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INTEGRATING SOCIO-TECHNICAL SYSTEMS (STS) AND KNOWLEDGE MANAGEMENT (KM) THEORIES IN BIM-FM CONTEXT: A LITERATURE REVIEW

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ABSTRACT

The integration of Socio-Technical Systems (STS) and Knowledge Management (KM) theories in Building Information Modelling for Facilities Management (BIM-FM) presents a transformative approach to enhancing information delivery and facility operations. This literature review aims to explore the synergistic benefits and inherent challenges of applying STS and KM frameworks within the context of BIM-FM. By examining a wide array of studies, this paper identifies key advantages such as improved collaboration, enhanced operational efficiency, increased adaptability, user-centered design, and sustainability. Additionally, it addresses the challenges faced, including technological interoperability, cultural resistance, and the complexities of managing large-scale data. The review highlights significant gaps in the current research, particularly in the practical integration of these theories, and suggests directions for future studies to bridge these gaps. The findings underscore the potential of STS and KM to drive innovation and improve the overall effectiveness of BIM-FM practices, paving the way for more resilient and adaptive facility management strategies.

Keywords: *Socio-Technical Systems (STS), Knowledge Management (KM), Building Information Modelling for Facilities Management (BIM-FM)*

INTRODUCTION

In the evolving landscape of facilities management (FM), the adoption of Building Information Modelling (BIM) has emerged as a pivotal innovation, revolutionizing how buildings are designed, constructed, and maintained. BIM provides a comprehensive digital representation of a building's physical and functional characteristics, facilitating enhanced collaboration, efficiency, and decision-making across the lifecycle of a facility (Becerik-Gerber et al., 2012; Dahanayake & Sumanarathna, 2022; McArthur, 2015). Despite its numerous advantages, the integration of BIM into FM practices is not without challenges, particularly in terms of managing the complex interplay between technological systems and human factors (Becerik-Gerber et al., 2012).

Theories of Socio-Technical Systems (STS) and Knowledge Management (KM) offer valuable frameworks for addressing these challenges. Originating from the Tavistock Institute in the 1950s, STS theory emphasizes the interdependence of social and technical elements within organizational systems, advocating for their simultaneous optimization to achieve improved performance and employee satisfaction (Fischer & Herrmann, 2011a; Ghansah et al., 2022). KM theory, on the other hand, focuses on the systematic management of an organization's knowledge assets to create value and meet strategic objectives, distinguishing between tacit and explicit knowledge and facilitating their conversion through structured processes (Nonaka, 2009).

Applying STS and KM theories to BIM-FM integration provides a holistic approach that considers both the technological and human dimensions of facility management. This integration is essential for enhancing information delivery, improving operational efficiency, fostering innovation, and achieving sustainability goals (Nicał & Wodyński, 2016; Tezel et al., 2022). However, the practical application of these theories in the context of BIM-FM remains underexplored, with significant gaps in the literature regarding the benefits, challenges, and best practices for their integration.

This paper aims to fill these gaps by systematically examining existing studies on the application of STS and KM theories in BIM-FM. The review explores the potential benefits of integrating these frameworks, such as enhanced collaboration, increased adaptability, user-centered design, and improved sustainability. It also addresses the challenges encountered, including technological interoperability issues, cultural resistance, and the complexities of managing large-scale data within BIM-FM systems (Azmi et al., 2023; Hilal et al., 2019; Pavón et al., 2021; Tezel et al., 2022).By identifying these key themes and providing a comprehensive analysis of the current state of research, this paper seeks to offer valuable insights and directions for future studies aimed at optimizing BIM-FM practices through the integration of STS and KM theories.

LITERATURE REVIEW

Building Information Modelling (BIM) in Facilities Management (FM)

Overview of BIM

Building Information Modeling (BIM) is a digital representation of the physical and functional characteristics of a facility, serving as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life cycle from inception onward (Edirisinghe & Woo, 2021). BIM is a collaborative process that involves the generational and management of digital representations of physical and functional characteristics of places. This technology enhances collaboration among architects, engineers, and construction professionals by providing a centralized repository of information, which leads to increased accuracy in design, improved construction efficiency, and enhanced facility management (Pishdad-Bozorgi et al., 2018).

Moreover, BIM integrates various tools, technologies, and contract policies to support the collaborative design, construction, and operation of buildings (Valerie Leonard Doudilim et al., 2021). It facilitates better planning, design, construction, and management by enabling the visualization of a building in a simulated environment, which helps stakeholders identify potential issues early in the project lifecycle (Dahanayake & Sumanarathna, 2022). The ability to create and manage detailed 3D models allows for improved coordination and communication among project teams, ultimately leading to more efficient and cost-effective project delivery. BIM's capabilities extend beyond the design and construction phases, providing substantial benefits in the facilities management phase by offering detailed data that can be used for the maintenance and operation of buildings (Azhar, 2011).

BIM in Facilities Management

Building Information Modelling (BIM) significantly enhances Facilities Management (FM) by providing comprehensive and accurate data about a building's components and systems throughout its lifecycle (Carbonari et al., 2018). BIM offers a centralized, digital repository of information that includes detailed specifications, maintenance schedules, and operational data. This facilitates efficient space management, equipment maintenance, and resource allocation. By integrating BIM into FM processes, facility managers can access real-time data, enabling proactive maintenance and reducing the risk of unexpected failures. The precise and updated information available through BIM helps in optimizing energy use, improving indoor environmental quality, and ensuring regulatory compliance (Becerik-Gerber et al., 2012).

