Elmualim, 2010). Thus, the government must invest extensively in infrastructure maintenance, renovation, and rehabilitation (Schraven, Hartmann and DeWulf, 2011) to deal with the poor state of existing infrastructure assets (Kumaraswamy, 2011). This necessitates a new approach to project delivery since the project's lifecycle integration in terms of project phases has become more reliable (Hilal, Maqsood and Abdekhodaee, 2019). The industry experts suggested a proactive, sustainable, and effective asset management program (Halfawy, 2008) by adopting building information modelling (BIM) as a measure (Munir, et al., 2020a) to handle growing demands and aging infrastructures (Jones, 2020). The operational phase of built assets can be integrated with initial project phases through BIM tools and workflows (Patacas, Dawood and Kassem, 2020). Thus, facility/building owners can utilize BIM to better organize and schedule preventative maintenance for new and existing structures (Volk, Stengel and Schultmann, 2014).

BIM being a multidimensional technology can be used for 3D visualization, 4D scheduling, 5D costing, 6D sustainability, and 7D FM. 4D and 5D-BIM are more widely adopted and implemented, whereas 6D and 7D-BIM are still under development (Wang and Liu, 2020). 7D-BIM is employed (GhaffarianHoseini, et al., 2017b) for indoor navigation (Isikdag, 2012), identification of building components including interior space analyses (Bansal, 2021), maintenance and improvement planning (Motawa and Almarshad, 2013), renovation/retrofitting (Becerik-Gerber, et al., 2012; Davila Delgado and Oyedele, 2020) and operational energy analysis during design phase (Andreani, et al., 2019). However, there exists a state of perplexity and uncertainty among the key stakeholders within the construction industry (Tucker, 1986), extending beyond the 5th dimension of BIM as it jeopardizes the potential advantages and gains that can be derived from the incorporation of these supplementary BIM dimensions (Charef, Alaka and Emmitt, 2018).

The key stakeholders in this context consist of clients who establish the project's BIM execution plan, contractors who utilize BIM for designing, planning, coordinating, and managing construction activities, consultants who supervise the BIM process, ensuring its implementation and promoting collaboration, and government agencies or regulatory bodies that establish standards and guidelines for BIM implementation. BIM integrates all disciplines (Vilventhan, Razin and Rajadurai, 2020) and asset management systems into a virtual model, enabling virtual iterations during the design and construction of the project (Lee, et al., 2015), hence, eliminating mistakes and inefficiencies (Won, et al., 2013). BIM can manage physical assets throughout their lifecycle by contributing towards an asset information management system (AIMS), which contains geometric and non-geometric information derived from data gathered throughout the project's lifecycle even before built assets are put into service (Eastman, et al., 2011). Hence, BIM is not a 3D modelling tool but a process (Mahalingam, Yadav and Varaprasad, 2015) for designing, constructing, and operating an infrastructure asset, through which its entire lifecycle can be managed effectively with time, cost saving, and increased service life as shown through a case study (Cantisani, et al., 2022).

There have been several studies over the past two decades demonstrating the increased implementation of BIM during the design and construction phases of the project, but the utilization of BIM tools and procedures for FM is very rare (Arayici, Onyenobi and Egbu, 2012; Hilal, Maqsood and Abdekhodaee, 2019; Durdyev, et al., 2022). This is because, the implementation of BIM for the management of infrastructure assets post-construction phase is riddled with challenges, and therefore, the focus of this study is to gain insights from the literature to find various success factors which can act as potential solutions to overcome those challenges using a theoretical approach. Hence, the current study has systematically considered five critical challenges (CCs) with 17 sub-challenges faced by asset managers for BIM implementation for FM and the six success factors (SFs) that are mentioned in the literature to overcome these challenges. There have been few studies including literature-review based in the past 10 years discussing the CCs and SFs affecting BIM implementation for FM but none of them was able to link the CCs and SFs with each other for understanding their interrelationship (Williams, Shayesteh and Marjanovic-Halburd, 2014; Gheisari and Irizarry, 2016; Naghshbandi, 2016; Dixit, et al., 2019; Gao and Pishdad-Bozorgi, 2019; Jang and Collinge, 2020; Bademosi and Issa, 2021; Oluleye, et al., 2021; Awwad, Shibani and Ghostin, 2022; Durdyev, et al., 2022). Thus, this research adds to the body of knowledge, by reviewing systematically the existing research on InfraAM/FM by analysing and linking the critical challenges (CCs) and success factors (SFs) with each other.

Research methodology

The study used PRISMA framework (Fig. 1) to conduct systematic literature review as it analyses sources methodically and has been used in various similar studies conducted recently (Antwi-Afari, et al., 2018; Sidani, et al., 2021; Abideen, et al., 2022; He and Liu, 2022; Ozarisoy, 2022; Tsay, Staub-French and Poirier, 2022). SLR aims to offer a critical overview of the present state of research for the topic being studied (Tranfield, Denyer and Smart, 2003). The SLR was conducted based on the following review stages:

Stage I: Planning the review
Stage II: Conducting the review
Stage III: Analysing the review

PLANNING THE REVIEW

In the planning stage, the review methodology includes the study's questions, population (or sample), search strategy, and inclusion and exclusion criteria (Davies and Crombie, 1998). Based on our study, the review questions were:

