EXPLORING CURRENT RESEARCH GAPS AND OPPORTUNITIES IN FACILITY MANAGEMENT FOR CONSTRUCTION

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SUMMARY: *Successful operation and maintenance of buildings relies on facility management (FM). However, effective implementation of FM practices poses diverse challenges. Through quantitative and qualitative analysis, this research briefly assesses the current state of FM, explores the main challenges in the sector and identifies the underlying gaps causing these challenges. 11 substantial gaps are identified in knowledge, integration, information, interoperability, education and training, validation, tools, collaboration, standardization, communication, and awareness. The paper suggests future research directions for enhancing information quality through knowledge management, fostering seamless data integration and interoperability in FM, data-driven decision support for sustainable facility management, and immersive learning environments in the construction industry.*

KEYWORDS: *construction, data integration, facility management, gaps and challenges, information quality, knowledge management.*

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1. INTRODUCTION

Facility Management (FM) is an integrated approach that helps organizations, facility managers, owners, and end-users to achieve their main objectives by ensuring the functionality of the built environment (Ensafi & Thabet, 2021). According to The International Facility Management Association, the most recent definition of facility management is "a profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, place, process, and technology." It is interesting to note that this newest definition highlights the importance of technology, which was lacking previously.

Facility managers require access to accurate and reliable information about building systems and components, which enables them to make informed decisions and take actions that enhance efficiency and productivity (Ensafi & Thabet, 2021). According to Cotts et al. (2010) facility managers play an vital role in 'planning, organizing and coordinating the strategic and operational management of facilities to provide an environment that supports the core activities of the organization'. This definition involves a wide range of activities, including the management of real estate, architectural and engineering planning, space planning and allocation, and operations and maintenance. However, FM presents many challenges, including data loss, time wasted searching for information, lack of interoperability, and data inconsistency (Yang & Bayapu, 2019). Due to the increasing demand for a high quality of life, globalization, and the development of information technology, managing properties and facilities in the built environment has become increasingly important. To meet these challenges, facility managers are constantly looking for new approaches that enable them to harness the power of technology and leverage data to improve their operations to fulfil the evolving needs of their stakeholders (Irizarry et al., 2013).

The Architecture, Engineering, Construction and Operation (AECO) industry and FM play a vital role in shaping the built environment and ensuring that it meets the needs of people. While AECO traditionally focuses on the design, construction, and initial operation of buildings, FM is concerned with the ongoing management and maintenance of these facilities throughout their lifecycle. Although "Operation" within AECO does overlap with FM, FM is a more specialized discipline that extends beyond the initial operation phase to include long-term maintenance, optimization, and adaptation of the built environment to changing needs. (Hobees et al., 2021; Y. Zhang et al., 2022)

The rapid changes in the technology and societies affect the construction sector as well as the requirements of an efficient facility management system today. Current literature suggests significant issues related to inadequate information infrastructure, a lack of standardized processes, poorly identified required data, bad information quality, and insufficient training. These challenges, collectively, impede the seamless functionality of the built environment and hinder the ability of facility managers to make informed decisions.

Therefore, the primary motivation behind this research is to address the evolving needs of stakeholders in the face of these challenges. By undertaking a thorough examination of the existing literature, this study aims to shed light on the intricacies of these challenges and propose avenues for future research.

To fulfill this objective, a mixed-review approach is adopted, encompassing both bibliometric analysis (quantitative analysis) and systematic review (qualitative analysis). This approach ensures a brief exploration of research trends and comprehensive explanation of challenges in facility management. The use of bibliometric analysis allows one to identify major research topics and trends, offering statistical insights into the structural and dynamic aspects of the targeted research fields. Subsequently, the qualitative review, specifically the systematic review, delves into the existing research challenges and requirements, providing a deeper understanding of the evolving landscape of facility management.

The rest of this paper is organized as follows: Chapter 2 explains the research methodology in detail, Chapter 3 provides a bibliometric analysis of the keywords and current research trends in the selected area. Chapter 4 provides a systematic literature review and the discussion for the gap analysis in FM. Chapter 5 subsequently outlines synthesis of bibliometric analyses conducted at the outset of the article and the insights obtained from the subsequent qualitative systematic research review and provides future research lines to be considered in this research field. Finally, Chapter 6 concludes the paper.

2. RESEARCH METHODOLOGY

This study aims to gain an in-depth understanding of the current research trends in facility management within the construction industry, while identifying the associated research gaps and challenges. To achieve this objective, a mixed-methods review approach is employed, integrating bibliometric analysis (quantitative) and systematic review (qualitative). This approach ensures a comprehensive exploration of both statistical patterns and contextual insights within the research field.

The logic for using both bibliometric and systematic methods lies in four principles: triangulation, complementarity, development, and expansion. Triangulation ensures the convergence and cross-verification of results from both methods, providing robust conclusions in case of discrepancies. Complementarity allows mutual reinforcement, where the qualitative insights enhance the statistical findings, mitigating subjective interpretation biases. Development is achieved by using results from the bibliometric analysis to guide and refine the focus of the systematic review. Lastly, expansion broadens the scope and depth of the analysis, leading to a multidimensional review of research trends and challenges in facility management.

2.1 Data Collection

The initial step in this study involved a comprehensive literature search using the Scopus database, due to its extensive coverage of scientific publications. The search was conducted using a combination of keywords relevant to "facility management", "construction", "AEC" (architecture, engineering, construction), "gaps", and "challenges" to ensure the focus remained within the domain of facility management in the construction industry. The search covered articles published between 2002 and 2024 to ensure both historical and contemporary research trends were considered.

The initial search yielded 380 results. After applying specific inclusion criteria—such as language (English) and document type (journal articles, conference papers, and review papers)—the number of relevant records was reduced to 134. The abstracts and keywords of these articles were then manually assessed by the authors to ensure relevance, leading to the exclusion of 13 papers that were deemed unrelated. A further review identified 22 additional relevant articles through reference tracking from the selected literature, resulting in a final set of 143 articles (Figure 1).

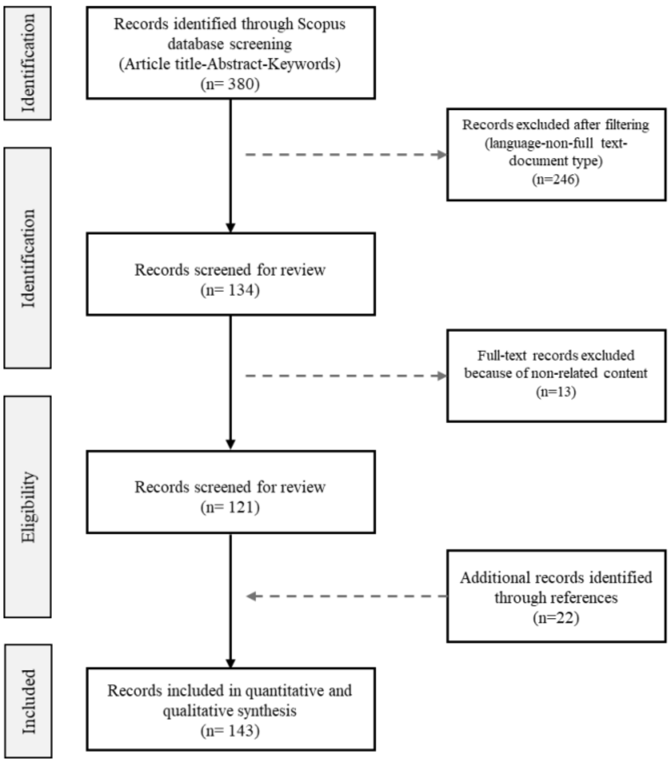

Figure 1: Flow diagram of literature review

2.2 Quantitative Analysis: Bibliometric Review

The bibliometric analysis was conducted to statistically map the structure and dynamics of the research field. Using tools such as VOSviewer, keyword co-occurrence networks were created to explore relationships between key terms, articles, and research themes. This quantitative analysis identified significant research topics, trends, and gaps by analyzing the frequency and clustering of keywords and the connections between them. The results of this phase served as the foundation for categorizing the research topics into thematic clusters.

2.3 Qualitative Analysis: Systematic Review

Building on the bibliometric findings, a systematic review is conducted to qualitatively assess the research gaps and challenges. Manual identification of challenges and the gaps in research through readings, help to outline both the current state of research and emerging areas for further investigation.

This mixed-method approach ensures that the quantitative findings (from the bibliometric analysis) are complemented and contextualized by qualitative insights (from the systematic review), allowing for a more robust understanding of the research landscape.

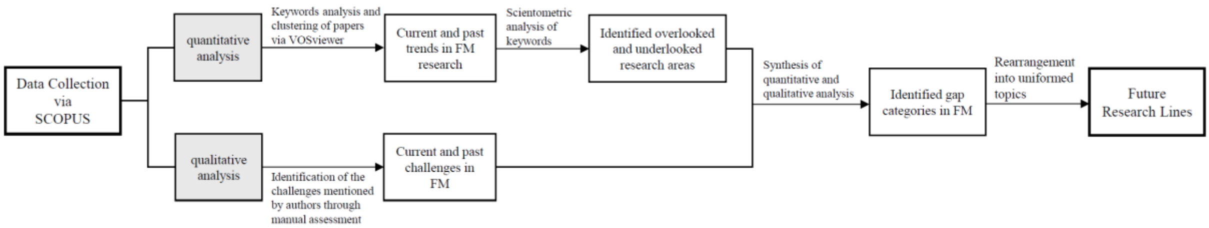

Figure 2: Overview of research methodology

Figure 2 illustrates the research methodology that integrates both quantitative and qualitative analysis to map current and future research trends in facility management. The step of integrating these two methodologies is critical as it bridges high-level statistical trends with contextual interpretations, enabling more in-depth analyses of both established and emerging areas in FM. By examining these areas from both quantitative and qualitative perspectives, this review identifies priority research topics that are both theoretically important and practically urgent. This approach not only reveals gaps, but also guides future research directions necessary to advance FM practice in real-world applications.

The quantitative analysis uses scientometric tools such as VOSviewer to analyze keyword co-occurrences and identify popular and overlooked research areas. This helps to highlight the key trends and research gaps. On the other hand, the qualitative analysis focuses on detecting and extracting challenges discussed in the literature, assessing both past and current issues in the industry. By synthesizing insights from both analyses, this approach shapes a structured path towards identifying future research lines, providing a clear direction for subsequent investigations in facility management.

3. BIBLIOMETRIC ANALYSIS AND RESULTS

Bibliometric analysis, a quantitative method for assessing research literature in the context of scientific progress, provides a comprehensive overview of a given field by bringing together various forms of information, including research impact, citation patterns, knowledge organization and research trends. Unlike manual review, bibliometric methods facilitate the identification of implicit systematic knowledge within the literature through the application of data mining techniques. In this study, it is utilized the freely available software tool, VOSviewer, for the bibliometric analysis. VOSviewer is widely recognized for its capability to construct bibliometric maps, enabling the visualization of keyword co-occurrence, bibliographic connections, and other pertinent factors through distance-based representations. Bibliographic coupling analysis and keywords co-occurrence analysis applied to a dataset comprising 143 articles. Bibliographic link analysis provides insight into the interrelatedness of research within the field by measuring reference similarity and potential links between articles. Keywords Co-occurrence Analysis identify core keywords prevalent in studies concern about the gaps and challenges of facility management for construction industry.

Additionally, a notable finding is the yearly distribution of publications, presented in Figure 3, which shows an increasing trend in research activity especially after 2016. Overall, this bibliometric analysis offers a comprehensive understanding of research trends, setting the stage for future systematic reviews and investigations into collaboration patterns, and research networks.

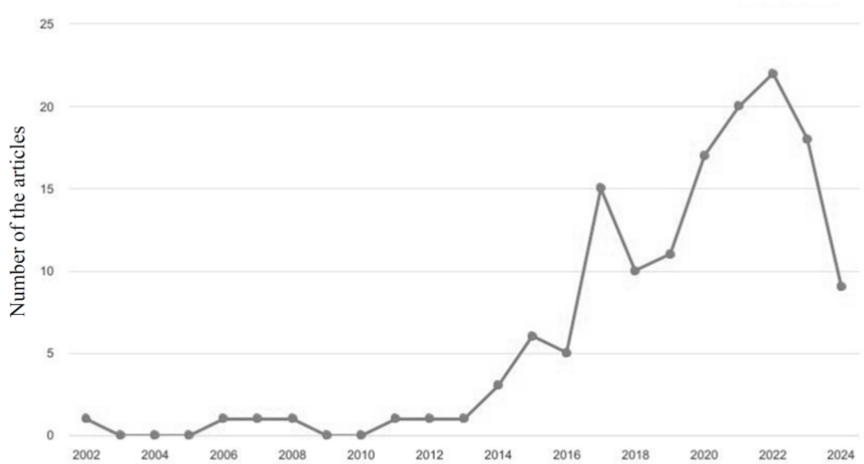

Figure 3: Distribution of the articles by year

3.1 Scientometric Analysis and Mapping Keywords

Keywords are the most essential elements in the detection of the key aspects of research (Su & Lee, 2010). A network of keywords was established in VOSviewer by using natural language processing algorithms and text mining methods to explore the relationship between them and to organize the knowledge by using clustering methods(van Eck & Waltman, 2010). Apart from author-generated keywords, some databases use “index keywords” as subject headings to avoid neglecting any keywords overlooked by authors. In this research, both author-generated and index keywords were used to perform scientometric analysis. Keyword filtering was adopted for determining the number of keywords in all the papers considered in the study. The number of times a keyword occurs in a document depicts the general scope of the paper. The number of co-occurrences, on the other hand, represents the number of occurrences of two keywords in a paper’s title, abstract, or keyword list. The co-occurrence network of keywords presented in figure 4 is a visualization map that was established by analyzing the bibliometric data. The diagram is based on a process that considers a minimum of 4 co-occurrences of keywords. A total of 60 out of 936 keywords met or exceeded the threshold of 4 co-occurrences. After excluding keywords such as “literature review” and “systematic review”, which are too generic and not relevant to the context, the data for these 55 keywords were summarized in a table (Table 1).

The keywords were clustered by using the VOS clustering technique and color-coded in Figure 4. The 5 clusters were named according to the field of study to which the keywords belong. The color of a keyword symbolizes the cluster to which it belongs.

(1) cluster 1- BIM and Data Interoperability in Construction (red coded)

(2) cluster 2- building lifecycle management (green coded)

(3) cluster 3-Facilities and Asset Management (blue coded)

(4) cluster 4-Smart/innovative Construction Technologies (yellow coded)

(5) cluster 5-Immersive Decision-Making Tools (purple coded)

The circles and labels represent the keywords in Figure 4. There are two weight attributes namely link and total link strengths. The keywords and links form a network. The relatedness of the keywords is measured by the distance between them in the network. The stronger the relationship between two keywords the closer they are placed in the network, while the weaker the relationship between two keywords the farther apart they are from each other.

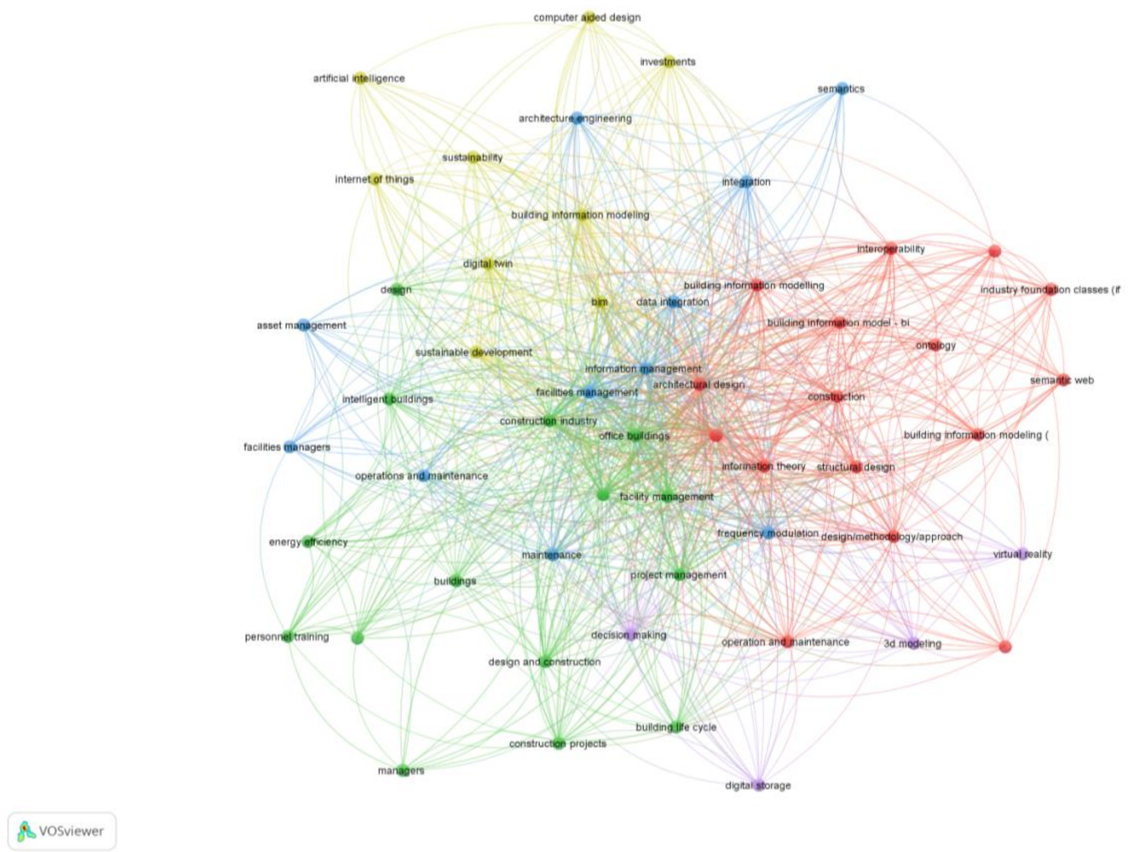

Figure 4: Map of keyword co-occurrence analysis of FM research in construction industry from 2002 to 2024 (up to August)

The five clusters are presented in Table 1 alongside their constituent keywords. The strength of a link is denoted by a positive value. The lower the strength, the weaker the link; the higher the strength, the stronger the link. The strength of a link represents the number of papers in which two keywords occur together. The meanings of the column headings in Table 1 are:

- N**umber of links** shows the number of links a keyword has with other keywords..
- **Total link strength** shows the total strength of a keyword's links to other keywords.
- **Occurrence frequency** shows the number of occurrences of a keyword in articles, which reflects the focus of the article. A high frequency of occurrence of a keyword indicates an intense focus on that particular field of research.
- **Average publication year** of articles in which a keyword appears indicates the chronology of the keyword's appearance in the relevant literature. The more recent the average publication year, the more recent the keyword and therefore the research topic (Ozturk, 2021).