Furthermore, BIM in FM enables better decision-making by offering predictive analytics and visualization tools that aid in forecasting future maintenance needs and assessing the impact of potential changes. The integration of BIM with FM systems allows for seamless handover from construction to operation, ensuring that all relevant data is preserved and accessible. This continuous flow of information supports long-term asset management strategies and enhances the overall performance of the facility. For instance, BIM can be used to simulate various scenarios, such as space reconfigurations or system upgrades, allowing facility managers to evaluate the implications and make informed choices. The enhanced collaboration and communication facilitated by BIM lead to improved efficiency and cost savings in FM operations (Patacas et al., 2015).

In the context of FM, BIM facilitates the management of building data post-construction, supporting operations, maintenance, and space management (Carbonari et al., 2018). The transition from traditional 2D drawings to 3D BIM models enhances the accuracy and accessibility of facility information, thereby improving decision-making and operational efficiency (Becerik-Gerber et al., 2012). However, the practical integration of BIM into FM practices presents several challenges, including data interoperability, user training, and technology adoption (Azmi et al., 2023).

Socio-Technical Systems (STS) Theory

Origins and Core Principles

Socio-Technical Systems (STS) theory, developed in the 1950s by researchers at the Tavistock Institute, emphasizes the interdependence of social and technical elements within organizational systems (Fischer & Herrmann, 2011).The core principle of STS is the simultaneous optimization of both the social (people, culture, and organizational structure) and technical (tools, technologies, and processes) systems to enhance overall organizational performance and employee satisfaction (Fischer & Herrmann, 2011). Meanwhile, Lyytinen & Newman, (2008) clarifies the content of the components and their connections at the level of a building system as Figure 1.

The STS model for building system activities demonstrates how social and technical components are interconnected and mutually influential. This is further explained in Table 1 based on (Lyytinen & Newman, 2008) . By ensuring that technology, actors, tasks, and structure are aligned and optimized together, organizations can achieve higher performance and satisfaction among their members. The simultaneous optimization of these components is essential for creating a balanced and effective organizational systems (Fischer & Herrmann, 2011; Lyytinen & Newman, 2008).

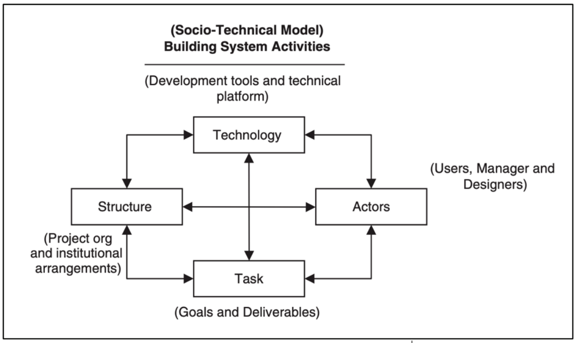

Figure 1. Socio-technical Model of a Building System

Source: Author

Table 1. Feature of Socio Technical Components of a Building System

Socio Technical Component	Main Content
Task	A task is defined by project deliverables and desired process features, specifying what developers should achieve and how they should proceed in the context of a socio-technical change.
Actors	Individuals or groups of stakeholders who can make claims or benefit from system development. These actors include customers, managers, maintainers, developers, and users.
Structure	The structure encompasses formal project organization and decision-making processes, work organization, workflow, and communication channels. It is defined by project management frameworks, methodologies for work organization and workflow, and communication frameworks.
Technology	Includes software and hardware technology, design methods, tools, and ICT infrastructure used to develop and implement the information system.

Source: Author

Research Studies Implementing Socio-Technical Systems (STS) Theory

Table 2 provides a comprehensive overview of various research studies that have implemented or combined Socio-Technical Systems (STS) theory across different domains. STS theory emphasizes the interdependence of social and technical elements within organizational systems, aiming to optimize both to enhance overall performance and user satisfaction. The studies listed below demonstrate how STS principles have been applied to create more effective and efficient systems in various fields.

Table 2. Research Studies Implementing Socio-Technical Systems (STS) Theory

Research Study	Authors	Year	Implementation of STS Theory
Healthcare Information Systems	(Cresswell et al., 2011)	2010	Applied STS principles to design user-friendly healthcare IT systems, ensuring the integration of clinical workflows with new technologies.
Integrating BIM and FM Systems	(Fischer & Herrmann, 2011c)	2011	Combined BIM tools with user training and communication protocols to optimize both technical and social elements in facilities management.
Smart Manufacturing Systems	(Baines et al., 2011)	2011	Implemented smart manufacturing technologies while addressing workforce training and organizational change management.
Sustainable Urban Planning	(Geels, 2011)	2011	Applied STS principles to urban planning, balancing technological innovations with community engagement and policy frameworks.
Educational Technology in Higher Education	(Bichsel, 2012)	2012	Integrated learning management systems with faculty development programs to improve teaching effectiveness and student learning experiences.
Renewable Energy Systems	(Sunil Luthra et al., 2014)	2015	Integrated renewable energy technologies with stakeholder engagement and policy frameworks to promote sustainable energy adoption.
Smart City Initiatives	(Albino et al., 2015)	2015	Combined IoT technologies with community participation and governance structures to create responsive and sustainable urban environments.
Human-Robot Collaboration in Manufacturing	(Villani et al., 2018)	2018	Developed collaborative robot systems considering ergonomic and cognitive aspects for workers.