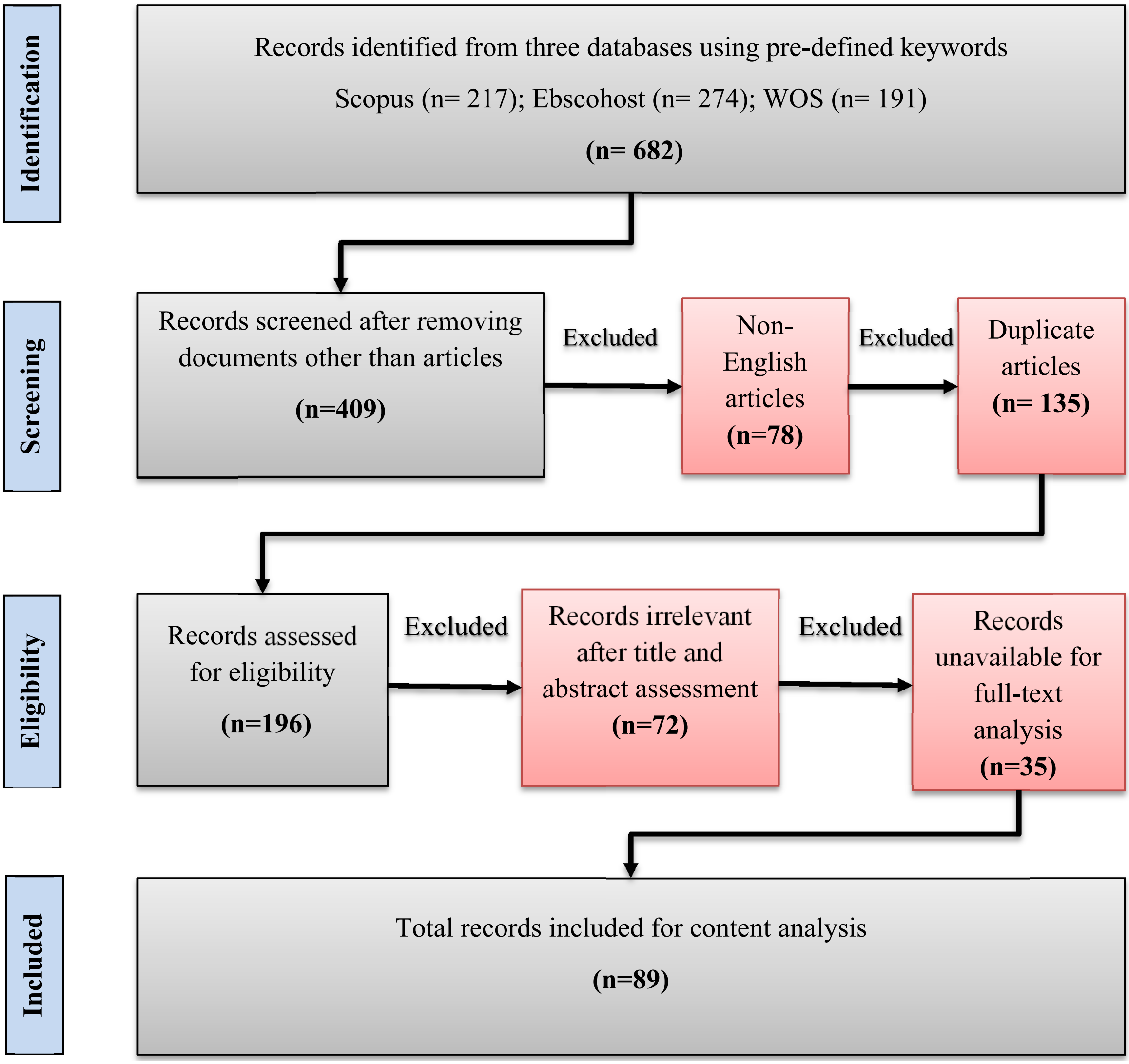


Figure 1. Research Methodology

1. What are the critical challenges and success factors for adopting 7D-BIM?
2. How can the critical challenges and success factors be linked together?

The search strategy involves finding the right data sources and keywords. The study included three databases: Scopus, Web of Science (WOS), and EBSCO host as they cover the vast majority of publications in the area of project and construction management (Chadegani, et al., 2013; Manatos, Sarrico and Rosa, 2017; Zhou and Mi, 2017). To search for pertinent keywords, our study employed a technique of building blocks, typically used by academics for doing SLR (Booth, 2008). Based on our research questions, we've identified the following terms significant to this research: " *BIM, Building Information Modeling, barriers, challenges, success factors, drivers, 7D, Asset Management, AM, Facility Management and FM*". These terms were then connected using Boolean functions like "AND" and "OR" to establish relationships between them.

CONDUCTING THE REVIEW

In this stage, shortlisted keywords were utilized to get a comprehensive list of 682 articles from three databases (Scopus = 217; Ebscohost = 274 and WOS= 191). The articles were initially screened by applying inclusion and exclusion criterions (Table 1). A total of 273 papers, including those published in conferences, book chapters, etc. were identified and removed during the screening process. Hence, only peer-reviewed publications were analysed, as they have high quality (Hohenstein, et al., 2015), reliability, and validity (Bronson and Davis, 2011), and on further removing 78 non-English articles, the list was reduced to 331 articles. In the next step, the articles were subsequently exported into Excel files and scrutinized for any instances of duplication or repetition. After eliminating 135 duplicate articles from the three databases, the list was reduced to 196 articles. Despite implementing the search restrictions, several journals from unrelated fields (such as medicine, nursing, applied economics, etc.) still appeared. The scope of the current research was limited to BIM and InfraAM studies in the construction sector, hence, non-construction-related journals were excluded using title and abstract assessments. In this stage, 72 articles were found irrelevant for further study analysis. Hence, after manually analysing the 124 articles based on full-text availability (35 articles were not available), 89 articles were chosen for the final systematic review analysis.