Table 1: Scientometric analysis of keywords of reviewed articles

Cluster and keywords within the cluster	**Number of Links**	**Total Link Strength**	**Occurrence Frequency**	**Avg. Publication Year**
Cluster 1- BIM and Data Interoperability in Construction (Red Coded)				
architectural design	53	445	53	2019.17
building information model- bim	36	116	14	2018.86
building information modeling (bim)	24	48	9	2020.33
building information modelling	51	351	44	2020.41
building information modelling (bim)	38	85	13	2020.38
construction	37	147	20	2018.65
design/methodology/approach	32	97	12	2019.50
industry foundation classes (ifc)	22	38	4	2020.75

Cluster and keywords within the cluster	Number of Links	Total Link Strength	Occurrence Frequency	Avg. Publication Year
industry foundation classes - ifc	25	40	4	2015.25
information and communication technologies	17	26	4	2016.20
information theory	47	182	19	2019.68
interoperability	31	84	10	2019.40
ontology	26	40	4	2022.25
operation and maintenance	34	76	10	2019.60
semantic web	20	30	4	2019.00
structural design	32	68	7	2018.00
Cluster 2- Building Lifecycle Management (Green Coded)				
building life cycle	20	39	4	2020.00
buildings	23	36	5	2016.60
construction industry	50	200	30	2018.97
construction projects	24	48	6	2016.67
design	21	29	4	2015.50
design and construction	31	64	7	2018.86
energy efficiency	18	28	5	2018.80
energy utilization	20	33	5	2017.20
facility management	48	216	40	2019.38
intelligent buildings	31	56	7	2017.00
life cycle	48	218	27	2019.93
managers	14	23	4	2018.75
office buildings	54	386	52	2019.56
personnel training	22	34	5	2018.00
project management	41	148	19	2017.95
Cluster 3-Facilities and Asset Management (Blue Coded)				
architecture engineering	23	37	5	2021.20
asset management	17	27	6	2018.33
data integration	34	106	11	2020.64
facilities management	52	265	45	2020.11
facilities managers	16	26	4	2021.50
frequency modulation	34	122	13	2020.15
information management	51	300	38	2018.74
integration	32	73	9	2020.56
maintenance	33	78	9	2021.33
operations and maintenance	24	46	5	2021.20
semantics	15	32	4	2021.25
Cluster 4-Smart/Innovative Construction Technologies (Yellow Coded)				
artificial intelligence	14	16	4	2023.25
bim	42	173	30	2019.17
building information modeling	33	111	17	2021.00
computer aided design	16	23	4	2015.00
digital twin	31	102	15	2022.20
internet of things	17	33	5	2022.40
investments	21	32	4	2021.00
sustainability	22	39	6	2020.33
sustainable development	35	74	10	2020.00
Cluster 5-Immersive Decision-Making Tools (Purple Coded)				
3d modeling	23	32	4	2018.00
decision making	35	85	12	2019.67
digital storage	18	25	4	2017.50
virtual reality	14	20	4	2019.75

3.2 Number of links

A look at the number of links reveals the relatedness of a keyword to other keywords. The largest number of links occurred in the case of FM is *office buildings* (54). This was followed by *architectural design* (53), *facilities management* (52), *building information modelling* (51), and *information management* (51) in AECO-FM industry. The top keywords show that facility management practices are strongly linked to architectural design and building information modeling, which form the basis of the AECO-FM lifecycle. The high number of links to office buildings may point to the fact that this facility type is at the center of FM discussions due to its complexity and large-scale management needs. Keywords such as *sustainability* (22), *design* (21) and *energy use* (20) indicate a growing acceptance of environmental efficiency and sustainable practices in FM. However, the relatively lower number of links implies that sustainability is still at a developing stage compared to more established topics such as building information modeling or information management. Advanced technologies such as the *Internet of Things* (17) and *artificial intelligence* (14) also have fewer links, even though they are now among the key topics in the sector, suggesting that they are still gaining attention in the AECO-FM sector, but it should be noted that these topics are relatively new and recently emerging. Interestingly, the presence of *asset management* (17) and *investments* (21) highlights the moderate focus on optimizing financial and physical assets. The small number of links for *virtual reality* (14) and *computer-aided design* (16) suggests that the application of these technologies in mainstream FM may still be evolving. Therefore, future research in FM will likely need to focus on integrating sustainability, advanced technology, and smart asset management solutions to create more comprehensive and efficient facility management practices.

3.3 Total Link Strength and Occurrence Frequency

The keywords that have high total link strength and occurrence frequency are seen as the most influential in facility management (FM) research within the AECO-FM industry. According to the scientometric analysis, *architectural design* holds both the highest total link strength (445) and the highest occurrence frequency (53). This was closely followed by *office buildings* (386 total link strength and 52 occurrences), *facilities management* (265 and 45), *building information modelling (BIM)* (351 and 44), and *information management* (300 and 38). These keywords dominate the research landscape due to their importance in the design, management, and operational phases of facility management. *Architectural design* plays a foundational role, often the starting point of the building lifecycle, which explains its high total link strength. Following *BIM* closely behind, keywords like *construction industry* (200 total link strength and 30 occurrences), *facility management* (216 and 40), *life cycle* (218 and 27) and *information theory* (182 and 19) emphasize the importance of integrating digital processes and lifecycle thinking into FM practices.

In contrast, there is a noticeable gap in research focusing on *artificial intelligence* (14 and 16), *virtual reality* (14 and 20), and *computer-aided design* (16 and 23), similar to the under-researched areas of *operation and maintenance* (34 and 10) and *data integration* (34 and 11). These technologies hold promise for future FM research, particularly in terms of integrating AI and VR for predictive maintenance and immersive design solutions. The presence of *sustainability* (22 and 39), *decision making* (35 and 85), and *sustainable development* (35 and 74) within the keyword analysis reflects the promising interest of creating more environmentally responsible and data-driven facilities. This analysis shows that architectural design, office buildings and facilities management have been playing a key role in AECO-FM research for a long time. However, with new technologies such as artificial intelligence and virtual reality, sustainability will undoubtedly receive more attention in the future.

3.4 Average Publication Year

The analysis of the average publication year gives a clear view of the progress of research in the AECO-FM sector. Advanced technologies such as *artificial intelligence* (2023.25), *digital twin* (2022.20) and *internet of things* (2022.40) are emerging as new research topics, as the sector moves towards more digital and data-driven applications. At the same time, the average publication year for more established topics such as *building information modeling (BIM)* ranges around 2018-202 (since the keyword has diverse uses), indicating that BIM remains an important area of focus. The *keyword interoperability* (2019.40) also reflects the growing interest in integrating digital tools and systems into different stages of the building lifecycle. Keywords such as *architectural design* (2019.17), *construction* (2018.65) and *office buildings* (2019.56) reflect traditional research areas that remain important but mature over time. On the other hand, areas such as *semantics* (2021.25) *maintenance*

(2021.33) remain in the spotlight, with a focus on optimizing operations through technology, even though they are known to have been studied for a long time. Environmental concerns such as *sustainability* (2020.33) and *energy efficiency* (2018.80) also feature frequently in publications, indicating a focus on sustainable practices in the industry. So, while core topics such as BIM and facility management remain relevant, newer technologies such as artificial intelligence and digital twin have been emerging strongly in recent years, signaling a shift towards innovation and smarter decision-making tools.

3.5 Clusters Analysis

Cluster 1- BIM and Data Interoperability in Construction (red coded)

The integration of Building Information Modeling (BIM) into construction has launched a new era in how data is handled throughout the lifecycle of a building. The core of this cluster focuses on data interoperability, which refers to the fluid information exchange between different platforms, phases and stakeholders involved in a construction project. Especially in complex projects that require collaboration between architects, engineers and facility managers, proper data flow is critical. Architectural design is often the starting point where BIM is heavily applied to create detailed digital models that serve as the basis for the rest of the project. BIM facilitates the creation and management of these digital representations, enabling better visualization, planning and analysis. The use of Industry Foundation Classes (IFC) standards ensures that information captured in BIM models can be shared across different software tools and disciplines, maintaining consistency and accuracy throughout the project lifecycle. In the construction context, BIM is used to streamline processes such as scheduling, cost estimating and site coordination, which improves both productivity and quality. As the industry progresses, information and communication technologies (ICT) play a vital role in enabling real-time data exchange, further enhancing collaboration between stakeholders. The use of interoperability standards such as IFC helps bridge the gap between various digital systems, enabling data to be accessible and usable across platforms. Information theory and ontology contribute to structuring this data, making it easier to analyze and retrieve information when needed. Emerging technologies such as the semantic web are being explored to improve the way BIM data is categorized and linked, enabling smarter query and decision-making processes. Furthermore, the role of BIM extends to operations and maintenance, ensuring that data collected during the design and construction phases remains useful throughout the building's lifecycle, particularly in structural design and ongoing building management.

Cluster 2- Building Lifecycle Management (green coded)

Building lifecycle management encompasses all phases of a construction project, from design and construction to operation, maintenance, and eventual demolition. This holistic approach ensures that buildings are managed efficiently throughout their entire lifespan. The key focus areas in this cluster include facility management, project management, and energy efficiency, all of which are integral to maintaining and optimizing building performance across its lifecycle. Energy efficiency and energy use are critical issues in building lifecycle management, especially as sustainability becomes an industry priority. As buildings account for a significant portion of global energy consumption, optimizing energy use throughout their lifecycle can deliver significant cost savings and environmental benefits. Technologies such as smart buildings and energy-efficient systems are becoming increasingly common, providing smarter control over energy use and improving the sustainability of buildings. As life cycle management evolves, it emphasizes creating efficient, sustainable and well-maintained buildings that effectively serve both occupants and managers. As the industry rapidly advances and expands into complex areas requiring a high degree of coordination and maintenance, the training of managers and staff is also emphasized in this cluster.

Cluster 3-Facilities and Asset Management (Blue Coded)

Facilities and asset management plays an essential role in ensuring that buildings and infrastructure operate efficiently throughout their lifecycle. The focus of this cluster is to integrate the management of physical assets with building operations, facilitated by technological advances such as data integration and information management. These technologies support facility managers by providing real-time access to critical data, enabling them to make accurate decisions about asset maintenance, energy use and overall building performance. Asset management refers to the strategic coordination to optimize the value and functionality of building assets. It includes not only maintenance of equipment and infrastructure, but also planning for their future updating and replacement. This process is becoming increasingly supported by digital tools allowing the integration of data from diverse building systems, including those monitored through frequency modulation, which help to optimize energy consumption by adjusting system outputs according to real-time demand. Facility management is the comprehensive management that ensures all building systems are running efficiently. Facility managers are responsible for overseeing these systems, using advanced tools to predict when maintenance is required, and coordinating operations and maintenance (O&M) activities to prevent expensive faults. The efficient integration of these systems ensures the long-term sustainability of facilities and their assets. The most important insight from this cluster is the use of semantics and ontologies to improve the categorization and access of information. Semantic technologies standardize data across platforms, enabling better interoperability between different systems and ensuring the right information is available to support asset management and operational decisions.

Cluster 4-Smart/Innovative Construction Technologies (Yellow Coded)

This cluster focuses on the transformative impact of emerging technologies in the construction industry. Building Information Modeling (BIM) and Digital Twin technologies are pioneering by providing digital platforms to integrate design, construction and operational data. These tools improve project coordination and enable real-time monitoring, making construction processes more efficient and adaptable. Artificial Intelligence (AI) and the Internet of Things (IoT) are becoming crucial in this automation and data-driven era of decision-making. The cluster summarizes the importance of sustainability and sustainable development alongwith technological improvements in the industry. Investment in sustainable construction technologies is getting more important as the industry looks for ways to reduce its environmental impact. and promote long term sustainability.

Cluster 5-Immersive Decision-Making Tools (Purple Coded)

The insight provided by this last cluster is the use of immersive technologies to improve decision-making in the construction industry. 3D modeling and virtual reality (VR) offer interactive and visualization platforms that allow stakeholders to better understand complex design and construction elements. By simulating real-world scenarios before implementation, these tools help improve collaboration and enable more informed decision-making. Data-driven decision-making tools help reduce risks in project processes, while digital storage ensures that project data is securely protected and accessible. The integration of these technologies supports more efficient project management and improves results by enabling more comprehensive, hands-on decision-making. However, the application of immersive tools in the construction industry is relatively new and faces issues such as high costs, integration with BIM systems, lack of awareness and training needed for widespread adoption.

4. SYSTEMATIC REVIEW OF THE GAPS IN FM

While the identified research themes shed light on the structure of the facility management knowledge domain, it's important to note that bibliometric analysis alone cannot reveal research challenges or fully address emerging research needs. Therefore, a systematic review was conducted, in which academic publications were systematically categorized into distinct themes based on the mentioned gap causing the specific challenges. The categorization framework was developed through consensus-based discussions informed by quantitative techniques, including bibliometric analysis. It's important to acknowledge that bibliometric reviews have a limitation: they may not capture the significance of a small body of seminal research. Therefore, following the bibliometric analysis, also a qualitative research conducted. Each article was individually and thoroughly analyzed to identify the main challenges within the facility management field, followed by an examination of the gaps contributing to these challenges. Even though each paper has its unique challenge and research gaps mentioned, a total of 11 main gap categories were identified. These gaps are knowledge gaps, integration gaps, information gaps, interoperability gaps, education and training gaps, validation gaps, tool gaps, collaboration gaps, communication gaps, standardization gaps, and awareness gaps (Figure 5).

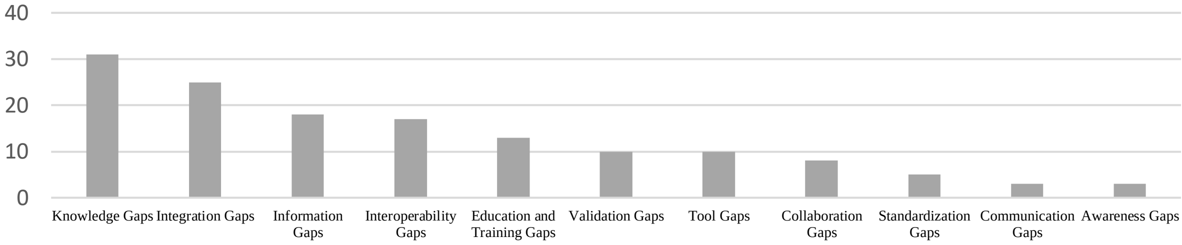

Figure 5: Gaps identified in the literature

In the following section, a chronological overview of the advances and roadblocks that the facility management industry has faced over the past 20 years is briefly presented, offering a glimpse into the comprehensive research findings. Subsequently, each identified gap is examined and discussed in detail.

4.1 Overview

Over the past two decades, Facility Management (FM) has faced significant advancements and challenges. In the early 2000s, one of the key advancements was the integration of Information and Communication Technologies (ICT) into building operations, allowing for enhanced connectivity between systems like HVAC and security (Maile & Fischer, 2007). This improved operational management by enabling better communication between systems. However, the lack of interoperability between different platforms was a major barrier, making it difficult to synchronize data and limiting the effectiveness of integrated facility management (Shen et al., 2008). Additionally, lack of adequate education among engineers and FM professionals caused challenges of the full utilization of these emerging technologies (Maile & Fischer, 2007).