The table presents diverse implementations of Socio-Technical Systems (STS) theory across various domains, highlighting how STS principles enhance both technical and social elements in different settings. Cresswell et al. (2011) applied STS to healthcare IT systems, effectively integrating clinical workflows with new technologies to improve user-friendliness and efficiency. Fischer & Herrmann (2011) optimized facilities management by combining BIM tools with user training and communication protocols, showcasing the balanced integration of technology and social factors. Baines et al. (2011) addressed workforce training and organizational change management while implementing smart manufacturing technologies, emphasizing the importance of aligning human and technical components. Geels (2011) balanced technological innovations with community engagement and policy frameworks in sustainable urban planning, demonstrating the holistic application of STS principles. Bichsel (2012) improved teaching effectiveness and student learning experiences by integrating learning management systems with faculty development programs. Luthra et al. (2015) promoted sustainable energy adoption by integrating renewable energy technologies with stakeholder engagement and policy frameworks. Albino et al. (2015) created responsive and sustainable urban environments by combining IoT technologies with community participation and governance structures. Finally, Villani et al. (2018) developed collaborative robot systems considering ergonomic and cognitive aspects for workers, highlighting the importance of human factors in technological integration. Despite the broad applications and benefits, challenges such as the need for cultural change, significant investment in technology and training, and difficulties in measuring direct impacts remain persistent across these implementations, underscoring the complexity of effectively applying STS theory.

Application in BIM-FM

The previous studies listed demonstrate the relevance of Socio-Technical Systems (STS) theory to Building Information Modelling (BIM) in Facilities Management (FM) by emphasizing the integration of technological and social elements to optimize system performance. Fischer & Herrmann (2011) specifically show how combining BIM tools with user training and communication protocols can enhance facilities management by ensuring both the technical aspects and the human factors are addressed. This approach aligns well with the principles seen in other domains, such as Cresswell et al. (2011) in healthcare IT systems, where the integration of clinical workflows with new technologies resulted in improved usability and efficiency. Similarly, the application of STS in smart manufacturing systems by Baines et al. (2011) and in sustainable urban planning by Geels (2011) underscores the importance of addressing workforce training, organizational change management, and community engagement—principles that are equally vital in the implementation of BIM for FM. These studies collectively highlight the importance of a holistic approach that balances technological innovations with social considerations, which is crucial for successful BIM integration in facilities management to enhance operational efficiency, sustainability, and user satisfaction.

Knowledge Management (KM) Theory

Overview of KM

Knowledge Management (KM) theory focuses on the systematic management of an organization's knowledge assets to create value and achieve strategic objectives (Nonaka, 2009). It is defined as an organizational optimization of knowledge to achieve enhanced performance, increased value, competitive advantage and return on investment, through the use of various tools, processes, methods, and techniques (Farooq, 2019). Since its inception in the 1990s, knowledge management (KM) has gained prominence as a key research focus in modern management and leadership, engaging both academics and practitioners. There is broad consensus among researchers that KM is a collaborative and integrated methodology that helps organizations create, capture, organize, access, and utilize intellectual assets, thereby ensuring long-term sustainability and strategic benefit (Ferreira et al., 2020; Martins et al., 2019; Nonaka, 2009; Tzortzaki & Mihiotis, 2014).

From an organizational perspective, knowledge is seen as a crucial resource for achieving a competitive advantage (Edwards, 2019).The knowledge-based view also regards knowledge as an essential resource for the firm. Knowledge-based resources, such as knowledge, skills, and capabilities, are difficult to replicate and are diverse, making them key contributors to sustainable competitive advantage (Ferreira et al., 2020). The aim of knowledge management (KM) is to provide the right knowledge to the right members at the right time, enabling them to make informed decisions and enhance the performance of organizations (Rashed, 2016). However, there is no consensus among researchers on the dimensions of KM due to its multifaceted and multidimensional nature (Farooq, 2019).

Research Studies Implementing Knowledge Management (KM) Theory

Table 3 provides an overview of various research studies that have implemented Knowledge Management (KM) theory within the construction industry. Knowledge Management involves the systematic process of creating, sharing, using, and managing knowledge and information within an organization. The studies listed below demonstrate how KM principles have been applied to enhance project efficiency, innovation, knowledge sharing, and overall performance in the construction sector.

Table 3. Research Studies Implementing Knowledge Management (KM) Theory

Research Study	Authors	Year	Implementation of KM Theory
KM and Business Process Improvement	(Davenport & Short, 1990)	1990	Linked KM with business process improvement to enhance organizational efficiency and performance.
KM and Organizational Learning	(Nonaka, 2009)	2009	Developed the SECI model (Socialization, Externalization, Combination, Internalization) for organizational knowledge creation and learning.
KM Systems in Construction Industry	(Egbu et al., 2001)	2001	Implemented KM systems to capture and reuse project knowledge, improving efficiency and reducing errors.
IT and KM in Construction	(Rezgui, 2001)	2001	Integrated IT tools with KM practices to enhance communication, information sharing, and project management in construction.
Knowledge Sharing in Virtual Teams	(Alavi & Leidner, 2001)	2001	Studied the role of KM in virtual teams to improve knowledge sharing, communication, and team performance.
KM Strategies in Construction	(Jashapara, 2003)	2003	Analyzed various KM strategies and their impact on organizational learning and performance in construction firms.
KM Practices in Construction Firms	(Carrillo et al., 2004)	2004	Studied KM practices to improve project management, collaboration, and knowledge sharing among construction professionals.
KM in Supply Chain Management	(Hult et al., 2006)	2004	Implemented KM in supply chain management to enhance coordination, information flow, and overall supply chain performance.
KM for Construction Project Teams	(Sik-wah Fong & Chu, 2006)	2006	Examined the role of KM in enhancing the performance of construction project teams through effective knowledge sharing and collaboration.
KM in Construction Project	(Tan et al., 2006)	2006	Explored the benefits and challenges of implementing KM practices in construction projects to enhance project outcomes.
KM for Sustainable Construction Practices	(Zhang & Ng, 2013)	2012	Applied KM to promote sustainable construction practices by capturing and sharing knowledge on green building techniques.