Table 1. Inclusion and Exclusion criteria

Inclusion Criteria	Exclusion Criteria
Publications in academic journals	Articles and books published on web platforms (master's/doctoral thesis, conferences, chapters, etc.)
Publications related to the construction industry	Publications focusing on fields other than construction
Publications in English language	Publications in languages other than English

ANALYSING THE REVIEW

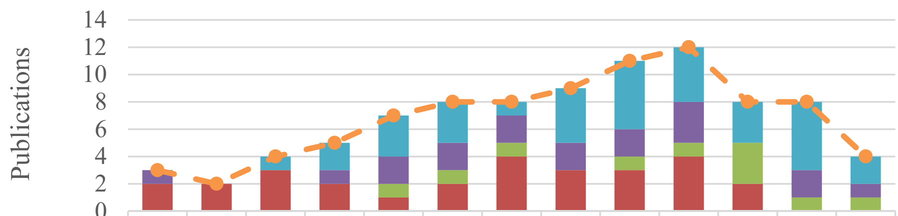
In this stage, quantitative and qualitative analyses of shortlisted articles were performed. The articles were categorized by publication year, research methods, journals, and author keywords in the form of tables and graphs. On the other hand, qualitative content analysis was done using an inductive approach to find and categorize the challenges and success factors based on the "what" and how" of the research questions. This approach involves deriving categories directly from the contents themselves through a process of iterative coding, category building, and re-examination based on consistent units of analysis to enhance precision (Seuring and Gold, 2012). Thus, the full text of the article was chosen as a unit of analysis and the papers were thoroughly reviewed multiple times to extract and organize codes, and ultimately, classify them.

Analysis and results

QUANTITATIVE ANALYSIS

Based on the year of publication, research methods, and journals

The descriptive analysis includes publications in different years starting from 2006 (Fig. 2). The graph demonstrates that publication frequency was low before 2015, but with growing innovations and BIM maturity, the frequency of publications has increased. The increase in publications can also be attributed to various BIM mandates and standards implemented by different countries and international organizations such as PAS 55-1: 2006 & 2008 (United Kingdom), IIMM: 2006, 2011 & 2016 (Australia), ISO 16739: 2013, ISO 55000: 2014 & 2016, ISO 55001: 2014 & 2016, ISO 55002: 2018, ISO/TS 55010: 2019, ISO 19650-1:2019, ISO 19650-2:2019, and ISO 19650-3:2020 to implement BIM and IAM principles, guidelines, and technical specifications for existing and future construction. The research methodologies adopted in the articles are categorized into (1) Surveys, (2) Literature reviews, (3) Case studies, and, (4) Conceptual/theoretical (Hesping and Schiele, 2015). Only 10 (11%) of the 89 shortlisted articles were case studies signifying lesser practical research on BIM for InfraAM. Significant papers have adopted survey methodology, accounting for 33 (37%) articles highlighting the value of survey methodology (questionnaire and interviews) to collect data in this research area. Conceptual/theoretical and literature reviews constituted 28 (31%) and 18 (20%) articles, respectively. The restricted use of BIM for FM can be attributed to a lack of real-world cases (Becerik-Gerber, et al., 2012) as facility/asset managers are hardly involved in BIM development during design and construction phases (Volk, Stengel and Schultmann, 2014). Even though there is growing interest in BIM for FM, it is still not clear how BIM could be realistically used as there is very little empirical data in this field (Becerik-Gerber, et al., 2012).



	2006	2009	2011	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Surveys	0	0	1	2	3	3	1	4	5	4	3	5	2
Literature Reviews	1	0	0	1	2	2	2	2	2	3	0	2	1
Case Studies	0	0	0	0	1	1	1	0	1	1	3	1	1
Conceptual/Theoretical	2	2	3	2	1	2	4	3	3	4	2	0	0
Total	3	2	4	5	7	8	8	9	11	12	8	8	4

Figure 2. List of Annual Publications

The articles were also listed based on their journals of publication as shown in Table 2.

Table 2. Journal-wise Publications

S. No.	Journal	Publications
1	Automation in Construction	12
2	Built Environment Project and Asset Management	9
3	Journal of Construction Engineering and Management	6
4	Facilities	5
5	Journal of Management in Engineering	4
6	International Journal of Construction Management	3
7	Procedia Engineering	3
8	Journal of Building Engineering	4
9	Advanced Engineering Informatics	3
10	Renewable and Sustainable Energy Reviews	3

Table 2. continued

S. No.	Journal	Publications
11	Buildings	2
12	Engineering, Construction and Architectural Management	2
13	Construction Innovation	2
14	Korean Journal of Construction Engineering and Management	2
15	Journal of Facilities Management	2
16	International Journal of Facility Management	2
17	Advances in Civil Engineering	2
18	Articles in other journals (one article each)	23

CLUSTER ANALYSIS BASED ON AUTHOR KEYWORDS

For analysing author keywords, VOSviewer was used to perform an in-depth examination of finalized articles. VOS-viewer creates bibliometric maps and visualizes keywords co-occurrence, citation, and co-citation map through a distance-based method (van Eck and Waltman, 2010). The distance between network nodes is proportional to the similarity of their reference lists; node size reflects citation frequency; and node colour shows subject clusters, creating a 2-dimensional image (van Eck and Waltman, 2010). High-resemblance things are closer, and similarly, thicker lines between nodes indicate a stronger connection (van Eck and Waltman, 2010). Based on 89 selected publications, a cluster network was established based on keywords co-occurrence using VOS-viewer software (Fig. 3). With 8 clusters and 33 links, BIM has the most links and is strongly bonded with facility management, operations and management, asset management, construction management, barriers, and interoperability.