In the 2010s, the adoption of Building Information Modeling (BIM) marked a critical leap forward for FM. The introduction of BIM 6D, which focuses on the operation and maintenance of facilities, allowed facility managers to improve lifecycle management, space utilization, and energy efficiency (Wang et al., 2013; Nicała & Wodyński, 2016). Despite these advances, the industry continued to face critical issues with interoperability, particularly in integration of BIM data with FM tools, leading to inefficiencies (Matarneh et al., 2019; Sani & Rahman, 2018). Lack of adequate information, or the quality of the existing information, or not knowing how to use the available information has been a constant problem in FM. Especially in BIM-enabled FM, many facility managers and industry professionals lacked the necessary knowledge and skills to effectively implement these technologies and continued to resist the adoption of innovations (Sarpin et al., 2018; Kassem et al., 2015). Moreover, building performance challenges were noted, especially regarding energy performance, persisted due to discrepancies between predicted and actual building performance (Menezes et al., 2012).

In the 2020s, the rise of Digital Twin technology alongside BIM provided a significant progress for the industry. These technologies, particularly when combined with a recent achievements in artificial intelligence (AI), have provided transformative capabilities such as real-time data visualization, predictive maintenance, and enhanced asset management (Hosamo et al., 2022; Tsay et al., 2022). By integrating real-time data from the Internet of Things (IoT), BIM, and Building Management Systems (BMS), Digital Twins have enabled a more dynamic and automated approach to facility management, resulting in notable operational efficiencies and improved asset oversight (Agostinelli, 2023; Hosamo et al., 2022).

However, persistent interoperability and collaborations problems, impede the full potential of these technologies. A major issue is the interoperability between Digital Twins and other digital platforms like BIM, as well as the limited integration of real-time data and standardized protocols (Arsiwala et al., 2023; Jia et al., 2024). This connectivity issues between BIM, IoT and BMS creates a significant barrier to efficiency by restricting the flow of data throughout the lifecycle of the facility. (Altohami et al., 2021; Slongo et al., 2022). Additionally, gaps in standardization and interoperability limit broader adoption of these advanced tools (Matarneh et al., 2022; Okonta et al., 2024). Moreover, capability challenges among professionals and workers remains a barrier for efficient FM. Research shows that many professionals lack the necessary training to effectively utilize emerging technologies, which prevents full-scale implementation and diminishes the potential gains in operational efficiency (Stride et al., 2020; Babatunde et al., 2020).

4.2 Knowledge Gaps

The review revealed that the knowledge gaps in facility management (FM) highlights a recurring challenge in implementing advanced technologies, optimizing processes, and ensuring efficient operations in the construction industry (Table 2). One key issue identified by Lai et al. (2011) is the lack of comprehensive benchmarking for performance, which hinders estate managers' ability to deliver quality services. This challenge is repeated in Kassem et al. (2015) and Hor et al. (2016), who note the gaps in implementing Building Information Modeling (BIM) in FM and the complexity of data integration between BIM and Geographic Information Systems (GIS). These technological challenges are further compounded by issues with interoperability, limited skills, and the difficulty of managing irregularly shaped building designs, as seen in studies by Lee et al. (2016) and Aziz et al. (2017). Furthermore, the knowledge gaps in green building maintainability (Chew et al., 2017) and Big Data utilization (Ahmed et al., 2017) reveal that FM organizations often lack the infrastructure, knowledge, and data management skills necessary for sustainable, data-driven operations.

Table 2: Knowledge gaps detected in the literature review

AUTHORS	PRIMARY CHALLENGE CONCERNING FM	THE GAP CAUSING THE MENTIONED CHALLENGE
(Lai, 2011)	lack of comprehensive studies on the cost-effectiveness and performance of FM services in housing estates	KNOWLEDGE GAP IN PERFORMANCE BENCHMARKING
(Kassem et al., 2015)	lack of methodologies that demonstrate the tangible benefits of BIM in FM	KNOWLEDGE GAP FOR IMPLEMENTING BIM IN FACILITY MANAGEMENT
(Hor et al., 2016)	difficulty in data sharing and exchanging	KNOWLEDGE AND INFORMATION GAP DURING DATA INTEGRATION
(Lee et al., 2016)	difficulty in integrating structural constructability with usable floor area and planning for irregular shaped buildings	KNOWLEDGE GAP FOR BIM-ENABLED FM IMPLEMENTATION
(Aziz et al., 2017)	challenge of information loss during the handover phases	KNOWLEDGE AND INFORMATION GAP DURING THE HANDOVER PROCESS
(Chew et al., 2017)	lack of integration between design intent and maintenance practices	KNOWLEDGE GAP IN GREEN BUILDING MAINTENANCE
(Ahmed et al., 2017)	lack of knowledge and skills to effectively differentiate and utilize the extensive data generated from various processes	KNOWLEDGE GAP ABOUT BIG DATA
(Edirisinghe et al., 2017)	lack of research legal and policy frameworks relative to other aspects of BIM in FM	KNOWLEDGE GAP FOR BIM-ENABLED FM IMPLEMENTATION
(Ahuja et al., 2017)	inability to identify crucial BIM capabilities	KNOWLEDGE GAP FOR BIM-ENABLED FM IMPLEMENTATION
(Tan et al., 2018)	knowledge and information gap that exists during the handover process	KNOWLEDGE AND INFORMATION GAP DURING THE HANDOVER PROCESS
(Alnaggar & Pitt, 2018)	lack of a well-structured approach to manage COBie data throughout the building lifecycle	KNOWLEDGE GAP ABOUT ROLES OF STAKEHOLDERS
(Hossain & Yeoh, 2018)	absence of BIM for existing buildings	KNOWLEDGE GAP FOR BIM-ENABLED FM IMPLEMENTATION
(Sarpin et al., 2018)	lack of understanding and skills required to effectively implement the sustainability agenda	KNOWLEDGE GAP FOR IMPLEMENTING SUSTAINABLE FM
(Bensalah et al., 2019)	lack of maturity and adaptability in implementing BIM	KNOWLEDGE GAP FOR BIM-ENABLED FACILITY MANAGEMENT IMPLEMENTATION
(Hoang et al., 2020)	the cultural approach to adopting BIM in the facility management sector, along with the lack of knowledge and experience among practitioners	KNOWLEDGE GAP FOR BIM ADOPTION
(Ali et al., 2020)	discrepancy between the expected and actual energy performance of buildings	KNOWLEDGE GAP IN OCCUPANT BEHAVIOR IMPACT ON ENERGY PERFORMANCE
(Yusoff & Brahim, 2021)	lack of knowledge and expertise regarding the implementation of BIM for heritage	KNOWLEDGE GAP FOR BIM IMPLEMENTATION
(Hobees et al., 2021)	frequent occurrence of defects, such as leaking and jointing problems, particularly in Industrialized Building System (IBS) projects	KNOWLEDGE GAP IN DEFECT MANAGEMENT
(Y. Zhang et al., 2022)	insufficient exploration of integrated interventions that consider occupant behaviors and the combined effects of various FM activities on mitigating respiratory infection transmission	KNOWLEDGE AND INTEGRATION GAP FOR HEALTH AND SAFETY MANAGEMENT
(Mewomo et al., 2022)	insufficient involvement of facility managers during the design and planning stages	KNOWLEDGE AND INTEGRATION GAPS IN FM PRACTICES
(Abideen et al., 2022)	lack of effective communication and coordination among stakeholders, coupled with insufficient awareness and demand for BIM integration in operation and maintenance (O&M) processes	KNOWLEDGE GAP BETWEEN THE PROJECT PHASES

AUTHORS	PRIMARY CHALLENGE CONCERNING FM	THE GAP CAUSING THE MENTIONED CHALLENGE
(Pinti et al., 2022)	the lack of quantitative information regarding organizational problems within FM literature, which limits meaningful analysis and comparison of research results across different studies and contexts	KNOWLEDGE GAP FOR BIM-ENABLED FM IMPLEMENTATION
(Tsay et al., 2022)	the limited understanding of how BIM can effectively support existing FM activities and the lack of clear, owner-defined information requirements	KNOWLEDGE GAP IN BIM-ENABLED FM IMPLEMENTATION
(Al-Behadili et al., 2023)	the lack of adequate information and data availability	KNOWLEDGE AND INFORMATION GAP IN BIM-ENABLED FM
(Kazeem et al., 2023)	the lack of a detailed depiction of AI and ML techniques	KNOWLEDGE GAP FOR AI AND ML IMPLEMENTATION
(Kamaruzzaman et al., 2023)	slow integration of BIM into FM practices	KNOWLEDGE GAP FOR BIM INTEGRATION IN FM
(Yilmaz et al., 2023)	lack of effective BIM utilization at the enterprise level, as companies often do not integrate BIM processes for FM	KNOWLEDGE GAP FOR BIM-ENABLED FM IMPLEMENTATION
(Hou et al., 2024)	a significant gap in the literature regarding the application of DT in heritage conservation within the context of facility management	KNOWLEDGE GAP IN DT FOR HERITAGE BUILDINGS
(Molén et al., 2023)	lack of integration of FM knowledge during the early design stages of construction projects	KNOWLEDGE GAP IN EARLY DESIGN INTEGRATION
(Baharetha et al., 2023)	lack of measures to maintain the privacy and data security of users	KNOWLEDGE GAP IN PRIVACY AND DATA SECURITY MEASURES
(Radzi et al., 2023)	lack of understanding of the relationship between DT and BIM, insufficient integration of real-time data into BIM frameworks, and the need for improved methods for addressing FM issues	KNOWLEDGE GAP FOR DT AND BIM RELATIONSHIP

Several studies also point to gaps in the adoption of BIM, particularly in specialized areas like heritage conservation and industrialized building systems (Yusoff et al., 2021; Hobees et al., 2021). Despite BIM's potential to organize processes and enhance operational efficiency, the lack of standardized processes, insufficient training, and fragmented information management continue to pose challenges (Edirisinghe et al., 2017; Ahuja et al., 2017). Similar issues are noted in the integration of COBie data, where confusion over roles and responsibilities further complicates FM practices (Alnaggar & Pitt, 2018). Cultural resistance to adopting BIM, especially in countries like Vietnam (Hoang et al., 2020), and the limited understanding of occupant behavior's impact on energy efficiency (Qadeer et al., 2020) add to the barriers preventing the full utilization of advanced technologies. Finally, emerging technologies like AI and digital twins face their own knowledge gaps, with studies by Kazeem et al. (2023) and Radzi et al. (2024) highlighting the need for improved methodologies, data integration, and real-time application frameworks to optimize FM processes across the asset lifecycle. Addressing these gaps requires a concerted effort to develop robust knowledge systems, knowledge-sharing platforms, training programs, and industry-wide standards that promote better collaboration and technological integration in FM.

4.3 Integration Gaps

The literature covering facility management (FM) in the construction industry reveals a recurring theme: the integration gap across various stages of the project lifecycle, technologies and processes (Table 3). Research consistently points to a lack of early involvement of FM professionals, particularly during the design phase, which limits opportunities to influence adaptive designs. Wang et al. (2013) and Murguia et al. (2020) highlight silo working practices that prevent valuable insights from FM teams from being integrated into early design stages, leading to higher costs and rework due to design errors. Codinhoto and Kiviniemi (2014) highlight the lack of transparency and ownership in FM processes, while Isa et al. (2017) highlight the lack of collaboration between design, construction and FM. These issues result in missing opportunities for total asset management, as shown by Smyth et al. (2017), who point to synergies lost during project phases.

Table 3:Integration gaps detected in the literature review

AUTHORS	PRIMARY CHALLENGE CONCERNING FM FOR CONSTRUCTION INDUSTRY	THE GAP CAUSING THE MENTIONE CHALLENGE
(Wang et al., 2013)	lack of involvement of facility managers in the early design stage of construction projects	INTEGRATION GAP IN FM ROLES
(Zhou et al., 2014)	need for enhanced awareness, transparency, and transition among collaborative sessions	INTEGRATION GAP BETWEEN MANAGEMENT METHODOLOGIES
(Codinhoto & Kiviniemi, 2014)	lack of integration and transparency across organizational functions	INTEGRATION GAP IN FM PROCESSES
(Smyth et al., 2017)	lack of effective integration between design and construction (DC) and operations management (OM)	INTEGRATION GAP BETWEEN PROJECT PHASES
(Isa et al., 2017)	lack of early engagement of FM during the pre-construction stage	INTEGRATION GAP BETWEEN PROJECT PHASES
(Pärn & Edwards, 2017)	difficulty in transforming raw point cloud data into semantically rich BIM models	INTEGRATION GAPS IN FM TECHNOLOGIES
(Godager, 2018)	need for better integration of Semantic Web technology in FM	INTEGRATION GAP FOR SEMANTIC WEB TECHNOLOGY IN FM
(Jin et al., 2019)	insufficient application and integration of BIM in FM	INTEGRATION GAP FOR BIM IN FM
(Murguia et al., 2020)	difficulty in incorporating valuable lessons learned from facility managers into the design stage of new construction projects due to the prevailing silo mentality and late involvement of key stakeholders	INTEGRATION GAP BETWEEN DESIGN AND FM
(Werbrouck et al., 2020)	difficulty for adjacent disciplines to become more BIM-compliant	INTEGRATION GAP IN FACILITY MANAGEMENT WITH BIM
(Altohami et al., 2021)	the fragmentation and inaccessibility of live data due to non-standardized data input and the lack of standard processes for capturing and recording building information	INTEGRATION GAP BETWEEN BIM AND IoT
(Coupry et al., 2021)	integration of BIM-based digital twins with XR (Extended Reality) technologies	INTEGRATION GAP BETWEEN BIM-BASED DIGITAL TWINS AND XR TECHNOLOGIES
(Villa et al., 2021)	limited research and application of new technologies, particularly IoT and automated sensors, during the building's service life	INTEGRATION GAP BETWEEN IoT AND FM
(Kumar & Teo, 2021)	inconsistent guidelines for asset data capture and inadequate data integration	INTEGRATION GAP FOR ASSET DATA CAPTURE
(Vukmirovic et al., 2021)	lack of FM involvement throughout the entire construction process	INTEGRATION GAP IN FM ROLE FOR CONSTRUCTION PROCESS
(Vite et al., 2021)	the underrepresentation of 6D (facility management) and 7D (sustainability) information in BIM tools	INTEGRATION GAP IN SUSTAINABILITY DATA WITHIN BIM
(Pogorelskiy & Kocsis, 2022)	the challenges associated with manual processes in the design of data centers, particularly regarding the creation of layouts and specifications	INTEGRATION GAP BETWEEN AUTOMATED DESIGN PROCESSES AND FM
(Yan, Lu, Chen, et al., 2022)	lack of integration and effective communication between existing carbon footprint estimation tools and the broader digitalization efforts within the building environment	INTEGRATION GAP BETWEEN CARBON MANAGEMENT TOOLS AND DIGITAL ENVIRONMENTS
(Wang et al., 2013)	lack of a comprehensive management mechanism to dynamically manage changes in distribution network facilities	INTEGRATION GAP BETWEEN SPATIAL AND OPERATIONAL DATA
(Wildenauer et al., 2022)	inadequate data integration and management across the lifecycle of buildings	INTEGRATION GAP IN LIFECYCLE DATA AND DIGITAL TWINS
(Ghalandar & Lindkvist, 2023)	insufficient representation and input from facility management during the earlier stages of projects	INTEGRATION GAP BETWEEN TECHNOLOGICAL SOLUTIONS AND ORGANIZATIONAL PROCESSES
(Pomè et al., 2023)	no established framework or strategy to effectively assess the sustainability performance of operation and maintenance activities	INTEGRATION GAP BETWEEN THE PROCESSSES AND TECHNOLOGY
(Hassanain & Hamida, 2023)	lack of effective integration and communication among different professionals throughout the life cycle of adaptive reuse projects	INTEGRATION GAP IN AEC/FM PRACTICES FOR ADAPTIVE REUSE PROJECTS
(Agostinelli, 2023)	difficulties in integration of real-time, high-quality data from diverse sources	INTEGRATION GAP IN REAL-TIME DATA FOR COGNITIVE DIGITAL TWIN IMPLEMENTATION
(ElArwady et al., 2024)	challenges in the construction industry related to the integration of BIM data into digital twin frameworks	INTEGRATION GAP FOR BIM DATA INTO DIGITAL TWIN FRAMEWORKS

While technological advances are promising, they are still constrained by significant integration challenges. Studies by Jin et al. (2019), Werbrouck et al. (2020) and Altohami et al. (2021) point to limited implementation of BIM in FM due to fragmentation of data and lack of compatible systems. The complexity of merging BIM data into digital twin frameworks, as investigated by ElArwady et al. (2024), further illustrates the inefficiencies caused by non-standardized data input and poor interoperability. Similarly, as noted by Villa et al. (2021) and Altohami et al. (2021), IoT technologies have yet to realize their full potential in FM due to challenges in live data management. The integration of Semantic Web technology (Godager, 2018) and XR technologies (Coupry et al., 2021) into FM still faces roadblocks, primarily due to insufficient real-time data integration and inconsistent standards across platforms.