The table highlights significant research studies that have applied Knowledge Management (KM) theory in the construction industry, demonstrating diverse applications and benefits. Davenport and Short (1990) linked KM with business process improvement to enhance efficiency, while Nonaka, (2009) developed the SECI model to foster organizational learning. Egbu et al., (2001) implemented KM systems in construction to capture and reuse project knowledge, improving efficiency and reducing errors, and Rezgui (2001) integrated IT tools with KM practices to enhance communication and project management. Studies by Carrillo et al., (2004) explored KM practices and their impact on project management and risk mitigation, respectively. However, these studies also reveal limitations such as the need for cultural change to support KM practices, the challenge of integrating KM with existing IT infrastructure, and the difficulty in measuring the direct impact of KM on organizational performance. Furthermore, implementing KM strategies often requires significant investment in technology and training, which can be a barrier for smaller firms. The evolving nature of construction projects and the transient workforce also pose challenges for sustained knowledge sharing and retention. Despite these limitations, the adoption of KM in construction has shown potential for driving innovation, improving project outcomes, and promoting sustainable practices, as evidenced by the studies conducted by Zhang & Fai Ng (2012). These findings underscore the importance of tailored KM approaches to address specific industry needs and the ongoing need for research to refine and enhance KM applications in construction.

Relevance to BIM-FM

The relevance of past studies to Building Information Modelling (BIM) in Facilities Management (FM) lies in their exploration of Knowledge Management (KM) principles and their potential applications in optimizing construction and facilities management processes. For instance, Fischer & Herrmann (2011) demonstrated how integrating BIM tools with user training and communication protocols can optimize both technical and social elements in facilities management. This is directly applicable to BIM in FM, where effective management of building data through BIM tools can enhance the efficiency of maintenance operations and information delivery.

Egbu et al. (2001) and Carrillo et al. (2004) studied the implementation of KM systems in the construction industry to capture and reuse project knowledge, improving efficiency and reducing errors. These insights are relevant to BIM in FM, as they highlight the importance of capturing and leveraging project knowledge to improve facilities management outcomes. Moreover, integrating IT tools with KM practices, as explored by Rezgui (2001), can enhance communication, information sharing, and project management in construction, directly benefiting BIM in FM by ensuring that all stakeholders have access to accurate and up-to-date information.

The studies by Sik-wah Fong & Chu, (2006) and Tan et al., (2006) on KM in construction project teams and the benefits and challenges of implementing KM practices also provide valuable insights into how BIM can be effectively integrated into FM practices to enhance collaboration and project outcomes. Finally, the focus on sustainable construction practices by Zhang & Fai Ng (2012) through KM can inform the use of BIM in FM to promote sustainability by capturing and sharing knowledge on green building techniques. This comprehensive approach to integrating KM with BIM in FM underscores the potential for improving the efficiency, sustainability, and overall performance of facilities management processes.

METHODOLOGY

The study employs a comprehensive literature review methodology to investigate the integration of Socio-Technical Systems (STS) and Knowledge Management (KM) theories within the context of Building Information Modelling for Facilities Management (BIM-FM). The review stages approach recommended by Kouchaksaraei and Karl (2019) was used for conducting this study. It also met the selection criteria established by Moher et al (2009). The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart for the process of selecting the studies is shown in Figure 1. The search and selection methods used in this systematic literature review are discussed in depth below.

Inclusion Criteria

All publication's keywords represent the research's primary concepts. The technique included looking for terms related to "BIM in Facilities

Management" as well as exploring the terms "Socio-Technical Systems," "Knowledge Management," "Building Information Modelling," "Facilities Management," "BIM-FM integration," "information delivery," "operational efficiency" separately. The systematic review includes studies from chosen databases that were written in English and published in peer-reviewed journals and conference proceedings to ensure that all published methods were included. According to Santini, (2018) if the most current citation is older than five years, this may indicate that an exhaustive, up-to-date assessment of the literature has not been done.

Search Strategy

Numerous studies on the topic were obtained through the use of three distinct database platforms such as Scopus, Web of Science, IEEE Xplore, Google Scholar. Due to the vast number of publications on Google Scholar that forbade searches on keywords and abstracts, the search for terms was restricted to publication titles in optimising the research methods and evaluating studies relevant to the defined scope. The papers were analysed comprehensive understanding of the benefits and challenges of integrating STS and KM frameworks within BIM-FM. Thus, duplicate publications from multiple databases were eliminated from the findings obtained. Therefore, the initial sorting was performed by merely reading the titles.