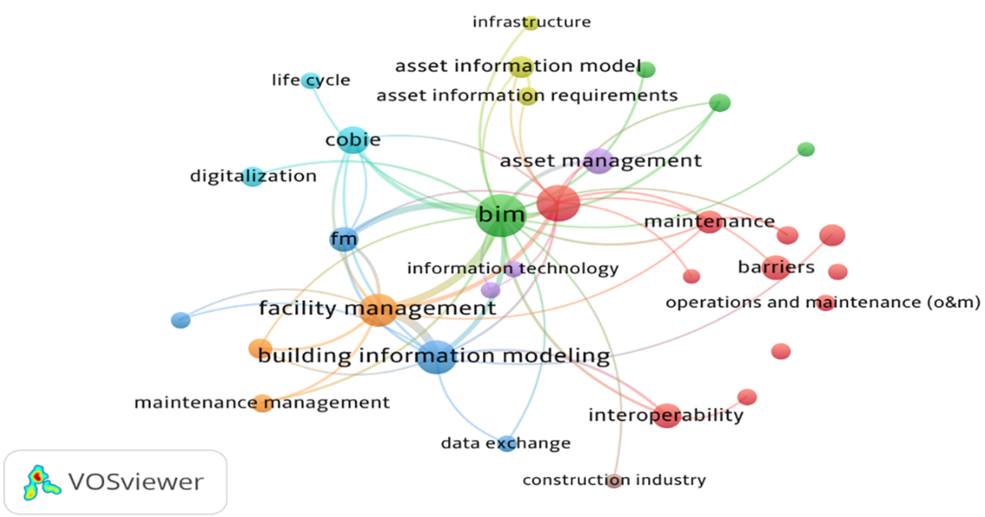


Figure 3. Cluster based on Author Keywords

QUALITATIVE ANALYSIS

The subsequent section 3.2.1 discusses the works of literature that were obtained from the SLR process and section 3.2.2 discusses critical challenges (CCs) affecting the implementation of 7D-BIM and success factors (SFs) to overcome those challenges through a theoretical approach.

Systematic literature review

This section provides a detailed literature assessment of the studies related to BIM implementation for FM. The review discussed research methodologies and outcomes of various studies related to critical challenges and success factors of BIM implementation for FM.

The studies adopted different research methodologies such as a literature review approach (Volk, Stengel and Schultmann, 2014; Naghshbandi, 2016; Nicał and Wodyński, 2016; Misron, Naim and Asmoni, 2018; Gao and Pishdad-Bozorgi, 2019), online survey/interviews (Williams, Shayesteh and Marjanovic-Halburd, 2014; Gheisari and Irizarry, 2016; Dixit, et al., 2019; Jang and Collinge, 2020; Bademosi and Issa, 2021; Oluleye, et al., 2021; Awwad, Shibani and Ghostin, 2022; Durdyev, et al., 2022), case study approach (Kassem, et al., 2015; Korpela, et al., 2015; Heaton, Parlikad and Schooling, 2019; Kula and Ergen, 2021; Tsay, Staub-French and Poirier, 2022) and conceptual/theoretical approach (Pishdad-Bozorgi, et al., 2018) to discuss the challenges and success factors affecting BIM implementation for FM.

Many studies concluded cost-based factors (Gheisari and Irizarry, 2016; Bademosi and Issa, 2021; Durdyev, et al., 2022), technical and interoperability issues (Volk, Stengel and Schultmann, 2014; Korpela, et al., 2015; Naghshbandi, 2016; Pishdad-Bozorgi, et al., 2018; Jang and Collinge, 2020; Kula and Ergen, 2021) as major challenges for implementing BIM for FM. In a recent study, which was based on three case study projects in Canada, Tsay, Staub French and Poirier (2022) concluded that even if asset owners are involved in project beginning, various other problems still impede owners from fully utilizing BIM, and those project-specific challenges were mapped and connected. Similarly, Durdyev, et al. (2022) did a study in New Zealand using semi-structured interviews and found that besides cost factors, lack of BIM knowledge, and lack of BIM expertise among the FM practitioners remain the most significant in BIM implementation for FM. Also, in the study, Dixit, et al. (2019) used a survey approach and categorized the challenges into four themes and found that lack of FM involvement in initial project phases is the most important issue affecting BIM implementation for FM. Similarly, the organization's commitment to accepting change (Misron, Naim and Asmoni, 2018; Oluleye, et al., 2021) and staff training/BIM-consultant involvement (Misron, Naim and Asmoni, 2018; Awwad, Shibani and Ghostin, 2022) were found as a major success factor for BIM implementation for InfraAM. A recent study by Awwad, Shibani and Ghostin (2022), conducted semi-structured interviews from three case studies to explore CSFs influencing BIM level 2 implementation in the UK and found that BIM awareness and training, and hiring an external consultant for successful implementation were highly effective for BIM deployment. Similarly, (Pishdad-Bozorgi, et al., 2018) designed a conceptual model and concluded that understanding of FM-enabled BIM, seamless process of collecting FM-enabled BIM data, and, well-executed interoperability plan for exchanging data are the most important CSFs for BIM implementation.

As mentioned above, there have been studies that utilized the literature review approach as an effective method to summarize the existing studies for understanding the challenges and success factors affecting 7D BIM implementation, but no such study has been able to establish the link between them to understand how SFs can eliminate various CCs.

CRITICAL CHALLENGES (CCS) AND SUCCESS FACTORS (SFS) AFFECTING BIM IMPLEMENTATION FOR FM

Critical challenges (CCs) and sub-challenges

This section discusses about five critical challenges (CCs) and 17 sub-challenges affecting BIM implementation (Table 3).