As mentioned before, sustainability becomes an increasingly important goal, the integration of sustainability data into BIM and other FM tools is lacking. Vite et al. (2021) and Yan et al. (2022) both highlight how sustainability (6D/7D) information is underrepresented in BIM tools, hampering efforts to optimize building performance across the lifecycle. Additionally, carbon management tools face integration challenges with broader digital environments, as outlined by Yan et al. (2022). To close these gaps, several authors, including Agostinelli (2023) and Hassanain & Hamida (2023), stress the need for cohesive strategies that link innovative technologies like cognitive digital twins and predictive maintenance with standardized processes and real-time data from diverse sources. Addressing these integration gaps is essential for advancing FM practices and ensuring the efficient operation, sustainability, and adaptability of building assets throughout their lifecycle.

4.4 Information Gaps

Challenges related to knowledge gaps in facility management (FM) in the construction industry arise from a wide range of issues, from problems with data access to, again, the absence of standardized processes (Table 4). A key theme highlighted in the literature is inadequate information flow between project phases. Isa and Usmen (2015) highlight the lack of systematic methods for collecting customer feedback in university facilities and point out how this affects service quality. This need for structured feedback collection is repeated by McArthur (2015) who explores the inefficient transfer of real-time operational data between BIM models and other FM tools, making it difficult to effectively manage day-to-day activities. Similarly, Oti et al. (2016) highlight the data disconnection between early project phases and building operations, stating that better planning, design and information from the outset can greatly reduce costs and improve sustainability over a building's lifecycle.

The challenge of managing and capturing information during the handover process is another issue that appears in the review. Hosseini et al. (2018) and Kumar and Teo (2020) highlight the lack of clarity in the transfer of information between BIM and FM, which leads to gaps in data accuracy and availability and impacts FM once the building is operational. In addition, Muhammad and Mustapa (2020) state that building data is inconsistently transferred between phases, which hinders automated FM processes. Furthermore, Soliman et al. (2022) emphasize that these issues are worsened in existing buildings, where capturing relevant building data is particularly challenging. The need for accurate and real-time data is critical, which reduces the efficiency of FM, as underlined by Merino et al. (2023) who mention the difficulty of integrating different information sources into digital twins. Some authors also cite the lack of a comprehensive information infrastructure as one of the barriers to effective FM. De Silva et al. (2017) highlight the disconnect between project management (PM) and FM, pointing to gaps in stakeholder relationships and information sharing. This issue of poor communication is echoed by Dehbi et al. (2018), who focus on the difficulty of identifying the necessary information to create 3D interior models, further complicating the enrichment of BIM models. In addition, Sadeghineko & Kumar (2022) discuss the challenge of managing large-scale data in retrofit projects, highlighting interoperability problems between stakeholders and the need for an upgraded information exchange framework. These concerns are also raised by Mousharbash et al. (2022) who investigate the gaps in managing emergency strategies in BIM environments, noting that the complexity of integrating algorithms and information flow affects effective facility operations during emergencies. Moreover, emerging technologies also face information management challenges. Khan et al. (2021) highlight the lack of reliable immersive technologies for use on construction sites and call for further research to identify trends and patterns in these innovations. Öztürk (2021) similarly emphasizes the need for more research on information-based predictive management and suggests that digital twins can improve FM outcomes if these technologies are fully integrated. As Matos et al. (2023) discuss, the issues in personalizing maintenance management information for each specific case and accurately modeling the as-built conditions.

Table 4: Information gaps detected in the literature review

AUTHORS	PRIMARY CHALLENGE CONCERNING FM FOR CONSTRUCTION INDUSTRY	THE GAP CAUSING THE MENTIONED CHALLENGE
(Isa & Usmen, 2015)	lack of systematic evaluation and improvement of service quality	INFORMATION GAP FOR CUSTOMER FEEDBACK
(Zhang et al., 2015)	issue of incomplete or inaccurate documentation	INFORMATION GAP IN CONSTRUCTION DOCUMENTATION
(McArthur, 2015)	need to manage information transfer between real-time operations and monitoring systems and the BIM model	INFORMATION GAP WHILE DATA TRANSFER
(Oti et al., 2016)	the disconnection between the building operations phase and earlier phases of the project life cycle	INFORMATION GAP FOR RESEARCH VALIDATION
(De Silva et al., 2017)	disconnect between the project management (PM) phase and the facility management (FM) phase	INFORMATION GAP ABOUT THE ROLE OF FACILITY MANAGERS
(Hosseini et al., 2018)	lack of effective technical infrastructure and workable solutions for integrating BIM into FM	INFORMATION GAP IN DATA HANDOVER
(Dehbi et al., 2017)	challenges of transition from observed building data to BIM objects	INFORMATION GAP IN IDENTIFICATION OF THE REQUIRED DATA FOR THE BUILDING MODELS
(Terreno et al., 2019)	inefficiencies and variability in information management	INFORMATION GAP IN MANAGEMENT AND INTEGRATION OF BIM
(Kumar & Teo, 2020)	lack of clarity and understanding regarding the specification of information needed during the handover stage	INFORMATION GAP IN SPECIFICATION OF DATA REQUIRED FOR FM HANDOVER
(Muhammad & Mustap 2020)	lack of accurate transmission of building information from the earlier stages of a project to FM professionals	INFORMATION GAP IN THE TRANSMISSION OF BUILDING DATA BETWEEN PROJECT STAGES
(Ozturk, 2021)	need for further research and development in 'information-based predictive management' and 'virtual-based information utilization'	INFORMATION GAP BETWEEN COGNITIVE TECHNOLOGIES AND THE BIM PLATFORM FOR EFFECTIVE DECISION-MAKING
(Chung et al., 2021)	the difficulty in identifying and integrating the vast and varied information required for effective facility management from the design and construction phases into on-site applications	INFORMATION GAP IN INTEGRATING DESIGN AND CONSTRUCTION DATA
(Khan et al., 2021)	lack of robustness and reliability of immersive technologies (ImTs), such as VR, AR, and MR, for use in tough construction site conditions	INFORMATION GAP IN TRENDS AND PATTERNS
(Sadeghineko & Kumar, 202	difficulty in effectively capturing and managing large-scale data generated during the life-cycle of existing and retrofit buildings	INFORMATION AND INTEROPERABILITY GAP IN RETROFIT FACILITY MANAGEMENT
(Soliman et al., 2022)	lack of accurate and raw building data for existing structures	INFORMATION GAP IN ACCURATE DATA CAPTURE FOR EXISTING BUILDINGS
(Mousharbash et al., 2022)	the need for effective management of information flow in a BIM environment, particularly in integrating emergency management strategies with existing building systems and processes	INFORMATION GAP IN EMERGENCY MANAGEMENT STRATEGIES WITHIN BIM ENVIRONMENTS.
(Matos et al., 2023)	difficulty in personalizing maintenance management information for each specific case and accurately modeling the as-built conditions during the building use phase	INFORMATION GAP BETWEEN PROJECT PHASES AND STAKEHOLDERS
(Merino et al., 2023)	difficulty in obtaining real-time access to diverse and often siloed data from building automation systems (BAS)	INFORMATION GAP FOR REAL-TIME DATA ACCESS

This research synthesis reveals that information gaps in FM are not only technical challenges, but also reflect a broader need for better communication, data integration and stakeholder engagement throughout the project lifecycle. Addressing these gaps requires not only improved tools and systems, but also a holistic approach to managing the flow of information that enables FM to be effectively incorporated from design to operation.

4.5 Interoperability Gaps

Interoperability gaps in FM in the construction industry pose significant challenges, especially when it comes to the integration of various systems, tools and technologies (Table 5). Moum and Bock (2006) highlighted the interoperability gap in IFC-based 3D product models almost 2 decades ago, noting that the lack of integration between different systems causes data inconsistency and technical limitations. This issue was also highlighted by

Weiming Shen et al. (2008), who pointed out the difficulty of accessing timely and accurate data across construction projects due to poor interoperability. Similarly, Jallow et al. (2014) focused on the lack of centralized systems for managing client requirements, which makes change management and information flow between project phases difficult.

Table 5: Interoperability gaps detected in the literature review

AUTHORS	PRIMARY CHALLENGE CONCERNING FM FOR CONSTRUCTION INDUSTRY	THE GAP CAUSING THE MENTIONE CHALLENGE
(Moum & Bock, 2006)	the difficulty in achieving consistent information management during the building design and management process	INTEROPERABILITY GAP IN IFC-BASED 3D PRODUCT MODELS
(W. Shen et al., 2008)	lack of interoperability between hardware and software systems for facility management	INTEROPERABILITY GAP IN FM SYSTEMS
(Jallow et al., 2014)	lack of an integrated and centralized system for managing client requirements information	INTEROPERABILITY GAP BETWEEN THE SYSTEMS FOR CLIENT REQUIREMENTS
(Mondrup et al., 2015)	difficulty in ensuring successful information flow management and interoperability between software tools	INTEROPERABILITY GAP BETWEEN THE TOOLS
(Araszkiewicz, 2017)	fragmentation of information exchange throughout the facility life cycle	INTEROPERABILITY GAP BETWEEN THE SYSTEMS FOR CLIENT REQUIREMENTS
(Pärn et al., 2017)	lack of alignment in the supply and demand of semantic data	INTEROPERABILITY GAP IN SEMANTIC DATA
(Zou et al., 2018)	lack of effective interactions with building information models	INTEROPERABILITY GAP BETWEEN BIM MODELS
(Sani & Rahman, 2018)	difficulty in achieving effective data interoperability between GIS and BIM	INTEROPERABILITY GAP BETWEEN BIM AND GIS
(Matarneh et al., 2019)	poor interoperability between BIM and FM systems	INTEROPERABILITY GAP BETWEEN BIM AND FM SYSTEMS
(Ozturk, 2020)	inefficiencies in integration and collaboration	INTEROPERABILITY GAP IN BIM FOR PROJECT LIFECYCLE
(Paskaleva et al., 2021)	the need for seamless integration and interoperability among diverse data models and applications	INTEROPERABILITY GAP BETWEEN DATA MODELLING TOOLS
(Matarneh et al., 2022)	inadequate interoperability between Building Information Modeling (BIM) and Facility Management (FM) systems	INTEROPERABILITY GAP BETWEEN BIM AND FM SYSTEMS
(Slongo et al., 2022)	the lack of interoperability between BIM and GIS systems, which poses significant barriers to effective data integration and utilization for facility management	INTEROPERABILITY GAP BETWEEN BIM AND GIS SYSTEMS
(Arsiwala et al., 2023)	the limited efforts to validate and evaluate the technical aspects of implementing digital twins, as well as addressing interoperability challenges for the integration of technologies such as BIM and IoT	INTEROPERABILITY GAP BETWEEN DT TECHNOLOGIES
(Gispert et al., 2023)	lack of a comprehensive framework that effectively integrates strategic, procedural, and technological standards for the development and maintenance of an ontology-based Asset Information Model (AIM)	INTEROPERABILITY GAP IN ONTOLOGY-BASED AIM
(Okonta et al., 2024)	need for enhanced interoperability and integration of emerging technologies	INTEROPERABILITY GAP IN FM DATA
(Jia et al., 2024)	the low flexibility and scalability of data, along with limited coverage of domain ontology and incomplete automation of processes	INTEROPERABILITY GAP IN FM DATA

Several studies highlight interoperability gaps between BIM and other systems. Mondrup et al. (2015) discuss the challenges in ensuring fluid information flow between software tools, while Araszkiewicz (2017) and Pärn et al. (2017) identify fragmentation in how BIM interacts with FM tools and semantic data, further complicating decision-making and long-term management. Similarly, Zou et al. (2018) expressed concerns regarding the lack of spatial understanding when transforming BIMs into virtual environments. This theme of BIM interoperability was continued by Matarneh et al. (2019) and Ozturk (2020), both of whom highlighted interoperability inadequacies in BIM-FM systems, referring to poor data exchange processes and collaboration tools.

BIM and GIS interaction is another important issue. Sani and Rahman (2018) noted that BIM and GIS systems often face technical barriers due to different data standards, which leads to information loss and disables effective facility management. Slongo et al. (2022) added that geometric and scale differences between these systems pose significant barriers to data integration, especially when managing underground networks. This disconnect between BIM and GIS directly affects how spatial data is used in FM operations.

The integration of emerging technologies such as digital twins (DT) and IoT into FM is another area plagued with interoperability issues. Arsiwala et al. (2023) and Matarneh et al. (2022) discussed how digital twins and IoT sensors face challenges in data exchange, especially when integrating real-time data from various sources such as CoBie and BIM. Poor data consistency and lack of standards continue to limit the potential of these technologies. Jia et al. (2024) and Gispert et al. (2023) also emphasized that ontology-based models for predictive maintenance need better frameworks to improve scalability and automation. These findings together with the ones mentioned above persistent interoperability gaps in facility management resulting from inconsistent data standards, fragmented tools and a lack of holistic integration frameworks between BIM, GIS, IoT and other digital technologies. Addressing these gaps is crucial for improving data exchange, decision-making processes.

4.6 Education and Training Gaps

Table 6: Education and training gaps detected in the literature review

AUTHORS	PRIMARY CHALLENGE CONCERNING FM FOR CONSTRUCTION INDUSTRY	THE GAP CAUSING THE MENTIONED CHALLENGE
(Maile et al., 2007)	educational gap among engineers and stakeholders The vision of integrated IP-based building systems	EDUCATION GAP AMONG ENGINEERS AND STAKEHOLDERS
(Sarpin et al., 2018)	lack of necessary capabilities, skills, and sustainability knowledge among facility managers	EDUCATION AND TRAINING GAP AMONG THE FACILITY MANAGERS
(Oduyemi et al., 2018)	lack of comprehensive awareness and application of economic performance measures in life cycle costing	EDUCATION AND TRAINING GAP IN ECONOMIC PERFORMANCE MEASURES
(Stride et al., 2020)	difficulty in maintaining up-to-date model data	EDUCATION AND TRAINING GAP IN BIM UTILIZATION
(Babatunde et al., 2020)	limited integration of Building Information Modelling (BIM) with current FM systems	EDUCATION AND TRAINING GAP AMONG THE PROFESSIONALS
(Darko et al., 2020)	limited studies applying Building Information Modeling (BIM) to manage risks during the FM phase of Modular Integrated Construction (MiC) projects	EDUCATION AND TRAINING GAP AMONG THE WORKERS
(Alhamami et al., 2020)	lack of adequate skills and training in using Building Information Modelling (BIM) for energy efficiency	EDUCATION AND TRAINING GAP FOR BIM IN ENERGY EFFICIENCY
(Marocco & Garofolo, 2021)	lack of technical skills necessary to manage advanced technologies in the operational phase of facility management	EDUCATION AND TRAINING GAP
(Low et al., 2019)	gap between the soft skills that employers in the construction industry expect from graduates and the actual soft skills that these graduates currently possess	EDUCATION AND TRAINING GAP AMONG THE FUTURE GRADUATES
(Ullah et al., 2022)	the lack of systematic investigation into the specific factors affecting the adoption of BIM-based building permit processes by public regulatory authorities	EDUCATION AND TRAINING GAP
Omayer, H.M. , Selim, O.	lack of effective integration and interaction between BIM data and FM practices	EDUCATION AND TRAINING GAP IN FM-BIM INTEGRATION
(Cepa et al., 2023)	lack of BIM skills among professionals	EDUCATION AND TRAINING GAP
(Musharavati, 2023)	lack of training and education among employees	EDUCATION AND TRAINING GAP AMONG THE EMPLOYEES

The literature consistently highlights education and training deficiencies as a major barrier to effective facility management (FM) in the construction industry (Table 6). Maile et al. (2007) were among the first to identify the training gap between engineers and stakeholders, highlighting the lack of knowledge required to implement integrated IP-based building systems. This fundamental problem persists even after decades, as Sarpin et al. (2018) and Babatunde et al. (2020) found that facility managers and construction professionals lack basic skills, especially in sustainability practices and BIM adoption. This skill gap limits the industry's ability to transition to more sustainable and efficient FM practices. Several studies highlight the need for BIM-specific training. Darko et al. (2020) and Alhamami et al. (2020) arise these concerns, pointing to insufficient training in risk management and energy efficiency using BIM. Stride et al. (2020) and Cepa et al. (2023) repeat the lack of BIM skills among FM professionals, which creates challenges in maintaining up-to-date model data and BIM applications. This lack of training not only affects current employees, but also future ones, as Low et al. (2021) found that there is a gap between the soft skills that employers expect and the skills that new graduates have in Industry 4.0.

Moreover, the integration of technologies such as IoT, Lean Construction and disruptive digital tools into FM is hampered by limited training. Marocco & Garofolo (2021) highlight technical skills gaps in managing advanced technologies in FM, while Musharavati (2023) highlights the lack of training in integrated methodologies such as BIM and Lean Construction, especially in developing countries. Omayer & Selim (2022) recapitulate the need for better training in BIM-FM integration. Without continuous education and hands-on training, as suggested by Ullah et al. (2022), adoption of innovative systems such as BIM-based building permit processes and digital twins will remain slow, limiting the potential of FM to fully embrace technological advances.