Systematic Review and Content Analysis

Based on the finalised papers, the benefits and challenges of integrating STS and KM frameworks were analysed critically, and the created themes were gleaned from prior research in the field. This section presents five distinct interactions of benefits and three challenges of integrating STS and KM frameworks, based on growing evidence from research and practise. By analysing the content of secondary data sources, including current academic literature, the literature review was undertaken. Following that, the literature artefacts were gathered and analysed to establish the appropriate issue classes.

FINDINGS

Integrating STS and KM Theories in BIM-FM

Benefits of Integration

The integration of Socio-Technical Systems (STS) and Knowledge Management (KM) theories into Building Information Modeling for Facilities Management (BIM-FM) presents significant opportunities for enhancing collaboration and operational efficiency. STS theory emphasizes the importance of optimizing both technical systems and social elements within an organization, fostering a collaborative work environment where human interactions and technology are harmonized (Trist & Bamforth, 1951). When applied to BIM-FM, STS principles support improved teamwork and communication among stakeholders by leveraging BIM's shared data environment. This enhanced collaboration facilitates better decision-making processes and operational efficiency, as all stakeholders can access and share critical information seamlessly (Ghosh et al., 2015; Fong & Kwok, 2009; Love et al., 2014; Succar, 2009).

Moreover, the integration of technical tools (BIM) with human elements (STS) and systematic knowledge processes (KM) streamlines facility management tasks, reducing time and costs associated with maintenance and operations (Liu & Issa, 2014; Motawa & Almarshad, 2013; Volk et al., 2014; Czmoch & Pękala, 2014). Furthermore, the adaptability and user-centered design promoted by STS principles contribute to the increased flexibility of BIM-FM systems. STS theory advocates for the creation of systems that can readily adapt to changes in building usage, maintenance needs, and technological advancements (Nicał & Wodyński, 2016; Arayici & Aouad, 2010; Underwood & Isikdag, 2011; Sabol, 2008). By incorporating user-centered design principles, BIM tools can be made more intuitive and accessible, enhancing their effectiveness in supporting daily FM tasks (Tezel et al., 2022). This adaptability is crucial in dynamic environments where FM professionals need to respond swiftly to new challenges and opportunities.

Additionally, the combination of BIM's technical capabilities with

STS and KM approaches can lead to more sustainable facility management practices. For instance, BIM can facilitate better energy management and maintenance strategies, resulting in reduced environmental impact and operational costs (Becerik-Gerber et al., 2012; Abanda et al., 2017; Azhar, 2011; Wong & Fan, 2013; Chong et al., 2017). Finally, the integration of KM theory into BIM-FM encourages continuous learning and innovation, vital for the long-term success of facilities management practices. KM processes, such as the SECI model (socialization, externalization, combination, and internalization), help convert tacit knowledge into explicit forms and facilitate its dissemination within the organization (Nonaka & Takeuchi, 1995; Santos et al., 2017; McArthur & Bortoluzzi, 2018; Rezgui & Miles, 2011).

This systematic management of knowledge assets ensures that FM professionals can continuously develop new skills and apply innovative practices using BIM technologies. The enhanced information delivery and improved decision-making processes fostered by KM theory not only improve current operations but also prepare organizations for future challenges by promoting a culture of continuous improvement and learning (Tezel et al., 2022). Integrating STS and KM theories into BIM-FM thus provides a robust framework for achieving greater sustainability, efficiency, and adaptability in facility management. Given the current research and academic involvement, these insights will be particularly beneficial for your work on developing a comprehensive understanding of integrating advanced theories into practical applications within the FM sector. The summary in Table 1 outlines the benefits of this integration.

Table 1. Benefits of Integrating STS and KM theories into BIM-FM

Aspects	Benefits	References
Enhanced Collaboration	STS supports improved teamwork and communication by leveraging BIM's shared data environment.	Trist & Bamforth, 1951; Ghosh et al., 2015;Love et al., 2014; Sik-wah Fong & Chu, 2006;Succar, 2009;Love et al., 2014
Improved Efficiency	Integration of technical tools (BIM) with human elements (STS) and systematic KM processes streamlines FM tasks, reducing time and costs associated with maintenance and operations.	Liu & Issa, 2013;Aibinu & Papadonikolaki, 2016; Czmoch & Pękala, 2014; Motawa & Almarshad, 2013; Volk et al., 2014

Increased Adaptability	STS promotes systems that can adapt to changes in building usage, maintenance needs, and technological advancements.	Nicał & Wodyński, 2016; Tezel et al., 2022 Arayici et al., 2012; Tezel et al., 2022;Underwood & Isikdag, 2011;(Sabol, 2008; Underwood & Isikdag, 2011)
Sustainability	Combining BIM's technical capabilities with STS and KM approaches leads to better energy management and maintenance strategies, reducing environmental impact and operational costs.	Becerik-Gerber et al., 2012; Abanda et al., 2017; Azhar, 2011; Chong et al., 2017; Wong & Fan, 2013
Continuous Learning and Innovation	KM processes help convert tacit knowledge into explicit forms, facilitating dissemination within the organization, promoting continuous learning and innovation.	Nonaka & Takeuchi, 1995; Tezel et al., 2022; McArthur & Bortoluzzi, 2018; Rezgui & Miles, 2011; Santos et al., 2017

Challenges of Integration

Integrating Socio-Technical Systems (STS) and Knowledge Management (KM) theories into BIM for Facilities Management (FM) poses significant challenges, particularly regarding technological interoperability. BIM tools and FM systems must effectively communicate and share data to fully realize the potential benefits of integration. This interoperability is often hindered by differing data formats, software incompatibilities, and the need for standardized protocols (Ghosh et al., 2015; Arayici & Aouad, 2010; Eastman, 2011; Liu & Issa, 2014; Solihin & Eastman, 2015). Ensuring seamless data exchange between these systems requires robust integration frameworks and consistent data standards, which are not always present. As a result, organizations may struggle with data silos and inefficiencies, impeding the smooth flow of information crucial for effective facility management.