Table 3. Critical Challenges Affecting BIM Implementation for IAM

Critical Challenges	Sub-Challenges	Papers
Technical based (CC1)	Complexity of BIM tools (CC1.1) Data interoperability issues from BIM to InfraAM tools (CC1.2) Software Security Issues (CC1.3) Less understanding of data requirement for InfraAM (CC1.4)	(Gu and London, 2010), (Becerik-Gerber, et al., 2012), (Volk, Stengel and Schultmann, 2014), (Ramilo and Embi, 2014), (McArthur, 2015), (Corry, et al., 2014), (Mahalingam, Yadav and Varaprasad, 2015), (Son, Lee and Kim, 2015), (Kassem, et al., 2015), (Naghshbandi, 2016), (Brous, Herder and Janssen, 2016), (Mayo and Issa, 2016), (GhaffarianHoseini, et al., 2017a), (Alreshidi, Mourshed and Rezgui, 2018), (Farghaly, et al., 2018), (Ahuja, et al., 2020), (Chan, Olawumi and Ho, 2019), (Dixit, et al., 2019), (Jang and Collinge, 2020), (Tsay, Staub-French and Poirier, 2022), (Ikediashi, et al., 2022)
Project based (CC2)	Separation of O&M stage from design stage (CC2.1) Traditional method for Procurement of Asset Managers (CC2.2) Lack of Contractual framework (CC2.3)	(Kumar and Mukherjee, 2009), (Becerik-Gerber, et al., 2012), (Lin and Su, 2013), (Kang and Choi, 2015), (Lee, Yu and Jeong, 2015), (Kassem, et al., 2015), (Naghshbandi, 2016), (Smyth, Anvuur and Kusuma, 2017), (Alreshidi, Mourshed and Rezgui, 2018), (Blay, Tuuli and France-Mensah, 2019), (Dixit, et al., 2019), (Blay, Tuuli and France-Mensah, 2019), (Jang and Collinge, 2020)
Actors based (CC3)	Roles and Responsibilities for model maintenance (CC3.1) Lack of Demand from Client (CC3.2) Non-involvement of Asset Managers from project beginning (CC3.3) Lack of BIM Knowledge and expertise of Asset Managers (CC3.4)	(Kumar and Mukherjee, 2009), (Gu and London, 2010), (Becerik-Gerber, et al., 2012), (Ramilo and Embi, 2014), (Williams, Shayesteh and Marjanovic-Halburd, 2014), (Chien, Wu and Huang, 2014), (Lee, Yu and Jeong, 2015), (Kassem, et al., 2015), (Bosch, Volker and Koutamanis, 2015), (Mahalingam, Yadav and Varaprasad, 2015), (Giel and Issa, 2016), (Naghshbandi, 2016), (Lee and Jung, 2016), (Jang and Collinge, 2020), (Patel, et al., 2021)

Table 3. continued

Critical Challenges	Sub-Challenges	Papers
Capital based (CC4)	High cost of implementation of BIM-InfraAM tools (CC4.1) High Training Costs (CC4.2) Low ROI risks (CC4.3)	(Williams, Shayesteh and Marjanovic-Halburd, 2014), (Ding, et al., 2015), (Naghshbandi, 2016), (GhaffarianHoseini, et al., 2017a), (Georgiadou, 2019), (Chan, Olawumi and Ho, 2019), (Blay, Tuuli and France-Mensah, 2019), (Bademosi and Issa, 2021), (Adekunle, Ejohwomu and Aigbavboa, 2021), (Durdyev, et al., 2022), (Ikediashi, et al., 2022)
Policies based (CC5)	Govt. Policies (CC5.1) Lack of BIM model updating processes (CC5.2) Insufficient Govt. Support (CC5.3)	(Gu and London, 2010), (Becerik-Gerber, et al., 2012), (Kassem, et al., 2015), (Ahuja, et al., 2020), (Mahalingam, Yadav and Varaprasad, 2015), (Son, Lee and Kim, 2015), (Alreshidi, Mourshed and Rezgui, 2018), (Li and Liu, 2019), (Patel, et al., 2021), (Adekunle, Ejohwomu and Aigbavboa, 2021)

Technical based challenges (CC1) includes various sub-challenges such as the *complex nature of BIM tools at higher maturity level* (CC1.1), *issues related to data interoperability* (CC1.2), *software security issues* (CC1.3), and *not able to understand the type of data required for InfraAM* (CC1.4). One of the biggest challenges facing FM business is the sheer volume of data, including schedules, asset details, etc., and less understanding of the data required for FM (Naghshbandi, 2016). Hence, effective InfraAM requires a clear understanding of what, when, and by whom information is required. The asset operations team is overloaded with BIM data and incapable of appropriately filtering it (Munir, et al., 2020b). It is challenging to implement FM updates when there is inaccurate, missing, or duplicate data (Jang and Collinge, 2020) in as-built models, resulting in the loss of countless hours of productive work and millions of dollars due to inefficient procedures (Kassem, et al., 2015; Gouda, Abdallah and Marzouk, 2020). Also, due to huge differences in development cycles and using different types of BIM and FM technologies, BIM-FM integration becomes very challenging (Naghshbandi, 2016).

Another category is *Project based* (CC2) challenges which include *separation of O&M stage from design stage* (CC2.1), *traditional method for procurement of asset managers* (CC2.2), and *lack of contractual framework* (CC2.3). There are several issues, including the disjointed AEC industry, regional disparities in market readiness, and resistance to change (Naghshbandi, 2016). Even FM service providers are hired on temporary contracts (often 3 to 5 years) (Kassem, et al., 2015) and they prefer conventional methods rather than learning new technologies to manage assets. Additionally, it is quite difficult to develop a complete legal and contractual framework and standards for 7D BIM deployment (Becerik-Gerber, et al., 2012) as there is still confusion among stakeholders on higher BIM dimensions like 6D, 7D, and beyond (Charef, Alaka and Emmitt, 2018), causing difficulty in accessing reliable data for InfraAM (Lin and Su, 2013).