4.7 Validation Gaps

Table 7:Validation gaps detected in the literature review

AUTHORS	PRIMARY CHALLENGE CONCERNING FM FOR CONSTRUCTION INDUSTRY	THE GAP CAUSING THE MENTIONED CHALLENGE
(Menezes et al., 2012)	lack of feedback to designers regarding the actual energy performance of buildings post-occupancy	VALIDATION GAP FOR PROJECT INFORMATION
(Jing et al., 2019)	significant inconsistency in the application of BIM between the design and construction stages compared to the operation and maintenance stage	VALIDATION GAP FOR PROJECT INFORMATION
(Collins et al., 2018)	lack of integration and consideration of sustainable facility management (SFM) practices during the early stages of building design	VALIDATION GAP IN ENERGY PERFORMANCE
(Chen & Tang, 2019)	lack of efficient methods and techniques for building maintenance management	VALIDATION GAP BETWEEN THEORITICAL AND PRACTICAL DATA
(Rasmussen et al., 2019)	insufficient transfer of operational knowledge from facility management to the design phase	VALIDATION GAP IN PERFORMANCE
(Zhu et al., 2019)	insufficient consideration of end users during the building handover process	VALIDATION GAP BETWEEN AS-DESIGN AND AS-BUILT PERFORMANCE
(Tamošaitienė et al., 2021)	lack of prioritization and systematic evaluation of appropriate repair and maintenance (R&M) methods for commercial buildings in developing countries	VALIDATION GAP IN REPAIR&MAINTENANCE CRITERIA.
(Ensafi & Thabet, 2021)	the mismatch between the information typically included in design and construction models and the actual data needed for effective facility management	VALIDATION GAP BETWEEN DESIGN AND MANAGEMENT DATA
(Pomè et al., 2023)	complexity in evaluating the return on investment for Digital Twin technology in operation and maintenance management	VALIDATION GAP IN RETURN ON INVESTMENT FOR DIGITAL TWIN TECHNOLOGY
(Egwim et al., 2024)	the low accuracy of AI technologies due to a scarcity of available data	VALIDATION GAP IN FM DATA

The literature on validation gaps in FM reveals challenges related to the inconsistency between theoretical models and practical applications, poor data accuracy, and poor knowledge transfer (Table 7). Menezes et al. (2012) emphasized the validation gap in energy performance by highlighting the discrepancy between predicted and actual energy consumption in non-domestic buildings, stressing the need for post-occupancy evaluations. Similarly, Collins et al. (2018) pointed out the inconsistency in integrating sustainable FM practices during the early design phases, leading to performance gaps between FM and sustainable building goals. Several studies focus on the conflicts between theoretical knowledge and operational practices such as Chen & Tang (2019) and Jing et al. (2018). Thabet et al. (2022) identified mismatches between design and management data. The building handover process also faces significant validation challenges. Zhu et al. (2021) found that the gap between as-designed and as-built performance creates poor information fidelity, complicating the handover process and reducing operational efficiency. Rasmussen et al. (2019) emphasized that knowledge transfer from FM to design is crucial for closing the gap between expected and actual building performance. More recent studies, like Pomè & Signorini (2023), explored the complexity of validating Digital Twin technologies in the operation and maintenance phases, pointing to difficulties in evaluating return on investment and collecting necessary data for implementation. Egwim et al. (2024) raised concerns about the low accuracy of AI technologies due to limited data and the lack of transparency in AI-driven decision-making processes in FM. Overall, validation gaps affects FM processes, from energy performance to data accuracy in new technologies like Digital Twins and AI.

4.8 Tool Gaps

Lack of specialized software tools and technological solutions designed for FM tasks is another gap in construction industry (Table 8). Azhar et al. (2015) identified lack of dedicated applications for facility managers during the operation and maintenance phase. Another example, Bazán et al. (2020) and Yin et al. (2020) emphasized the absence of specialized BIM tools for infrastructure management and utility tunnels, which limits the application of BIM in these specific sectors. Boyle & Michell (2017) and Asmone & Chew (2018) discussed the need for better tools to integrate sustainability and green maintenance practices into FM, especially in the early design stages. Neuville et al. (2019) highlighted a similar gap in visualization techniques where dense 3D spatial information in BIM models makes decision-making for FM tasks difficult.

Table 8: Tool gaps detected in the literature review

AUTHORS	PRIMARY CHALLENGE CONCERNING FM FOR CONSTRUCTION INDUSTRY	THE GAP CAUSING THE MENTIONED CHALLENGE
(Azhar et al., 2015)	lack of mobile apps available for facility managers to use during the operation and maintenance phase of a project	TOOL GAP FOR FACILITY MANAGERS
(Boyle & Michell, 2017)	inadequacy of prescriptive and outcomes-based assessment tools to accommodate the institutional and social imperatives of urban sustainability	TOOL GAP FOR SUSTAINABILITY ASSESSMENT
(Kim & Heo, 2017)	inability of the current 2D cadastral system to adequately register and manage the legal and administrative statuses of 3D underground parcels	TOOL GAP IN INFORMATION TECHNOLOGIES
(Asmone & Chew, 2018)	lack of tools to incorporate green maintenance or maintainability considerations at the early design stages	TOOL GAP IN INTEGRATING GREEN MAINTENANCE PRACTICES
(Neuville et al., 2019)	lack of effective automation and suitable management of 3D viewpoint	TOOL GAP IN VISUALIZATION TECHNIQUES FOR FM
(Moreno Bazán et al., 2020)	lack of specialized software that can effectively utilize BIM models for infrastructure management and maintenance	TOOL GAP FOR BIM IN THE MANAGEMENT AND MAINTENANCE OF INFRASTRUCTURE
(Wu & Lepech, 2020)	lack of accessible interfaces that connect BI) software with fundamental durability models	TOOL GAP FOR LIFECYCLE MANAGEMENT OF DURABILITY PERFORMANCE
(Yin et al., 2020)	lack of effective application of BIM in the O&M activities of utility tunnels	TOOL GAP IN INFORMATION TECHNOLOGIES
(Zhao et al., 2022)	lack of effective information management frameworks and comprehensive research and innovation	TOOL GAP FOR REAL-TIME DATA VISUALIZATION
(Awosode et al., 2024)	The low level of automation adoption in facility management activities within the Nigerian construction industry	TOOL GAP IN AUTOMATION ADOPTION FOR FM

Awosode et al. (2024) pointed out the low adoption of automation in FM, especially in high-rise buildings, while Zhao et al. (2022) emphasized the need for visualization tools for digital twin technologies. Both studies stressed that without the right tools for real-time data visualization and automation, FM struggles to optimize building performance and service delivery. Lastly, Wu & Lepech (2020) identified the absence of life-cycle management tools for building durability models. These reviews are strong proofs in tool gaps in FM, ranging from BIM integration and sustainability tools to real-time automation and visualization technologies, all of which are crucial for FM practices and achieving long-term efficiency.

4.9 Collaboration Gaps

Collaboration gaps in FM are an important issue affecting the integration of various systems, disciplines and stakeholders (Table 9). As a pioneer, Mervi (2002) identified the disconnect between scientific research and practical industry needs and emphasized the need for better collaboration between scientists and industry players to bridge this gap. Liang et al. (2020), mentioned poor coordination between decision makers leading to planning problems and operational inefficiencies, especially in environmental and site management. Likewise, Yan et al. (2022), Sedhom et al. (2022) and Lindkvist et al. (2022) recently identified gaps in collaboration between stakeholders, particularly in managing shared data environments and integrating FM practices between project phases. Additionally, Dossick et al. (2023) discussed how the changing time orientations between FM, IT, and capital projects lead to conflicts when implementing IoT systems, emphasizing the need for interdisciplinary collaboration to overcome these differences and effectively manage shared resources.

On a more technical level, Wen et al. (2021) and Mehedi & Shochchho (2021) focused on the collaboration gaps caused by BIM models and FM systems. Both studies highlighted the delayed knowledge transfer and lack of robust frameworks that decrease effective FM operations for building life cycle. Without proper data synchronization and stakeholder engagement, these gaps result in poor decision-making and underutilization of digital technologies such as Digital Twins. Adressing these gaps in future research is vital for the better coordinated FM between diverse stakeholders and diverse projects.

Table 9:Collaboration gaps detected in the literature review

AUTHORS	PRIMARY CHALLENGE CONCERNING FM FOR CONSTRUCTION INDUSTRY	THE GAP CAUSING THE MENTIONED CHALLENGE
(Mervi, 2002)	disconnection between scientific information and the practical information needs of the construction industry.	COLLABORATION GAP BETWEEN SCIENTIFIC AND PRACTICAL INFORMATION
(Liang et al., 2020)	challenges such as poor planning, lack of consensus among decision-makers, and inadequate coordination between government authorities and businesses	COLLABORATION GAP AMONG DECISION MAKERS
(Wen et al., 2021)	delayed information updates of FM systems in hospital projects	COLLABORATION GAP BETWEEN BIM MODELS AND FM SYSTEMS
(Mehedi & Shochchho, 2021)	insufficient collaboration among different parties and inadequate management of information throughout the building asset lifecycle	COLLABORATION GAP BETWEEN STAKEHOLDERS
(Yan, Lu, Fang, et al., 2022)	difficulty in constructing and providing a shared data environment that allows all stakeholders to collaborate effectively throughout the lifecycle of dynamic DT	COLLABORATION GAP AMONG STAKEHOLDERS
(Sedhom et al., 2023)	lack of a clear framework for stakeholder participation	COLLABORATION GAP BETWEEN STAKEHOLDERS
(Lindkvist et al., 2022)	inadequate integration and communication of data between project phases and facility management	COLLABORATION GAP BETWEEN STAKEHOLDERS
(Dossick et al., 2015)	challenges arising from differing time orientations and priorities among FM, IT, and capital projects, which complicates the effective integration of IoT systems	COLLABORATION GAP

4.10 Standardization Gaps

While standardization gaps in the industry are indeed at the root of many other problems, this issue has also been explicitly addressed separately in the literature (Table 10). Jang & Collinge (2020) and Godager et al. (2021) highlighted that the lack of detailed BIM standards leads to inconsistent information management and poor stakeholder coordination. Hosamo et al. (2022) noted the lack of standardized processes for the Digital Twin, which affects its use in predictive maintenance and design. Hmidah et al. (2022) highlighted that existing standards such as IFC are insufficient to optimize the integration of BIM with Building Management Systems (BMS). Furthermore, Gharaibeh et al. (2024) pointed out the lack of methods to assess BIM ROI, complicating investment justifications and limiting project efficiency.

Table 10: Standardization gaps detected in the literature review

AUTHORS	PRIMARY CHALLENGE CONCERNING FM FOR CONSTRUCTION INDUSTRY	THE GAP CAUSING THE MENTIONI CHALLENGE
(Jang & Collinge, 2020)	deficiencies in BIM regulations and standards, along with unclear information requirements and software interoperability issues	STANDARDIZATION GAP IN BIM-I INTEGRATION
(Godager et al., 2021)	integrating Building Information Modeling (BIM) into the operation and maintenance phases	STANDARDIZATION GAP FOR B IMPLEMENTATION
(Hosamo et al., 2022)	need for information standardization to effectively realize the use of Digital Twin technology in the AEC-FM sector	STANDARDIZATION GAP
(Hmidah et al., 2022)	limited integration of Building Information Modeling (BIM) with Building Management Systems (BMS)	STANDARDIZATION GAP IN BIM AND BI INTEGRATION
(Gharaibeh et al., 2024)	lack of an industry-established method for quantifying and benchmarking the BIM investment value	STANDARDIZATION GAP IN BIM R ASSESSMENT

Closing standardization gaps in FM requires clear and practical standards that allow better integration of technologies such as BIM and Digital Twin. By establishing industry-wide guidelines, the full potential of digital tools can be realized, leading to smarter operations and improved efficiency in the FM sector.

4.11 Communication Gap

The literature review has revealed that many of the issues mentioned above hinder communication among industry collaborators (Table 11). To clearly restate this, Nical et al. (2016) argued that poor information management across the building asset lifecycle leads to weak communication among industry actors, while Hilal et al. (2019) claimed that the lack of clear conceptual frameworks prevents effective communication between stakeholders. Similarly, Ventura et al. (2020) found communication problems in teams during design review meetings and emphasized the need for effective VR implementations to address this. It is an undeniable fact that FM is a discipline carried out by professionals from various fields. If the parties fail to communicate effectively for any reason, it will lead to poor decision-making. Therefore, the correct standards must be applied, and necessary implementations should be made to fix communication gaps in the industry.

Table 11:Communication gaps detected in the literature review

AUTHORS	PRIMARY CHALLENGE CONCERNING FM FOR CONSTRUCTION INDUSTRY	THE GAP CAUSING THE MENTIONE CHALLENGE
(Nical & Wodynski, 2016)	inefficiencies in information management across the building asset lifecycle and the lack of a collaborative attitude among industry actors	COMMUNICATION GAP BETWEEN STAKEHOLDERS
(Hilal et al., 2019)	lack of a clear conceptual framework to guide research on the key factors influencing the acceptance and adoption of BIM in the FM phase	COMMUNICATION GAP BETWEEN STAKEHOLDERS
(Ventura et al., 2020)	absence of structured guidelines for the effective implementation of VR in design review meetings	COMMUNICATION GAP BETWEEN STAKEHOLDERS

4.12 Awareness Gaps

Awareness gaps in facility management (FM) are not extensively covered in the literature, with only a few studies addressing the issue (Table 12). Lau et al. (2016) identified a limited awareness of disability inclusion, while Salleh et al. (2021) noted challenges in sustainable FM practices, particularly in elderly care environments. Glema (2017) emphasized resistance to digital technologies like BIM, largely due to traditional mindsets. Although these gaps are not prominently discussed, they still exist and present significant challenges. Addressing these awareness gaps is essential to advancing inclusivity, sustainability, and digital innovation in FM, as they hinder the industry's ability to fully realize its potential.

Table 12: Awareness gaps detected in the literature review

AUTHORS	PRIMARY CHALLENGE CONCERNING FM FOR CONSTRUCTION INDUSTRY	THE GAP CAUSING THE MENTIONE CHALLENGE
(Lau et al., 2016)	lack of a comprehensive and objective assessment for evaluating disability inclusiveness in buildings	AWARENESS GAP BETWEEN THE PRACTICIONERS FOR DETECTING USER NEEDS
(Salleh et al., 2021)	the need for a strategic transformation that integrates sustainable practices and effective management approaches	AWARENESS GAP FOR SUSTAINABLE FM PRACTICES
(Glema, 2017)	challenge of traditional inertia and resistance to adopting digital technologies	AWARENESS GAP IN BIM TECHNOLOGIES

4.13 Analysis of the Detected Gaps

Below is a summary of the research findings. This summary identifies the main emerging themes, recent findings and ongoing research challenges and opportunities. In addition, in the table below, the extent to which progress has been made on identified gaps over the years is indicated as partial/significant progress. These findings have led to recommendations for future research directions in the next section.

Table 13: Summary of the research findings

Gap Category	Summary of Current Situation Based on Reviewed Literature	Progress Level
Knowledge Gaps	Structured knowledge-transfer systems, maturity models, and scientometric analyses have greatly improved organizational FM knowledge (Jin et al., 2019; Khan et al., 2021; Yilmaz et al., 2023). However, know-how and knowledge integration issues among professionals persist in technologies like AI and digital twins (Kazeem et al., 2023; Radzi et al., 2023)	Partial Progress
Integration Gaps	BIM, IoT, Digital Twin, and technology integrations have advanced significantly through federated data models to unify FM information across multiple systems (Merino et al., 2023), yet practical challenges remain in integration processes such as real-time data integration full lifecycle integration because of inconsistent standards (Hassanain & Hamida, 2023; Villa et al., 2021)	Partial Progress
Information Gaps	Development of standardized typology matrices and ontology-based asset information models have enhanced information exchange (Gispert et al., 2023; Hosseini et al., 2018), though gaps remain in consistent data implementation (Merino et al., 2023)	Partial Progress
Interoperability Gaps	IFC standards, semantic web ontologies, and federated data models have markedly improved interoperability across BIM, GIS, IoT, and digital platforms (Hor et al., 2016; Khan et al., 2021), though issues on cross-platform consistency (Ozturk, 2020) and low flexibility and scalability of data interoperability required for automation remains a challenge (Jia et al., 2024)	Significant Progress
Education & Training Gaps	BIM and FM-specific training programs aligned with Industry 4.0 show notable growth (Low et al., 2019), but skill gaps and the need for continuous education persist industry-wide (Alhamami et al., 2020; Cepa et al., 2023; Musharavati, 2023)	Partial Progress
Validation Gaps	Recent developments in Digital Twins combined with machine learning and POE techniques have notably improved real-time validation of building performance in years (Arsiwala et al., 2023; Menezes et al., 2012); however, challenges in practical scalability and data accuracy remain unresolved (Pomè & Signorini, 2023)	Partial Progress
Tool Gaps	Advanced Digital Twin platforms, XR devices, BIM integrations, and Lean methodologies have notably enhanced predictive maintenance and operational efficiency by years (Coupry et al., 2021; Nical & Wodynski, 2016). Still, lack of effective information management framework limit tool accessibility and affordability (Zhao et al., 2022)	Significant Progress
Collaboration Gaps	Recent advancements in 6D BIM integration, AI-powered predictions, and ontology-based data standardization have significantly improved FM collaboration (Baharetha et al., 2023; Cepa et al., 2023; Gispert et al., 2023), but persistent issues such as data interoperability (Gispert et al., 2023) or lack of integration between design, construction, and FM teams (Hassanain & Hamida, 2023) still effects efficient collaboration	Partial Progress
Standardization Gaps	Progress in BIM-driven typology matrices and standardized ontologies (IFC, COBie) in years improved lifecycle consistency (Alnaggar & Pitt, 2018; Jia et al., 2024). Nevertheless, universal standard adoption and enforcement (Khan et al., 2021) and established methodologies for benchmarking gaps remains in the industry (Gharaibeh et al., 2024).	Partial Progress
Communication Gaps	Semantic web technologies and digital communication frameworks have enhanced clarity and efficiency (Godager, 2018; Lindkvist et al., 2022). However, communication between disciplines and stakeholder engagement in digital environments continues to face challenges (Ventura et al., 2020)	Partial Progress
Awareness Gaps	Even though awareness levels across sector is not in satisfactory level (Salleh et al., 2021), the sustainability-driven FM through digital tools and maturity models help organizations assess and improve their BIM awareness and implementation (Pomè et al., 2023; Yilmaz et al., 2023)	Significant Progress

5. SYNTHESIS OF FINDINGS AND SUGGESTIONS FOR FUTURE RESEARCH LINES

The synthesis presented in this section reflects the integration of both bibliometric and systematic review findings, which together provide a comprehensive view of the research landscape in facility management within the construction industry. This combined approach (Table 2) allows for a nuanced understanding where quantitative insights from bibliometric analysis (highlighting keyword trends and research focus areas) complement the in-depth qualitative insights gained through systematic review, which explores specific research gaps and practical challenges in the field.