Cultural resistance within organizations also presents a considerable barrier to the successful integration of STS and KM theories into BIM-FM. Change management is critical, as introducing new technologies and processes can meet with resistance from employees accustomed to traditional methods. Organizational culture significantly influences the acceptance and use of BIM tools, with resistance often stemming from a lack of understanding, fear of job displacement, or discomfort with new technologies (Tezel et al., 2022; Ahn et al., 2013; Davis, 2014; Liu & Issa, 2014; Love et al., 2014). Overcoming this resistance requires comprehensive change management strategies, including stakeholder engagement, effective communication of benefits, and fostering a culture that values continuous improvement and innovation.

Another critical challenge is the management of large-scale data generated by BIM systems, ensuring its accuracy, relevance, and accessibility. BIM generates vast amounts of data that must be meticulously managed to be useful for FM purposes (Liu & Issa, 2013; Becerik-Gerber et al., 2012; Demian & Walters, 2014; Motawa & Almarshad, 2013; Volk et al., 2014). This involves not only storing and maintaining data but also ensuring its accuracy and relevance over time. Furthermore, providing adequate training and support to FM professionals to use BIM tools effectively is crucial. Many FM professionals may lack the necessary skills to leverage BIM technologies fully, necessitating ongoing training and development programs. Such programs must be designed to enhance the technical proficiency of FM staff, ensuring they can effectively utilize BIM tools to improve facility operations and maintenance. Table 2 below presents the summary of challenges of the integration.

Table 2. Challenges of Integrating STS and KM theories into BIM-FM

Aspects	Challenges	References
Technological Interoperability	Ensuring effective communication and data sharing between BIM tools and FM systems is challenging due to differing data formats and software incompatibilities.	Ghosh et al., 2015; (Arayici & Aouad, 2010; Eastman, 2011; Liu & Issa, 2014; Solihin & Eastman, 2015
Cultural Resistance	Organizational culture and resistance to change can hinder the adoption of new technologies and processes. Overcoming resistance requires comprehensive change management strategies.	Tezel et al., 2022(Ahn et al., 2013; Davis, 2014; Liu & Issa, 2014; Love et al., 2014
Data Management	Managing large-scale data generated by BIM, ensuring its accuracy, relevance, and accessibility, and providing adequate training and support to FM professionals.	Liu & Issa, 2013; Becerik-Gerber et al., 2012;Demian & Walters, 2014; Motawa & Almarshad, 2013; Volk et al., 2014

Future Directions

Practical Frameworks of Integration

One of the most significant research gaps in integrating STS and KM theories into BIM-FM is the lack of practical frameworks that can be readily applied in real-world settings. Although the theoretical benefits of combining these approaches are well-documented, there is a need for clear, actionable guidelines that detail how organizations can effectively implement these integrated systems. Existing literature often focuses on the conceptual advantages without providing concrete steps for integration, leaving practitioners without the necessary tools to translate theory into practice (Ghosh et al., 2015; Eastman, Teicholz, Sacks, & Liston, 2011; Liu & Issa, 2014).

Many studies explored the potential benefits of STS and KM integration conceptually but lack detailed implementation strategies. For instance, Ghosh et al. (2015) discussed the benefits of integrating BIM with FM systems but did not provide a practical roadmap for achieving this integration. Furthermore, while theoretical frameworks exist, empirical testing and validation in real-world contexts are often missing. Eastman et al. (2011) highlighted the importance of BIM for facility management but noted that practical applications and case studies are still limited, underscoring the need for empirical research to validate these concepts.

Practitioners require detailed, step-by-step guidelines to implement integrated STS and KM systems effectively. Liu and Issa (2014) emphasized the necessity of developing practical frameworks that can guide practitioners in applying these theories to enhance FM processes. Additionally, operationalizing theoretical insights into practical tools and frameworks remains a significant challenge. For instance, Becerik-Gerber et al. (2012) discussed the potential of BIM-enabled facilities management but acknowledge the gap in translating theoretical concepts into practical applications.

Developing and empirically testing such frameworks is essential to bridge this gap, ensuring that theoretical insights can be operationalized in diverse organizational contexts. This will ultimately provide the necessary tools for practitioners to translate theory into practice effectively, enhancing the practical utility of these integrated systems in the field of facilities management.

Need for Case Studies

Another critical gap is the need for more case studies that demonstrate the real-world application and benefits of integrating STS and KM theories into BIM-FM. Case studies provide valuable insights into the practical challenges and successes of implementing these integrated approaches in various contexts. They offer detailed accounts of how specific projects have navigated issues related to technological interoperability, cultural resistance, and data management. By examining a diverse range of case studies, researchers and practitioners can identify best practices and lessons learned that can be applied to future projects (Nicał & Wodyński, 2016).