Failure to *assign roles and duties for model maintenance* (CC3.1) is an example of *managerial/actor based* (CC3) challenges. The client being a major stakeholder of the asset doesn't *demand the use of technology* (CC 3.2) for FM purposes. Also, there is a practice of *not involving asset managers from the beginning of the project* (CC3.3), and even when they are involved, they *lack knowledge and expertise* (CC3.4). With right who, what, and how, BIM can be beneficial for InfraAM by storing asset information in a centralized database (Lee and Jung, 2016). Clients need to understand their requirements from BIM and how to use feedback from BIM-based projects to improve future projects. Asset managers lack BIM knowledge and are unsure how to use it for FM (BIFM, 2012; Williams, Shayesteh and Marjanovic-Halburd, 2014). Indeed, a lack of interaction and collaboration (Thabet and Lucas, 2017) between project participants contributes to clients' unwillingness to engage with BIM (Becerik-Gerber, et al., 2012). Asset owners had traditionally been involved only in the project completion phase due to their BIM inability (Azhar, 2011).

The *Capital-based challenges* (CC4) include *high cost of BIM-InfraAM implementation* (CC4.1), *high training costs* (CC4.2) resulting from training being imparted to asset managers, and fear among asset managers on *low return on investment (ROI)* (CC4.3). Even though BIM is well known, small and medium-sized firms cannot invest in digital technologies due to budget restrictions (Georgiadou, 2019). Since BIM has not been validated for FM cost reductions (Williams, Shayesteh and Marjanovic-Halburd, 2014), investment in BIM lacks confirmation of its advantages over conventional approaches (Naghshbandi, 2016). Also, concerns and debates among operation managers have arisen since the cost and time to develop a 7D-BIM model is very large, and hence, its ROI has not yet been ascertained (Naghshbandi, 2016). A major obstacle to FM's upstream integration is the necessity to handle a variety of use cases that vary by project and user role (Kang and Choi, 2015).

Policies (CC5) related challenges are considered crucial as frameworks and policies govern how an organization operates. This includes sub-challenges such as *role of government policies* (CC5.1), *lack of BIM model updating processes in InfraAM stage* (CC5.2), and *insufficient support from the govt.* (CC5.3). The issue with using BIM for FM is inadequate procedures for updating the initially planned model with as-built data (Gu and London, 2010). While BIM has just recently been adopted by facilities managers, the accompanying policies, and standards are still in their infancy (Williams, Shayesteh and Marjanovic-Halburd, 2014). Also, the FM sector is significantly reluctant to accept cultural change for accepting new procedures and technology (Kassem, et al., 2015), which has been attributed to low BIM acceptance for FM (Becerik-Gerber, et al., 2012).

Overcoming CCs of BIM implementation through SFs (theoretical approach)

Similar to critical challenges, the six critical success factors (SFs) were also identified (Table 4). Additionally, this section links several CCs to establish interrelationships between them and illustrates how SFs can assist in addressing those challenges.

Involving *asset managers from the design phase of the project* (SF1) is a crucial technique that may speed up the FM system construction process and cut down on costs. Asset managers should be included from the onset of the project, rather than being brought in after the closeout phase, so that FM data is accessible earlier (Williams, Shayesteh and Marjanovic-Halburd, 2014; Ghosh, Chasey and Mergenschroer, 2015). Due to the separation of the O&M stage from the design stage (CC2.1), there is non-involvement of asset managers from the project beginning (CC3.3) resulting in the difficulty of assigning roles and responsibilities for model maintenance (CC3.1), which can be alleviated through SF1. It bridges design and FM gaps to improve AM, as, "BIM is something that FM must engage with as soon as possible" (BIFM, 2012). Hence, FM-compliant BIM data needs should be established at the project's inception (Ghosh, Chasey and Mergenschroer, 2015). Hence, involving asset managers in the initial project phase can eliminate organizational and managerial/actor-based challenges.

Asset managers often work on short-term contracts and rely on conventional methodologies. Therefore, it is necessary *to provide training of InfraAM tools* (SF2), so that as-built BIM models can be used efficiently for FM. The quality of data improves when individuals are actively involved in the BIM virtual environment (Eastman, et al., 2011). Complexities in BIM tools at higher maturity level (CC1.1) results in less understanding of the data requirement at the InfraAM stage (CC1.4) due to a lack of BIM expertise and knowledge of asset managers (CC3.4) and software security/ privacy issues (CC1.3) and can be addressed through SF2. There is a wide gap between FM employees skill sets and the ones needed for efficient asset management, thus training is essential (Woodhouse, 2003). Hence, if an organization invests in technology capacity building and training of staff (Misron, Naim and Asmoni, 2018), technical and actors related challenges can be handled.

Open system and data libraries for InfraAM systems (SF3) involve integrating readily accessible, openly editable repositories of InfraAM data sets and information (Kassem, et al., 2015). BIM can connect with current software and supply appropriate data for various FM applications (Davtalaba and Delgadob, 2014; Naghshbandi, 2016). Although integration of BIM and FM software allows fast data transfer despite compatibility issues (Shen, Hao and Xue, 2012), the business case for BIM in existing facilities cannot be demonstrated unless data transmission is automated and verified. Due to the complexity of BIM tools (CC1.1) and complex BIM model updating processes (CC5.2), asset managers lack an understanding of utilizing BIM data for InfraAM (CC1.4). Hence, in such cases, SF3 can help to eliminate technical and external challenges. There has been discussion about ways to automate data flow between BIM and FM technologies to visualize the benefits of BIM for InfraAM (Davtalaba and Delgadob, 2014; Ghosh, Chasey and Mergenschroer, 2015). In one of the studies (Farghaly, et al., 2018), an API plug-in was developed that can help BIM stakeholders identify the required data to be submitted to facility managers to improve AM processes, but still has limitations.