This combination of bibliometric analysis and systematic review provide important insights into the current state of research in construction industry, revealing both overlooked and underlooked areas that require urgent attention. The bibliometric analysis using VOSviewer highlighted important research focuses on architectural design, office buildings and building information modelling (BIM), which are at the center of the field. However, some key topics remain underlooked. For example, the analysis revealed relatively few attention to emerging technologies such as virtual reality (VR) and the Internet of Things (IoT), despite their potential to revolutionize facility management practices. Additionally, artificial intelligence (AI) is one of the areas that has not yet been studied much but according to the authors of this review, the main reason of this gap is that the topic of AI is just starting to come to the fore. The low frequency and link strength of these keywords suggest that, although these technologies are considered important, they are still in the early stages of research and adoption. Since these technologies are critical for intelligent and predictive facility management, research is urgently needed to fully integrate them into practice.

The systematic review adds these findings by identifying several gaps in areas such as information management, interoperability, training, validation, and collaboration so on. One of the most urgent matter mentioned in literature is the knowledge gap in effectively implementing BIM and Digital Twin technologies in facility management as it was discussed earlier in detail. The reviewed research point to insufficient training and a lack of clear frameworks for integrating necessary tools into daily FM operations. Another area that requires further research is the interoperability gaps between BIM, IoT and Building Management Systems (BMS), as advances in this area affect the overall performance of the industry.

The synthesis also points to sustainability and energy efficiency as emerging but still disregarded areas. Although sustainability-related keywords appear frequently in the analysis, the systematic review identified gaps in integrating sustainability data into BIM tools and the lack of concrete methodologies for energy management and sustainable construction. These topics demand immediate research focus as sustainability is increasingly becoming a priority across industries.

Addressing these issues, especially the underlooked areas, such as sustainability integration, knowledge management, interoperability improvements, and training gaps is essential for optimizing operational efficiency and supporting industry-wide optimization. The following sections will propose future research directions aimed at closing these gaps, with a focus on advancing facility management practices to provide better efficiency and effectiveness in construction and operational management.

5.1 Leveraging Knowledge Management for Enhanced Information Quality

Improving information quality is crucial for facility management (FM) in the construction industry, where data volume and complexity require solid knowledge management systems. Research shows that knowledge gaps, especially in data transfer and integration, cause problems in decision-making and operational efficiency (Isa and Usmen, 2015; Oti et al., 2016). Future research should focus on utilizing knowledge management systems (KMS) to facilitate the collection, storage and dissemination of information across project phases. This includes the development of BIM-enabled FM to facilitate data accuracy, integration and information sharing during the building life cycle (Kassem et al., 2015; Edirisinghe et al., 2017). Furthermore, the application of machine learning methods and getting support from artificial intelligence (AI) can help optimize knowledge transfer by estimating knowledge needs and improving data relevance in FM operations (Egwim et al., 2024). By giving more focus in knowledge management, facility managers can improve decision-making processes, reduce information silos, and ensure that critical information is stored and accessed by all the industry actors over the building lifecycle (Ahmed et al., 2017; Radzi et al., 2024).

5.2 Fostering Seamless Data Integration and Interoperability in Facility Management

As the bibliometric research and systematic review reveal, data integration and interoperability remain key challenges in FM, especially with the increasing adoption of BIM, IoT and Digital Twin technologies (Matarneh et al., 2019; Altohami et al., 2021). These challenges leading to inefficiencies and misalignment (Mervi, 2002; Hossain and Yeoh, 2018; Zhu et al., 2019; Matarneh et al., 2022). Despite widespread adoption of BIM in design (Yilmaz et al., 2023), its limited application in FM requires more research into standardized processes for effective data usage throughout the facility lifecycle. Therefore, future research should focus on developing standardized protocols and frameworks that allow integration of data from diverse sources and enable fluent interaction between platforms (Zou et al., 2018). Addressing interoperability issues between BIM and GIS, as well as BIM and IoT, will be crucial in improving real-time decision-making capabilities of facility managers (Slongo et al., 2022). By enabling enhanced interoperability, FM can achieve a more holistic, data-driven approach and improve operational efficiency and management of building assets (Godager et al., 2021; Jia et al., 2024).

5.3 Sustainable Facility Management Strategies through Data-Driven Decision Support

Su stainability is a growing concern within the construction industry, yet sustainable development practices are underrepresented in existing BIM tools (Vite et al., 2021). The integration of sustainability and data-driven decision support systems offers a path towards more environmentally responsible facility management. Moreover, as highlighted earlier in Section 3.2, the bibliometric analysis showed limited research activity surrounding advanced technologies like AI and IoT. This aligns with the systematic review findings in Section 4.3, which suggest a critical need for further exploration of these technologies to enhance predictive maintenance and data-driven decision-making in facility management. Therefore, future research should explore how predictive analytics driven by real-time data from BIM, IoT and Digital Twins can be used to optimize energy efficiency, resource management and life cycle costs (Pomè & Signorini, 2023). Furthermore, addressing the sustainability data gap in BIM frameworks will be vital for aligning facility operations with green building standards and improving building performance (Yan et al., 2022). By improving sustainable facility management through data-driven decision making, FM practitioners can increase operational efficiency while minimizing environmental impacts (Altohami et al., 2021).

5.4 Immersive Learning Environments and Collaborative Learning Platforms

Addressing the educational challenges noted by Maiale (2007) more than a decade ago, recent research from Low et al. (2019) and Alhamami et al. (2020) about training and education area are revealing insights in several dimensions. The bibliometric analysis highlights 'immersive technologies' in Cluster 5 as a relatively new and underexplored area in FM research. The systematic review in Section 4.6 further elaborates that while these technologies hold promise for interactive learning and real-time collaboration, practical applications and comprehensive training frameworks remain limited. As immersive technologies such as Virtual Reality (VR) and 3D modeling continue to arise and evolve, new opportunities for collaborative learning and decision-making in FM are opening up. These tools enable stakeholders to interact even in virtual environments for improving design skills and operational planning (Khan et al., 2021; Ozturk, 2021). Future research should explore the development of immersive learning platforms that integrate BIM with VR to facilitate training, simulate real-world scenarios, and foster interdisciplinary collaboration (Ventura et al., 2020). Furthermore, using these platforms for collaborative learning can help bridge training gaps by educating facility managers and operators on advanced technologies in more interactive approach and ensure that FM teams are better equipped to manage complex building systems (Maile et al., 2007; Babatunde et al., 2020). Thus, further research and practice on immersive platforms can play a critical role in improving knowledge transfer and increasing collaboration within FM.

6. CONCLUSION

Facility Management (FM) is a multidisciplinary approach that plays a pivotal role in ensuring the functionality of the built environment. It encompasses the integration of people, place, process, and technology to achieve organizational objectives. This research has provided an in-depth exploration of the current landscape in facility management (FM), focusing on the challenges and opportunities for future development in construction industry. Through the integration of bibliometric and systematic review methodologies, the study has identified critical research gaps, and technological challenges that have shaped the field over the past two decades.

The bibliometric analysis has revealed key themes dominating FM research, such as BIM integration, data interoperability, energy efficiency, and sustainability. The scientometric mapping of keywords further showed the significance of tools like BIM, AI, and digital twins, which are increasingly gaining momentum as the industry moves towards more data-driven, real-time operational strategies.

From the systematic review, the study has also uncovered 11 substantial gaps in knowledge, integration, information, interoperability, education and training, validation, tools, collaboration, standardization, communication, and awareness that impede the full-scale implementation of FM innovations. Persistent issues like poor data exchange between BIM and FM systems, inadequate involvement of FM professionals in the early design stages, and the lack of training on emerging technologies reflect the need for more cohesive and standardized frameworks. Moreover, the interoperability of FM systems with other digital platforms, such as GIS and IoT, remains a significant barrier, as fragmented processes and inconsistent data inputs limit the effective utilization of real-time data.

This synthesis of quantitative and qualitative insights has important implications for future research. By conducting this review, the future lines are detected as leveraging knowledge management for enhanced information quality, fostering data integration and interoperability in facility management, sustainable facility management strategies through data-driven decision support, immersive learning environments and collaborative learning platforms. There is an urgent need for more research focusing on improving the quality of information between FM tools and stakeholders, integrating more technological aspects in FM processes, exploring their potential for predictive maintenance and asset optimization. Furthermore, the sustainability agenda in FM requires greater attention, particularly in embedding energy-efficient and green maintenance practices across the building lifecycle.

In conclusion, the future of FM lies in its ability to embrace technological innovation while overcoming integration hurdles. By developing standardized methodologies, enhancing collaborative efforts, and adopting a culture of continuous learning within the industry, FM can evolve into a more proactive and efficient discipline. The insights gained from this research provide a robust foundation for guiding both academic inquiry and practical application, shaping the future trajectory of facility management in an increasingly digitalized and environmentally conscious world.

REFERENCES

Abideen, D. K., Yunusa-Kaltungo, A., Manu, P., & Cheung, C. (2022). A Systematic Review of the Extent to Which BIM Is Integrated into Operation and Maintenance. *Sustainability*, *14*(14), Article 14. https://doi.org/10.3390/su14148692

Agostinelli, S. (2023). COGNIBUILD: Cognitive Digital Twin Framework for Advanced Building Management and Predictive Maintenance. *Urban Book Series*, *Part F813*, 69–78. Scopus. https://doi.org/10.1007/978-3-031-29515-7_8

Ahmed, V., Tezel, A., Aziz, Z., & Sibley, M. (2017). The future of Big Data in facilities management: Opportunities and challenges. *Facilities*, *35*(13–14), 725–745. Scopus. https://doi.org/10.1108/F-06-2016-0064

Ahuja, R., Sawhney, A., & Arif, M. (2017). *Prioritizing BIM Capabilities of an Organization: An Interpretive Structural Modeling Analysis*. *196*, 2–10. Scopus. https://doi.org/10.1016/j.proeng.2017.07.166

Al-Behadili, K. A., Ali, Y. M., & Asser, E. (2023). *Using BIM for building maintenance management in Iraq*. *402*. Scopus. https://doi.org/10.1051/e3sconf/202340207007

Alhamami, A., Petri, I., Rezgui, Y., & Kubicki, S. (2020). Promoting Energy Efficiency in the Built Environment through Adapted BIM Training and Education. *Energies*, *13*(9), Article 9. https://doi.org/10.3390/en13092308

Ali, Q., Thaheem, M. J., Ullah, F., & Sepasgozar, S. M. E. (2020). The Performance Gap in Energy-Efficient Office Buildings: How the Occupants Can Help? *Energies*, *13*(6), Article 6. https://doi.org/10.3390/en13061480

Alnaggar, A., & Pitt, M. (2018). Towards a conceptual framework to manage BIM/COBie asset data using a standard project management methodology. *Journal of Facilities Management*, *17*(2), 175–187. https://doi.org/10.1108/JFM-03-2018-0015

Altohami, A. B. A., Haron, N. A., Alias, A. H. A., & Law, T. H. (2021). Investigating Approaches of Integrating BIM, IoT, and Facility Management for Renovating Existing Buildings: A Review. *SUSTAINABILITY*, *13*(7), 3930. https://doi.org/10.3390/su13073930

Araszkiewicz, K. (2017). Digital technologies in Facility Management—The state of practice and research challenges. In M. Hajdu & M. E. Skibniewski (Eds.), *CREATIVE CONSTRUCTION CONFERENCE 2017, CCC 2017* (Vol. 196, pp. 1034–1042). Elsevier Science Bv. https://doi.org/10.1016/j.proeng.2017.08.059

Arsiwala, A., Elghaish, F., & Zoher, M. (2023). Digital twin with Machine learning for predictive monitoring of CO2 equivalent from existing buildings. *ENERGY AND BUILDINGS*, *284*, 112851. https://doi.org/10.1016/j.enbuild.2023.112851

Asmone, A. S., & Chew, M. Y. L. (2018). Merging building maintainability and sustainability assessment: A multicriteria decision making approach. *IOP Conference Series: Earth and Environmental Science*, *117*(1), 012029. https://doi.org/10.1088/1755-1315/117/1/012029

Awosode, O. S., Ebiloma, D. O., Ajayi, C. A., Aigbavboa, C. O., & Akinradewo, O. (2024). The Relevance of Automation in the Facility Management of Selected High-Rise Buildings in Lagos, Nigeria. *Buildings*, *14*(1), Article 1. https://doi.org/10.3390/buildings14010016

Azhar, S., Jackson, A., & Sattineni, A. (2015). Construction Apps: A Critical Review and Analysis. *ISARC Proceedings*, 1–7.

Aziz, Z., Riaz, Z., & Arslan, M. (2017). Leveraging BIM and Big Data to deliver well maintained highways. *Facilities*, *35*(13/14), 818–832. https://doi.org/10.1108/F-02-2016-0021

Babatunde, S. O., Ekundayo, D., Adekunle, A. O., & Bello, W. (2020). Comparative analysis of drivers to BIM adoption among AEC firms in developing countries: A case of Nigeria. *Journal of Engineering, Design and Technology*, *18*(6), 1425–1447. https://doi.org/10.1108/JEDT-08-2019-0217

Baharetha, S., Soliman, A. M., Hassanain, M. A., Alshibani, A., & Ezz, M. S. (2023). Assessment of the challenges influencing the adoption of smart building technologies. *Frontiers in Built Environment*, *9*. Scopus. https://doi.org/10.3389/fbuil.2023.1334005

Bensalah, M., Elouadi, A., & Mharzi, H. (2019). Overview: The opportunity of BIM in railway. *Smart and Sustainable Built Environment*, *8*(2), 103–116. Scopus. https://doi.org/10.1108/SASBE-11-2017-0060

Boyle, L., & Michell, K. (2017). Urban facilities management: A systemic process for achieving urban sustainability. *International Journal of Sustainable Development and Planning*, *12*(3), 446–456. Scopus. https://doi.org/10.2495/SDP-V12-N3-446-456

Cepa, J. J., Pavon, R. M., Alberti, M. G., Ciccone, A., & Asprone, D. (2023). A Review on the Implementation of the BIM Methodology in the Operation Maintenance and Transport Infrastructure. *APPLIED SCIENCES-BASEL*, *13*(5), 3176. https://doi.org/10.3390/app13053176

Chen, C., & Tang, L. (2019). BIM-based integrated management workflow design for schedule and cost planning of building fabric maintenance. *Automation in Construction*, *107*, 102944. https://doi.org/10.1016/j.autcon.2019.102944

Chew, M. Y. L., Conejos, S., & Asmone, A. S. (2017). Developing a research framework for the green maintainability of buildings. *Facilities*, *35*(1/2), 39–63. https://doi.org/10.1108/F-08-2015-0059

Chung, S., Cho, C.-S., Song, J., Lee, K., Lee, S., & Kwon, S. (2021). Smart Facility Management System Based on Open BIM and Augmented Reality Technology. *APPLIED SCIENCES-BASEL*, *11*(21), 10283. https://doi.org/10.3390/app112110283

Codinhoto, R., & Kiviniemi, A. (2014). BIM for FM: A Case Support for Business Life Cycle. In S. Fukuda, A. Bernard, B. Gurumoorthy, & A. Bouras (Eds.), *Product Lifecycle Management for a Global Market* (pp. 63–74). Springer. https://doi.org/10.1007/978-3-662-45937-9_7

Collins, D., Haugen, T., Lindkvist, C., & Aamodt, C. (2018). Bridging the gap between sustainable FM and sustainable buildings – an exploratory study of six public buildings in Norway. *Facilities*, *37*(9/10), 639–652. https://doi.org/10.1108/F-01-2018-0007

Cotts, D. G., Roper, K. O., & Payant, R. P. (2010). *The facility management handbook* (3rd ed). American Management Association.