Case studies allow for the examination of real-world applications, offering practical insights that theoretical research alone cannot provide. For example, Nicał and Wodyński (2016) discuss the practical application of BIM in facilities management but highlight the need for more comprehensive case studies to understand the complexities involved fully. Specific case studies can demonstrate how different projects have addressed the challenges of technological interoperability. Liu and Issa (2014) and Eastman et al. (2011) indicate that while interoperability is a known issue, there is a lack of detailed accounts showing successful integration strategies in practice. Additionally, case studies can provide detailed narratives on overcoming cultural resistance, showcasing change management strategies that have been effective in various organizational settings. Tezel et al. (2022) and Ahn et al. (2013) emphasize the importance of understanding organizational culture, but concrete examples are necessary to illustrate successful approaches.

The management of large-scale BIM data is a critical challenge that needs practical solutions. Case studies, such as those discussed by Becerik-Gerber et al. (2012) and Motawa and Almarshad (2013), can reveal effective data management practices, including training programs and data accuracy strategies. A diverse range of case studies helps in generalizing findings across different types of projects and organizational contexts. Without sufficient case studies, it is challenging to develop robust integration strategies that are widely applicable. This gap is highlighted by the limited empirical testing and validation in existing literature (Eastman et al., 2011; Volk et al., 2014).

Empirical validation through case studies is crucial for advancing theoretical frameworks. Detailed case studies provide the evidence needed to validate and refine theoretical models, ensuring they are practical and effective in real-world settings (Liu & Issa, 2013; Rezgui & Miles, 2010). Addressing this gap by conducting and documenting more case studies is critical for advancing the integration of STS and KM theories into BIM-FM. These case studies will provide the necessary empirical evidence to validate theoretical models and develop practical, actionable frameworks that can be widely applied across various projects and organizational contexts.

Evaluation of Benefits and Challenges

While some studies discuss the benefits and challenges of integrating STS and KM theories into BIM-FM, there is a need for more comprehensive evaluations that consider a wide range of factors. Most existing research tends to focus on specific aspects, such as technological challenges or cultural resistance, without providing a holistic view of how these factors interact and impact overall project outcomes. Future research should aim to conduct in-depth evaluations that consider the interdependencies between various elements of STS and KM in the context of BIM-FM (Liu & Issa, 2013). This would involve assessing not only the immediate impacts on operational efficiency and collaboration but also the long-term effects on organizational culture, employee satisfaction, and sustainability .

CONCLUSION

The integration of Socio-Technical Systems (STS) and Knowledge Management (KM) theories into Building Information Modelling for Facilities Management (BIM-FM) presents both significant opportunities and critical challenges. While the theoretical benefits are well-documented, including enhanced collaboration, improved efficiency, increased adaptability, sustainability, and continuous learning, the practical implementation of these integrated systems remains a substantial hurdle. The lack of practical frameworks and detailed case studies impedes the translation of theory into practice. Addressing technological interoperability, cultural resistance, and data management requires comprehensive strategies and empirical validation through diverse case studies. Bridging these gaps will enable the development of robust, actionable frameworks that can be widely applied, ultimately enhancing the efficacy and sustainability of FM practices through the integration of STS and KM with BIM.

Recommendations for Future Research

Develop and testing frameworks

A key future direction for research is the development and empirical testing of practical frameworks that integrate Socio-Technical Systems (STS) and Knowledge Management (KM) theories into Building Information Modelling for Facilities Management (BIM-FM). Currently, there is a gap in actionable guidelines that detail the steps for implementing these integrated systems effectively. Researchers need to create frameworks that outline clear methodologies for combining STS and KM with BIM, ensuring that the integration enhances collaboration, operational efficiency, and overall facility management performance (Ghosh et al., 2015). These frameworks should be tested in real-world settings through pilot studies and case studies to validate their effectiveness and adaptability across different organizational contexts. This process will help bridge the gap between theoretical insights and practical applications, providing practitioners with the tools they need to optimize BIM-FM integration.

The rapid advancement of technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), and Machine Learning (ML) presents new opportunities for enhancing the integration of STS and KM in BIM-FM. Future research should explore how these emerging technologies can be leveraged to support the principles of STS and KM. For instance, IoT sensors can provide real-time data on building performance, which can be integrated into BIM models to facilitate more effective facility management (Nicał & Wodyński, 2016). AI and ML algorithms can analyze large datasets to identify patterns and predict maintenance needs, improving decision-making processes and operational efficiency. Investigating the potential applications and challenges of these technologies will be crucial for developing more intelligent and responsive BIM-FM systems. Research should focus on creating frameworks and protocols for integrating these technologies seamlessly with existing BIM-FM systems, ensuring that they enhance rather than complicate facility management practices.

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All authors contributed to the design of the research, the analysis, and the write-up. The data identification and tabulation were undertaken by the researchers. All authors have read and approved the final manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Abanda, F. H., Kamsu-Foguem, B., & Tah, J. H. M. (2017). BIM–New rules of measurement ontology for construction cost estimation. Engineering Science and Technology. *International Journal, 20*(2), 443–459. https://doi.org/10.1016/j.jestch.2017.01.007.

Ahn, Y. H., Pearce, A. R., Wang, Y., & Wang, G. (2013). Drivers And Barriers Of Sustainable Design And Construction: The Perception Of Green Building Experience. *International Journal of Sustainable Building Technology and Urban Development, 4*(1), 35–45. http://dx.doi.org/10.1080/2093761X.2012.759887.