The InfraAM tools can be modified as per the requirement of asset managers *by Aligning IT researchers/ BIM consultants with InfraAM industry practitioners* (SF4). If the information in the BIM model can be customized as per asset owners' needs, it will aid in effective decision-making (Azhar, 2011), since imported models contain too much extra data that needs to be filtered out (Gu and London, 2010). So, if a collaborative approach is employed and clients take initiative, then only such challenges can be handled. Hence, SF4 can help to solve technical challenges by eliminating data interoperability issues (CC1.2) resulting from complex BIM tools (CC1.1). By using appropriate software plugins, asset managers and external consultants can extract required data from the as-built model (Gu and London, 2010; Azhar, 2011; Brunet, et al., 2019).

The *government policies and contractual frameworks* (SF5) can aid in BIM implementation on a larger scale. Hence, the government's involvement in implementing technology-based solutions is critical for InfraAM, so BIM-FM must be incorporated into conventional contracting procedures (Naghshbandi, 2016). There is a lack of demand from client (CC3.2) because of the risk of getting low return on investment (ROI) (CC4.3), high BIM software and hardware cost (CC4.1), high training costs (CC4.2), and insufficient government support (CC5.3). Also, due to lack of govt. policies (CC5.1) and contractual framework (CC2.3) use of traditional practices (CC2.2) exist. Hence, if govt. develops modern contracts and provides sufficient incentives to private contractors, challenges due to cost, management, and policies can be eliminated. Getting effective BIM output for InfraAM (Mahalingam, Yadav and Varaprasad, 2015) requires new rules and frameworks to remove conventional project management contract procedures and focus on digital management of assets (Love, et al., 2014; Naghshbandi, 2016).

The construction industry is typically slow to adopt new technology, and, hence, requires *cultural change to adopt technology in InfraAM industry* (SF6). When the organization is open to change and its goals are aligned with BIM-FM, successful integration is achieved (Ghosh, Chasey and Mergenschroer, 2015; Chan, Olawumi and Ho, 2019). SF6 is a long-term approach that requires a company-wide commitment to risk-taking to achieve cultural change. It can help in eliminating challenges related to organization and management which includes traditional procurement of asset managers (CC2.2) and non-involvement of asset managers from project beginning (CC3.3). The construction industry must embrace new methods and technology to combine associated information throughout the project lifecycle (Shen, Hao and Xue, 2012; Ghosh, Chasey and Mergenschroer, 2015). It is highly recommended that construction stakeholders should look beyond massive investments (Wang and Liu, 2020) and experience a cultural shift to utilize BIM for effective InfraAM (Shen, Hao and Xue, 2012; Bui, Merschbrock and Munkvold, 2016).

Table 4. Success Factors for Implementing BIM for FM

ID	Description	Papers
SF1	Involving Asset Managers from Design Phase of Project	(Kumaraswamy, Anvuur and Smyth, 2010), (Azhar, 2011), (BIFM, 2012), (Wang, et al., 2013), (Williams, Shayesteh and Marjanovic-Halburd, 2014), (Ghosh, Chasey and Mergenschroer, 2015), (Mayo and Issa, 2016), (Naghshbandi, 2016), (Misron, Naim and Asmoni, 2018), (Olawumi and Chan, 2019), (Darwish, Tantawy and Elbeltagi, 2020)
SF2	Providing training of InfraAM tools to Asset managers	(Woodhouse, 2003), (Eastman, et al., 2011), (Won, et al., 2013), (Chan, 2014), (Giel and Issa, 2016), (Misron, Naim and Asmoni, 2018), (Amuda-yusuf, 2018), (Patel, et al., 2021), (Awwad, Shibani and Ghostin, 2022)
SF3	Open System and Data Libraries for InfraAM systems	(Shen, Hao and Xue, 2012), (Davtalaba and Delgadob, 2014), (Ghosh, Chasey and Mergenschroer, 2015), (Naghshbandi, 2016), (Misron, Naim and Asmoni, 2018), (Carbonari, Stravoravdis and Gausden, 2018), (Farghaly, et al., 2018), (Farghaly, et al., 2019), (Abideen, et al., 2022)
SF4	Aligning IT researchers/BIM consultants with InfraAM Practitioners	(Gu and London, 2010), (Azhar, 2011), (Staykova and Underwood, 2017), (Misron, Naim and Asmoni, 2018), (Brunet, et al., 2019), (Darwish, Tantawy and Elbeltagi, 2020), (Vilventhan, Razin and Rajadurai, 2020), (Awwad, Shibani and Ghostin, 2022)
SF5	Government Policies and Contractual Frameworks	(Kumaraswamy, Anvuur and Smyth, 2010), (Love, et al., 2014), (Naghshbandi, 2016), (Misron, Naim and Asmoni, 2018), (Carbonari, Stravoravdis and Gausden, 2018), (Olawumi and Chan, 2019), (Patel, et al., 2021), (Abideen, et al., 2022)
SF6	Cultural change to adopt technology	(Shen, Hao and Xue, 2012), (Ghosh, Chasey and Mergenschroer, 2015), (Kassem, et al., 2015), (Sarkar, Raghavendra and Ruparelia, 2015), (Chan, Olawumi and Ho, 2019), (Olawumi and Chan, 2019), (Oluleye, et al., 2021)

DISCUSSION

BIM implementation during design and construction applications has increased considerably, but its implementation for FM purposes is very slow. Hence, this study did an SLR to find the critical challenges (CCs) and success factors (SFs) and linked them theoretically. The main research outputs are depicted in Figure 4 in the form of a flowchart. The results from theoretical analysis of the literature state that SF1 & SF6 can help to overcome challenges related to organization and actors, SF2 can manage technical and actors-based challenges, SF3 can manage technical and policies-based challenges, SF4 can also help to overcome technical challenges and SF5 alone can help to overcome actors, capital and policies-based challenges.