Coupry, C., Noblecourt, S., Richard, P., Baudry, D., & Bigaud, D. (2021). BIM-Based Digital Twin and XR Devices to Improve Maintenance Procedures in Smart Buildings: A Literature Review. *APPLIED SCIENCES-BASEL*, *11*(15), 6810. https://doi.org/10.3390/app11156810

Darko, A., Chan, A. P. C., Yang, Y., & Tetteh, M. O. (2020). Building information modeling (BIM)-based modular integrated construction risk management – Critical survey and future needs. *Computers in Industry*, *123*, 103327. https://doi.org/10.1016/j.compind.2020.103327

De Silva, N., Weerasinghe, R. P. N. P., Madhusanka, H. W. N., & Kumaraswamy, M. (2017). Relationally integrated value networks (RIVANS) for total facilities management (TFM). *Built Environment Project and Asset Management*, *7*(3), 313–329. https://doi.org/10.1108/BEPAM-08-2016-0037

Dehbi, Y., Haunert, J.-H., & Plümer, L. (2017). STOCHASTIC AND GEOMETRIC REASONING FOR INDOOR BUILDING MODELS WITH ELECTRIC INSTALLATIONS – BRIDGING THE GAP BETWEEN GIS AND BIM. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *IV-4-W5*, 33–39. https://doi.org/10.5194/isprs-annals-IV-4-W5-33-2017

Dossick, C. S., Anderson, A., Azari, R., Iorio, J., Neff, G., & Taylor, J. E. (2015). Messy Talk in Virtual Teams: Achieving Knowledge Synthesis through Shared Visualizations. *Journal of Management in Engineering*, *31*(1). https://doi.org/10.1061/(ASCE)ME.1943-5479.0000301

Edirisinghe, R., London, K. A., Kalutara, P., & Aranda-Mena, G. (2017). Building information modelling for facility management: Are we there yet? *Engineering, Construction and Architectural Management*, *24*(6), 1119–1154. https://doi.org/10.1108/ECAM-06-2016-0139

Egwim, C. N., Alaka, H., Demir, E., Balogun, H., Olu-Ajayi, R., Sulaimon, I., Wusu, G., Yusuf, W., & Muideen, A. A. (2024). Artificial Intelligence in the Construction Industry: A Systematic Review of the Entire Construction Value Chain Lifecycle. *Energies*, *17*(1). Scopus. https://doi.org/10.3390/en17010182

ElArwady, Z., Kandil, A., Afiffy, M., & Marzouk, M. (2024). Modeling indoor thermal comfort in buildings using digital twin and machine learning. *DEVELOPMENTS IN THE BUILT ENVIRONMENT*, *19*, 100480. https://doi.org/10.1016/j.dibe.2024.100480

Ensafi, M., & Thabet, W. (2021). *Challenges and Gaps in Facility Maintenance Practices*. *2*, 237–245.

Ghalandar, T., & Lindkvist, C. (2023). Digital Transitions for Future Building Scenarios. *IOP Conference Series: Earth and Environmental Science*, *1176*(1), 012007. https://doi.org/10.1088/1755-1315/1176/1/012007

Gharaibeh, L., Eriksson, K., & Lantz, B. (2024). Quantifying BIM investment value: A systematic review. *JOURNAL OF ENGINEERING DESIGN AND TECHNOLOGY*. https://doi.org/10.1108/JEDT-06-2023-0259

Gispert, D. E., Yitmen, I., Sadri, H., & Taheri, A. (2023). Development of an ontology-based asset information model for predictive maintenance in building facilities. *SMART AND SUSTAINABLE BUILT ENVIRONMENT*. https://doi.org/10.1108/SASBE-07-2023-0170

Glema, A. (2017). Building Information Modeling Bim—Level of Digital Construction. *ARCHIVES OF CIVIL ENGINEERING*, *63*(3), 39–51. https://doi.org/10.1515/ace-2017-0027

Godager, B. (2018). *Critical review of the integration of bim to semantic web technology*. *42*(4), 303–308. Scopus. https://doi.org/10.5194/isprs-archives-XLII-4-233-2018

Godager, B., Onstein, E., & Huang, L. (2021). The Concept of Enterprise BIM: Current Research Practice and Future Trends. *IEEE Access*, *9*, 42265–42290. IEEE Access. https://doi.org/10.1109/ACCESS.2021.3065116

Hassanain, M. A., & Hamida, M. B. (2023). AEC/FM performance in adaptive reuse projects: Investigation of challenges and development of practical guidelines. *Facilities*, *41*(7–8), 477–497. Scopus. https://doi.org/10.1108/F-04-2022-0053

Hilal, M., Maqsood, T., & Abdekhodaee, A. (2019). A hybrid conceptual model for BIM in FM. *Construction Innovation*, *19*(4), 531–549. https://doi.org/10.1108/CI-05-2018-0043

Hmidah, N. A., Haron, N. A., Alias, A. H., Law, T. H., Altohami, A. B. A., & Effendi, R. A. A. R. A. (2022). The Role of the Interface and Interface Management in the Optimization of BIM Multi-Model Applications: A Review. *Sustainability*, *14*(3), Article 3. https://doi.org/10.3390/su14031869

Hoang, G. V., Vu, D. K. T., Le, N. H., & Nguyen, T. P. (2020). Benefits and challenges of BIM implementation for facility management in operation and maintenance face of buildings in Vietnam. *IOP Conference Series: Materials Science and Engineering*, *869*(2), 022032. https://doi.org/10.1088/1757-899X/869/2/022032

Hobees, M. A. S., Riazi, S. R. M., Ismail, R., Yusuf, A. A., Nawi, M. N. M., & Omar, M. F. (2021). Facilities Management (FM) in Industrialized Building System (IBS) Projects in Malaysia: Challenges and Strategies for Improvement. *Webology*, *18*, 1–13. Scopus. https://doi.org/10.14704/WEB/V18SI03/WEB18016

Hor, A.-H., Jadidi, A., & Sohn, G. (2016). BIM-GIS INTEGRATED GEOSPATIAL INFORMATION MODEL USING SEMANTIC WEB AND RDF GRAPHS. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *III–4*, 73–79. XXIII ISPRS Congress, Commission IV (Volume III-4) - 12–19 July 2016, Prague, Czech Republic. https://doi.org/10.5194/isprs-annals-III-4-73-2016

Hosamo, H. H., Imran, A., Cardenas-Cartagena, J., Svennevig, P. R., Svidt, K., & Nielsen, H. K. (2022). A Review of the Digital Twin Technology in the AEC-FM Industry. *Advances in Civil Engineering*, *2022*, e2185170. https://doi.org/10.1155/2022/2185170

Hossain, M. A., & Yeoh, J. K. W. (2018). *BIM for Existing Buildings: Potential Opportunities and Barriers*. *371*(1). Scopus. https://doi.org/10.1088/1757-899X/371/1/012051

Hosseini, M. R., Roelvink, R., Papadonikolaki, E., Edwards, D. J., & Pärn, E. (2018). Integrating BIM into facility management: Typology matrix of information handover requirements. *International Journal of Building Pathology and Adaptation*, *36*(1), 2–14. https://doi.org/10.1108/IJBPA-08-2017-0034

Hou, H., Lai, J. H. K., Wu, H., & Wang, T. (2024). Digital twin application in heritage facilities management: Systematic literature review and future development directions. *Engineering, Construction and Architectural Management*, *31*(8), 3193–3221. Scopus. https://doi.org/10.1108/ECAM-06-2022-0596

Irizarry, J., Gheisari, M., Williams, G., & Walker, B. N. (2013). InfoSPOT: A mobile Augmented Reality method for accessing building information through a situation awareness approach. *Automation in Construction*, *33*, 11–23. https://doi.org/10.1016/j.autcon.2012.09.002

Isa, M. F. M., & Usmen, M. (2015). Improving university facilities services using Lean Six Sigma: A case study. *Journal of Facilities Management*, *13*(1), 70–84. https://doi.org/10.1108/JFM-09-2013-0048

Isa, N. M., Kamaruzzaman, S. N., Mohamed, O., & Berawi, M. A. (2017). Review of Facilities Management Functions in Value Management Practices. *INTERNATIONAL JOURNAL OF TECHNOLOGY*, *8*(5), 830–840. https://doi.org/10.14716/ijtech.v8i5.865

Jang, R., & Collinge, W. (2020). Improving BIM asset and facilities management processes: A Mechanical and Electrical (M&E) contractor perspective. *JOURNAL OF BUILDING ENGINEERING*, *32*, 101540. https://doi.org/10.1016/j.jobe.2020.101540

Jia, J., Ma, H., & Zhang, Z. (2024). Integration of Industry Foundation Classes and Ontology: Data, Applications, Modes, Challenges, and Opportunities. *BUILDINGS*, *14*(4), 911. https://doi.org/10.3390/buildings14040911

Jin, R., Zou, Y., Gidado, K., Ashton, P., & Painting, N. (2019). Scientometric analysis of BIM-based research in construction engineering and management. *Engineering, Construction and Architectural Management*, *26*(8), 1750–1776. https://doi.org/10.1108/ECAM-08-2018-0350

Jing, Y., Chen, C., Tang, L., Xiong, H., & Wang, Y. x. (2019). Development of BIM-Sensor Integrated Platform for MEP Piping Maintenance. In *International Conference on Smart Infrastructure and Construction 2019 (ICSIC)* (pp. 55–60). ICE Publishing. https://doi.org/10.1680/icsic.64669.055

Kamaruzzaman, S. N., Suznan, S. N., & Myeda, N. E. (2023). Building information modelling facilities management (BIMFM) coordination for digital construction project. *Journal of Facilities Management*, *ahead-of-print*(ahead-of-print). https://doi.org/10.1108/JFM-10-2021-0127

Karim Jallow, A., Demian, P., N. Baldwin, A., & Anumba, C. (2014). An empirical study of the complexity of requirements management in construction projects. *Engineering, Construction and Architectural Management*, *21*(5), 505–531. https://doi.org/10.1108/ECAM-09-2013-0084

Kassem, M., Kelly, G., Dawood, N., Serginson, M., & Lockley, S. (2015). BIM in facilities management applications: A case study of a large university complex. *Built Environment Project and Asset Management*, *5*(3), 261–277. https://doi.org/10.1108/BEPAM-02-2014-0011

Kazeem, K. O., Olawumi, T. O., & Osunsanmi, T. (2023). Roles of Artificial Intelligence and Machine Learning in Enhancing Construction Processes and Sustainable Communities. *Buildings*, *13*(8), Article 8. https://doi.org/10.3390/buildings13082061

Khan, A., Sepasgozar, S., Liu, T., & Yu, R. (2021). Integration of BIM and Immersive Technologies for AEC: A Scientometric-SWOT Analysis and Critical Content Review. *Buildings*, *11*(3), Article 3. https://doi.org/10.3390/buildings11030126

Kim, S., & Heo, J. (2017). Development of 3D underground cadastral data model in Korea: Based on land administration domain model. *Land Use Policy*, *60*, 123–138. https://doi.org/10.1016/j.landusepol.2016.10.020

Kumar, V., & Teo, A. L. E. (2021). Development of a rule-based system to enhance the data consistency and usability of COBie datasheets. *JOURNAL OF COMPUTATIONAL DESIGN AND ENGINEERING*, *8*(1), 343–361. https://doi.org/10.1093/jcde/qwaa083

Kumar, V., & Teo, E. A. L. (2020). Perceived benefits and issues associated with COBie datasheet handling in the construction industry. *Facilities*, *39*(5/6), 321–349. https://doi.org/10.1108/F-09-2019-0100

Lai, J. H. K. (2011). Comparative evaluation of facility management services for housing estates. *Habitat International*, *35*(2), 391–397. https://doi.org/10.1016/j.habitatint.2010.11.009

Lau, W. K., Ho, D. C. W., & Yau, Y. (2016). Assessing the disability inclusiveness of university buildings in Hong Kong. *International Journal of Strategic Property Management*, *20*(2), Article 2. https://doi.org/10.3846/1648715X.2015.1107653

Lee, X. S., Yan, C. P., & See, Z. S. (2016). *Irregular Shaped Building Design Optimization with Building Information Modelling*. *66*. Scopus. https://doi.org/10.1051/matecconf/20166600027

Liang, C.-F., Li, X.-Y., Lin, T.-Y., & Lin, H.-H. (2020). *The Effect of Environmental Engineering on Existing Venues and Operation Management: A Case Study of Minxiong Township*. *526*(1). Scopus. https://doi.org/10.1088/1755-1315/526/1/012044

Lindkvist, C. M., Hafeld, A., & Haugen, T. B. (2022). Interfacing between FM and project phases through digital processes and collaborative practices. *IOP Conference Series: Earth and Environmental Science*, *1101*(6), 062010. https://doi.org/10.1088/1755-1315/1101/6/062010

Low, S. P., Gao, S., & Ng, E. W. L. (2019). Future-ready project and facility management graduates in Singapore for industry 4.0: Transforming mindsets and competencies. *Engineering, Construction and Architectural Management*, *28*(1), 270–290. https://doi.org/10.1108/ECAM-08-2018-0322

Maile, T., Fischer, M., & Huijbregts, R. (2007). The vision of integrated IP-based building systems. *Journal of Corporate Real Estate*, *9*(2), 125–137. https://doi.org/10.1108/14630010710828126

Marocco, M., & Garofolo, I. (2021). Integrating disruptive technologies with facilities management: A literature review and future research directions. *Automation in Construction*, *131*, 103917. https://doi.org/10.1016/j.autcon.2021.103917

Matarneh, S., Danso-Amoako, M., Al-Bizri, S., Gaterell, M., & Matarneh, R. (2019). BIM-based facilities information: Streamlining the information exchange process. *Journal of Engineering, Design and Technology*, *17*(6), 1304–1322. https://doi.org/10.1108/JEDT-02-2019-0048

Matarneh, S., Elghaish, F., Rahimian, F. P., Dawood, N., & Edwards, D. (2022). Automated and interconnected facility management system: An open IFC cloud-based BIM solution. *Automation in Construction*, *143*, 104569. https://doi.org/10.1016/j.autcon.2022.104569

Matos, R., Rodrigues, H., Costa, A., & Rodrigues, F. (2023). BIM-FM integrated solution resourcing to digital techniques. *Neural Computing and Applications*. https://doi.org/10.1007/s00521-023-08907-0

McArthur, J. J. (2015). A building information management (BIM) framework and supporting case study for existing building operations, maintenance and sustainability. In W. O. Chong, J. Chang, K. Parrish, & U. Berardi (Eds.), *DEFINING THE FUTURE OF SUSTAINABILITY AND RESILIENCE IN DESIGN, ENGINEERING AND CONSTRUCTION* (Vol. 118, pp. 1104–1111). Elsevier Science Bv. https://doi.org/10.1016/j.proeng.2015.08.450

Mehedi, M. T., & Shochchho, A. H. (2021). Exploring Facility Management (7D) with BIM Considering Quality and Performance Assessment Models. *E3S Web of Conferences*, *304*, 02007. https://doi.org/10.1051/e3sconf/202130402007

Menezes, A. C., Cripps, A., Bouchlaghem, D., & Buswell, R. (2012). Predicted vs. actual energy performance of non-domestic buildings: Using post-occupancy evaluation data to reduce the performance gap. *Applied Energy*, *97*, 355–364. https://doi.org/10.1016/j.apenergy.2011.11.075

Merino, J., Moretti, N., Xie, X., Chang, J. Y., & Parlikad, A. (2023). Data integration for digital twins in the built environment based on federated data models. *Proceedings of the Institution of Civil Engineers: Smart Infrastructure and Construction*, *176*(4), 194–211. Scopus. https://doi.org/10.1680/jsmic.23.00002

Mervi, L. (2002). Multidisciplinary information management in const- ruction industry, example of facilities management. *Journal of Information Technology in Construction (ITcon)*, *7*(14), 213–244.

Mewomo, M. C., Ndlovu, P. M., & Iyiola, C. O. (2022). Factors affecting effective facilities management practices in South Africa: A case study of Kwazulu Natal Province. *Facilities*, *40*(15–16), 107–124. Scopus. https://doi.org/10.1108/F-09-2021-0087

Molén, J., Kadefors, A., & Troje, D. (2023). Integrating Facilities Management knowledge in municipal school building: Swedish case studies. *IOP Conference Series: Earth and Environmental Science*, *1176*(1), 012033. https://doi.org/10.1088/1755-1315/1176/1/012033

Mondrup, T. F., Treldal, N., Karlshoj, J., & Vestergaard, F. (2015). Introducing a new framework for using generic Information Delivery Manuals. In A. Mahdavi, B. Martens, & R. Scherer (Eds.), *EWORK AND EBUSINESS IN ARCHITECTURE, ENGINEERING AND CONSTRUCTION 2014* (pp. 295–301). CRC Press-Taylor & Francis Group. https://www.webofscience.com/wos/woscc/full-record/WOS:000380490000043

Moreno Bazán, Á., Alberti, M. G., Arcos Álvarez, A., & Trigueros, J. A. (2020). New Perspectives for BIM Usage in Transportation Infrastructure Projects. *Applied Sciences*, *10*(20), Article 20. https://doi.org/10.3390/app10207072

Moum, A., & Bock, T. (2006). A Framework for Exploring ICTM Impact on Building Design and Management Applied to a Hospital Development Project: Proposing ICTM to Building Design and Management for Information Consistent Control of Construction and Service Robots. *ISARC Proceedings*, 107–112.

Mousharbash, N., Carbonari, A., Giretti, A., & Turk, Ž. (2022). *CURRENT RESEARCH, TRENDS, AND CHALLENGES IN BUILDING EMERGENCY MANAGEMENT*. 138–144. Scopus. https://doi.org/10.35490/EC3.2022.215

Muhammad, M. Z., & Mustapa, M. (2020). A Review of Facilities Information Requirements towards Enhancing Building Information Modelling (BIM) for Facilities Management (FM). *IOP Conference Series: Materials Science and Engineering*, *884*(1), 012033. https://doi.org/10.1088/1757-899X/884/1/012033

Murguia, D., Felix, K. M., & Guerra, M. A. (2020). *An approach to capture design and construction lessons learned from facility managers*. 997–1008. Scopus. https://doi.org/10.24928/2020/0067

Musharavati, F. (2023). Optimized Integration of Lean Construction, Building Information Modeling, and Facilities Management in Developing Countries: A Case of Qatar. *Buildings*, *13*(12), Article 12. https://doi.org/10.3390/buildings13123051

Neuville, R., Pouliot, J., & Billen, R. (2019). Identification of the Best 3D Viewpoint within the BIM Model:

Application to Visual Tasks Related to Facility Management. *Buildings*, *9*(7), Article 7. https://doi.org/10.3390/buildings9070167

Nical, A. K., & Wodynski, W. (2016). Enhancing Facility Management through BIM 6D. In M. Hajdu & M. J. Skibniewski (Eds.), *5TH CREATIVE CONSTRUCTION CONFERENCE (CCC 2016)* (Vol. 164, pp. 299–306). Elsevier Science Bv. https://doi.org/10.1016/j.proeng.2016.11.623

Oduyemi, O., Okoroh, M. I., Fajana, O. S., & Arowosafe, O. (2018). The need for economic performance measures for life cycle costing of sustainable commercial office buildings. *Journal of Facilities Management*, *16*(1), 54–64. https://doi.org/10.1108/JFM-08-2017-0035

Okonta, E. D., Vukovic, V., & Hayat, E. (2024). Prospective Directions in the Computer Systems Industry Foundation Classes (IFC) for Shaping Data Exchange in the Sustainability and Resilience of Cities. *ELECTRONICS*, *13*(12), 2297. https://doi.org/10.3390/electronics13122297

Oti, A. H., Kurul, E., Cheung, F., & Tah, J. H. M. (2016). A framework for the utilization of Building Management System data in building information models for building design and operation. *Automation in Construction*, *72*, 195–210. https://doi.org/10.1016/j.autcon.2016.08.043

Ozturk, G. B. (2020). Interoperability in building information modeling for AECO/FM industry. *Automation in Construction*, *113*, 103122. https://doi.org/10.1016/j.autcon.2020.103122

Ozturk, G. B. (2021). Digital Twin Research in the AECO-FM Industry. *Journal of Building Engineering*, *40*, 102730. https://doi.org/10.1016/j.jobe.2021.102730

Pärn, E. A., & Edwards, D. (2017). Vision and advocacy of optoelectronic technology developments in the AECO sector. *Built Environment Project and Asset Management*, *7*(3), 330–348. https://doi.org/10.1108/BEPAM-11-2016-0081

Pärn, E. A., Edwards, D. J., & Sing, M. C. P. (2017). The building information modelling trajectory in facilities management: A review. *Automation in Construction*, *75*, 45–55. https://doi.org/10.1016/j.autcon.2016.12.003

Paskaleva, G., Mazak-Huemer, A., Wimmer, M., & Bednar, T. (2021). Leveraging integration facades for model-based tool interoperability. *Automation in Construction*, *128*, 103689. https://doi.org/10.1016/j.autcon.2021.103689

Pinti, L., Codinhoto, R., & Bonelli, S. (2022). A Review of Building Information Modelling (BIM) for Facility Management (FM): Implementation in Public Organisations. *Applied Sciences*, *12*(3), Article 3. https://doi.org/10.3390/app12031540

Pogorelskiy, S., & Kocsis, I. (2022). Automation for structured cabling system in data centers using Building Information Modelling. *International Review of Applied Sciences and Engineering*, *13*(3), 335–345. Scopus. https://doi.org/10.1556/1848.2022.00424

Pomè, A. P., Orlandini, G., & Tagliaro, C. (2023). Innovative VS. traditional: A framework to assess the sustainable trade-off of maintenance strategies. *IET Conference Proceedings*, *2023*(16), 90–99. Scopus. https://doi.org/10.1049/icp.2023.1739

Pomè, A. P., & Signorini, M. (2023). Real time facility management: Assessing the effectiveness of Digital Twin in the Operation and Maintenance phase of building life cycle. *IOP Conference Series: Earth and Environmental Science*, *1176*(1), 012003. https://doi.org/10.1088/1755-1315/1176/1/012003

Radzi, A. R., Azmi, N. F., Kamaruzzaman, S. N., Rahman, R. A., & Papadonikolaki, E. (2023). Relationship between digital twin and building information modeling: A systematic review and future directions. *Construction Innovation*, *ahead-of-print*(ahead-of-print). https://doi.org/10.1108/CI-07-2022-0183

Rasmussen, H. L., Jensen, P. A., Nielsen, S. B., & Kristiansen, A. H. (2019). Initiatives to integrate operational knowledge in design: A building client perspective. *Facilities*, *37*(11/12), 799–812. https://doi.org/10.1108/F-02-2017-0021

Sadeghineko, F., & Kumar, B. (2022). Application of semantic Web ontologies for the improvement of information exchange in existing buildings. *CONSTRUCTION INNOVATION-ENGLAND*, *22*(3), 444–464. https://doi.org/10.1108/CI-03-2021-0058

Salleh, N. A., Talib, Y. A., Ismail, K., & Alauddin, K. (2021). Challenges in maintaining facilities in elderly Pondok Village environment. *IOP Conference Series: Earth and Environmental Science*, *881*(1), 012039. https://doi.org/10.1088/1755-1315/881/1/012039

Sani, M. J., & Rahman, A. A. (2018). Gis and Bim Integration at Data Level: A Review. In A. A. Rahman & H. Karim (Eds.), *INTERNATIONAL CONFERENCE ON GEOMATIC & GEOSPATIAL TECHNOLOGY (GGT 2018): GEOSPATIAL AND DISASTER RISK MANAGEMENT* (Vols 42–4, Issue W9, pp. 299–306). Copernicus Gesellschaft Mbh. https://doi.org/10.5194/isprs-archives-XLII-4-W9-299-2018

Sarpin, N., Kasim, N., Zainal, R., Noh, H. M., Mohamed, S., & Ahmad, Md. F. (2018). A guideline for strategic capabilities enhancement to support sustainable facility management practices. *AIP Conference Proceedings*, *2016*(1), 020131. https://doi.org/10.1063/1.5055533

Sedhom, I., Khodeir, L. M., & Fathy, F. (2023). Investigating current practices for achieving effective participation of stakeholders in Facilities Management. *Ain Shams Engineering Journal*, *14*(6), 102099. https://doi.org/10.1016/j.asej.2022.102099

Shen, W., Hao, Q., Mak, H., Neelanikavil, J., Xie, H., & Dickinson, J. (2008). Systems integration and collaboration in construction: A review. In W. M. Shen, Q. H. Zheng, J. P. Barthes, J. Z. Luo, J. M. Yong, Z. H. Duan, & F. Tian (Eds.), *PROCEEDINGS OF THE 2008 12TH INTERNATIONAL CONFERENCE ON COMPUTER SUPPORTED COOPERATIVE WORK IN DESIGN, VOLS I AND II* (pp. 11–22). IEEE. https://www.webofscience.com/wos/woscc/full-record/WOS:000256900300002

Slongo, C., Malacarne, G., & Matt, D. T. (2022). The Ifc File Format as a Means of Integrating Bim and Gis: The Case of the Management and Maintenance of Underground Networks. In S. Ziatanova, G. Sithole, & J. Barton (Eds.), *XXIV ISPRS CONGRESS IMAGING TODAY, FORESEEING TOMORROW, COMMISSION IV* (Vols 5–4, pp. 301–309). Copernicus Gesellschaft Mbh. https://doi.org/10.5194/isprs-annals-V-4-2022-301-2022

Smyth, H., Anvuur, A. M., & Kusuma, I. (2017). Integrated solutions for total asset management through "RIVANS". *Built Environment Project and Asset Management*, *7*(1), 5–18. https://doi.org/10.1108/BEPAM-07-2015-0034

Soliman, K., Naji, K., Gunduz, M., Tokdemir, O. B., Faqih, F., & Zayed, T. (2022). BIM-based facility management models for existing buildings. *JOURNAL OF ENGINEERING RESEARCH*, *10*(1A), 21–37. https://doi.org/10.36909/jer.11433

Stride, M., Hon, C. K. H., Liu, R., & Xia, B. (2020). The use of building information modelling by quantity surveyors in facilities management roles. *Engineering, Construction and Architectural Management*, *27*(8), 1795–1812. https://doi.org/10.1108/ECAM-11-2019-0660

Su, H.-N., & Lee, P.-C. (2010). Mapping knowledge structure by keyword co-occurrence: A first look at journal papers in Technology Foresight. *Scientometrics*, *85*(1), 65–79. https://doi.org/10.1007/s11192-010-0259-8

Tamošaitienė, J., Sarvari, H., Cristofaro, M., & Chan, D. W. M. (2021). Identifying and prioritizing the selection criteria of appropriate repair and maintenance methods for commercial buildings. *International Journal of Strategic Property Management*, *25*(5), Article 5. https://doi.org/10.3846/ijspm.2021.15225

Tan, A. Z. T., Zaman, A., & Sutrisna, M. (2018). Enabling an effective knowledge and information flow between the phases of building construction and facilities management. *Facilities*, *36*(3/4), 151–170. https://doi.org/10.1108/F-03-2016-0028

Terreno, S., Asadi, S., & Anumba, C. (2019). An Exploration of Synergies between Lean Concepts and BIM in FM: A Review and Directions for Future Research. *BUILDINGS*, *9*(6), 147. https://doi.org/10.3390/buildings9060147

Tsay, G. S., Staub-French, S., & Poirier, É. (2022). BIM for Facilities Management: An Investigation into the Asset Information Delivery Process and the Associated Challenges. *Applied Sciences (Switzerland)*, *12*(19). Scopus. https://doi.org/10.3390/app12199542

Ullah, K., Witt, E., & Lill, I. (2022). The BIM-Based Building Permit Process: Factors Affecting Adoption. *Buildings*, *12*(1), Article 1. https://doi.org/10.3390/buildings12010045 van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, *84*(2), 523–538. https://doi.org/10.1007/s11192-009-0146-3

Ventura, S. M., Castronovo, F., & Ciribini, A. L. C. (2020). A design review session protocol for the implementation of immersive virtual reality in usability-focused analysis. *Journal of Information Technology in Construction (ITcon)*, *25*(14), 233–253. https://doi.org/10.36680/j.itcon.2020.014

Villa, V., Naticchia, B., Bruno, G., Aliev, K., Piantanida, P., & Antonelli, D. (2021). IoT Open-Source Architecture for the Maintenance of Building Facilities. *APPLIED SCIENCES-BASEL*, *11*(12), 5374. https://doi.org/10.3390/app11125374

Vite, C., Horvath, A.-S., Neff, G., & Moller, N. L. H. (2021). Bringing Human-Centredness to Technologies for Buildings An agenda for linking new types of data to the challenge of sustainability. *PROCEEDINGS OF THE 14TH BIANNUAL CONFERENCE OF THE ITALIAN SIGCHI CHAPTER (CHIITALY 2021)*. 14th Biannual Conference of the Italian-SIGCHI-Chapter (CHIItaly), New York. https://doi.org/10.1145/3464385.3464711

Vukmirovic, M., Salaj, A. T., & Sostaric, A. (2021). Challenges of the Facilities Management and Effects on Indoor Air Quality. Case Study 'Smelly Buildings' in Belgrade, Serbia. *SUSTAINABILITY*, *13*(1), 240. https://doi.org/10.3390/su13010240

Wang, Y., Wang, X., Wang, J., Yung, P., & Jun, G. (2013). Engagement of Facilities Management in Design Stage through BIM: Framework and a Case Study. *Advances in Civil Engineering*, *2013*, e189105. https://doi.org/10.1155/2013/189105

Wen, Y., Tang, L. C. M., & Ho, D. C. W. (2021). A BIM-based space-oriented solution for hospital facilities management. *Facilities*, *39*(11/12), 689–702. https://doi.org/10.1108/F-10-2019-0105

Werbrouck, J., Pauwels, P., Bonduel, M., Beetz, J., & Bekers, W. (2020). Scan-to-graph: Semantic enrichment of existing building geometry. *AUTOMATION IN CONSTRUCTION*, *119*, 103286. https://doi.org/10.1016/j.autcon.2020.103286

Wildenauer, A., Mbabu, A., Underwood, J., & Basl, J. (2022). Building-as-a-Service: Theoretical Foundations and Conceptual Framework. *BUILDINGS*, *12*(10), 1594. https://doi.org/10.3390/buildings12101594

Wu, J., & Lepech, M. D. (2020). Incorporating multi-physics deterioration analysis in building information modeling for life-cycle management of durability performance. *Automation in Construction*, *110*, 103004. https://doi.org/10.1016/j.autcon.2019.103004

Yan, J., Lu, Q., Chen, L., Broyd, T., & Pitt, M. (2022). *SeeCarbon: A review of digital approaches for revealing and reducing infrastructure, building and City's carbon footprint*. *55*(19), 223–228. Scopus. https://doi.org/10.1016/j.ifacol.2022.09.211

Yan, J., Lu, Q., Fang, Z., Li, N., Chen, L., & Pitt, M. (2022). From building to city level dynamic digital Twin: A review from data management perspective. *IOP Conference Series: Earth and Environmental Science*, *1101*(9), 092033. https://doi.org/10.1088/1755-1315/1101/9/092033

Yang, E., & Bayapu, I. (2019). Big Data analytics and facilities management: A case study. *Facilities*, *38*(3/4), 268–281. https://doi.org/10.1108/F-01-2019-0007

Yilmaz, G., Akcamete, A., & Demirors, O. (2023). BIM-CAREM: Assessing the BIM capabilities of design, construction and facilities management processes in the construction industry. *Computers in Industry*, *147*, 103861. https://doi.org/10.1016/j.compind.2023.103861

Yin, X., Liu, H., Chen, Y., Wang, Y., & Al-Hussein, M. (2020). A BIM-based framework for operation and maintenance of utility tunnels. *Tunnelling and Underground Space Technology*, *97*. Scopus. https://doi.org/10.1016/j.tust.2019.103252

Yusoff, S. N. S., & Brahim, J. (2021). Implementation of Building Information Modeling (BIM) for Social Heritage Buildings in Kuala Lumpur. *International Journal of Sustainable Construction Engineering and Technology*, *12*(1), Article 1.

Zhang, J., Seet, B.-C., & Lie, T. T. (2015). Building Information Modelling for Smart Built Environments. *BUILDINGS*, *5*(1), 100–115. https://doi.org/10.3390/buildings5010100

Zhang, Y., Hui, F. K. P., Duffield, C., & Saeed, A. M. (2022). A review of facilities management interventions to mitigate respiratory infections in existing buildings. *Building and Environment*, *221*. Scopus. https://doi.org/10.1016/j.buildenv.2022.109347

Zhao, J., Feng, H., Chen, Q., & Garcia de Soto, B. (2022). Developing a conceptual framework for the application of digital twin technologies to revamp building operation and maintenance processes. *Journal of Building Engineering*, *49*, 104028. https://doi.org/10.1016/j.jobe.2022.104028

Zhou, W., Heesom, D., Georgakis, P., & H.M. Tah, J. (2014). User-centred design for collaborative 4D modelling. *Construction Innovation*, *14*(4), 493–517. https://doi.org/10.1108/CI-01-2014-0008

Zhu, L., Shan, M., & Xu, Z. (2019). Critical review of building handover-related research in construction and facility management journals. *Engineering, Construction and Architectural Management*, *28*(1), 154–173. https://doi.org/10.1108/ECAM-10-2018-0442

Zou, Z., Arruda, L., & Ergan, S. (2018). Characteristics of Models That Impact Transformation of Bims to Virtual Environments to Support Facility Management Operations. *JOURNAL OF CIVIL ENGINEERING AND MANAGEMENT*, *24*(6), 481–498. https://doi.org/10.3846/jcem.2018.5689