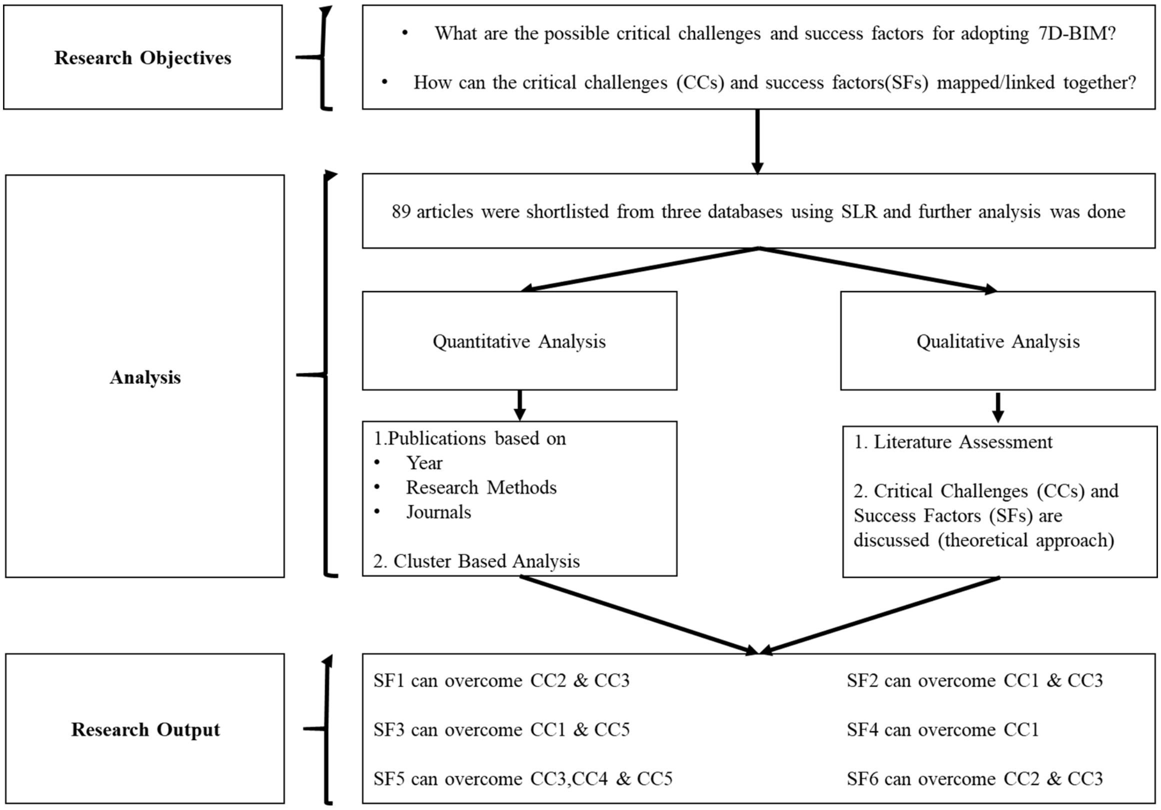


Figure 4. Flowchart of Research Output

Conclusions, limitations & the way forward

The present study conducted an SLR using three databases namely Scopus, Web of Science, and EBSCOhost which resulted in shortlisting 89 publications. To achieve our research objectives, those publications initially revealed relevant literature on BIM and FM/InfraAM, evaluating the critical challenges (CCs) and subsequent success factors (SFs) affecting BIM implementation for FM. The publications were also categorized based on the year of publications, research methodologies, journals and author keywords. The findings indicate that researchers predominantly chose qualitative ways of analysis. There existed some literature review studies related to various challenges and success factors affecting 7D-BIM implementation, but no study was able to holistically establish any inter-relationship between the CCs and demonstrate the role of individual or combination of SFs to overcome the barriers affecting BIM implementation for FM. Hence, to achieve this objective, this study adds to the body of knowledge by analysing 17 sub-challenges under five CCs, and six SFs affecting BIM implementation for FM and linking them together using a theoretical approach to show the interrelationship between them and highlight the role of SFs in overcoming those challenges. The result shows that the success factor related to government policies and contractual framework (SF5) can help to eliminate the majority of the challenges (CC3, CC4, and CC5). Therefore, the findings of the current study may help construction stakeholders and policymakers prioritize specific challenges and consider pairing success factors to accelerate BIM deployment for FM.

There also exist a few limitations of the study. Nevertheless, the findings of the study suggest that government policies and contractual framework can help in eliminating majority of challenges, there might be situations when other challenges are more critical to the ones being eliminated by it. Also, the study relies on a theoretical analysis of literature, establishing a basis for comprehending, scrutinizing, and interpreting facts. However, the process of pairing CCs and SFs may include issues related to individual's subjective judgment, validity and challenges in practical application. Therefore, as a potential approach for future research, the study might be corroborated by soliciting expert opinions and conducting a thorough analysis of data obtained from methods such as questionnaire surveys, interviews, the Delphi methodology, etc. Also, future studies may reveal additional factors based on BIM maturity within a country, sector of the construction industry, stakeholder's perception, value of construction project, and discipline-specific characteristics (such as civil, mechanical, electrical, or architectural). Hence, this may result in the development of novel as well intricate connections between the existing and additional identified factors leading to the development of a holistic framework. Furthermore, recent years have witnessed studies on the implementation of Lean Construction (LC) and Public Private Partnership (PPP) based contracts in the construction industry. Therefore, it is necessary to examine the methods and degree of application of these strategies to classify and assess them as relevant factors in the adoption of technology in the construction industry. Overall, the paper's findings are an initial step in helping researchers and practitioners to fill knowledge gaps to facilitate BIM implementation for FM.

Statement on ethics and informed consent

The research reported in this paper did not require ethical clearance as it involved analysis of articles that were published in peer-reviewed journals. Additionally, the study did not involve data collection with humans nor any secondary datasets involving data provided by humans.

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