Aibinu, A., & Papadonikolaki, E. (2016, January). BIM Implementation And Project Coordination In Design-Build Procurement. *In Proceedings* *of the 32nd Annual ARCOM Conference, ARCOM 2016* (pp. 15-24). https://discovery.ucl.ac.uk/id/eprint/10048671/.

Alavi, M., & Leidner, D. E. (2001). *Knowledge management and knowledge Management Systems: Conceptual Foundations And Research Issues*. MIS Quarterly, 107–136. http://dx.doi.org/10.2307/3250961.

Albino, V., Berardi, U., & Dangelico, R. M. (2015). Smart cities: Definitions, Dimensions, Performance, And Initiatives. *Journal of Urban Technology, 22*(1), 3–21. https://doi.org/10.1080/10630732.2014.942092.

Arayici, Y., & Aouad, G. (2010). *Building Information Modelling (BIM) for Construction Lifecycle Management.* Construction and Building: Design, Materials, and Techniques, 2010, 99–118. https://shorturl.at/EDtOL.

Azhar, S. (2011). Building information modeling (BIM): Trends, Benefits, Risks, And Challenges For The AEC Industry. *Leadership and Management in Engineering, 11*(3), 241–252. https://doi.org/10.1061/(ASCE)LM.1943-5630.0000127.

Azmi, N. A., Ismail, N. A. A., & Rosman, A. F. (2023). A Systematic Review On Barriers In Integrating Building Information Modelling (BIM) In Facilities Management. *MCRJ, 20*(3), 809–820. https://www.cream.my/prod/mcrj-special-issue-volume-20-no-3-2023-.

Baines, T., Lightfoot, H., & Smart, P. (2011). Servitization Within Manufacturing: Exploring The Provision Of Advanced Services And Their Impact On Vertical Integration. *Journal of Manufacturing Technology Management, 22*(7), 947–954. http://dx.doi.org/10.1108/17410381111160988.

Becerik-Gerber, B., Jazizadeh, F., Li, N., & Calis, G. (2012). Application Areas And Data Requirements For BIM-Enabled Facilities Management. *Journal of Construction Engineering and Management, 138*(3), 431–442. http://dx.doi.org/10.1061/(ASCE)CO.1943-7862.0000433.

Bichsel, J. (2012). *Analytics in higher education: Benefits, Barriers, Progress, And Recommendations.* EDUCAUSE Center for Applied

Research. http://dx.doi.org/10.13140/RG.2.1.1064.6244.

Carbonari, G., Stravoravdis, S., & Gausden, C. (2018). Improving FM task efficiency through BIM: a proposal for BIM implementation. *Journal of Corporate Real Estate, 20*(1), 4–15. https://doi.org/10.1108/JCRE-01-2017-0001.

Carrillo, P. M., Anumba, C. J., & Kamara, J. M. (2000). Knowledge Management Strategy For Construction: Key IT And Contextual Issues. *Proceedings of CIT, 2000*, 28–30. https://doi.org/10.1002/kpm.146.

Chong, H.-Y., Lee, C.-Y., & Wang, X. (2017). A Mixed Review Of The Adoption Of Building Information Modelling (BIM) For Sustainability. *Journal of Cleaner Production*, 142, 4114–4126. http://dx.doi.org/10.1016/j.jclepro.2016.09.222.

Czmoch, I., & Pękala, A. (2014). Traditional Design Versus BIM Based Design. *Procedia Engineering, 91(TFoCE)*, 210–215. https://doi.org/10.1016/j.proeng.2014.12.048.

Dahanayake, K. C., & Sumanarathna, N. (2022). IoT-BIM-based Digital Transformation In Facilities Management: A Conceptual Model. *Journal of Facilities Management, 20*(3), 437–451. https://doi.org/10.1108/JFM-10-2020-0076.

Davenport, T. H., & Short, J. E. (1998). The new industrial engineering: information technology and business process redesign. *IEEE Engineering Management Review, 26*(3), 46-60. https://shorturl.at/IoWQZ.

Davis, K. (2014). Different Stakeholder Groups And Their Perceptions Of Project Success. *International Journal of Project Management, 32*(2), 189–201. https://doi.org/10.1016/j.ijproman.2013.02.006.

Demian, P., & Walters, D. (2014). The Advantages Of Information Management Through Building Information Modelling. *Construction Management and Economics, 32*(12), 1153–1165. http:// dx.doi.org /10.1080 /01446193 . 2013 . 777754.

Eastman, C. M. (2011). *BIM Handbook: A Guide To Building Information Modeling For Owners, Managers, Designers, Engineers And*

Contractors. John Wiley & Sons.

Edirisinghe, R., & Woo, J. (2021). BIM-Based Performance Monitoring For Smart Building Management. *Facilities, 39*(1–2), 19–35. https://doi.org/10.1108/F-11-2019-0120.

Edwards, J. S. (2019). *Knowledge Management: Theories and Practices*. In M. Fedeli & L. L. Bierema (Eds.), Connecting Adult Learning and Knowledge Management: Strategies for Learning and Change in Higher Education and Organizations (pp. 139–156). Springer International Publishing. https://doi.org/10.1007/978-3-030-29872-2_8.

Egbu, C., Botterill, K., & Bates, M. (2001, September). The Influence Of Knowledge Management And Intellectual Capital On Organizational Innovations. *In Proceedings of the 17th Annual Conference of the Association of Researchers in Construction Management* (ARCOM) (Vol. 1, pp. 5-7).

Farooq, R. (2019). Developing A Conceptual Framework Of Knowledge Management. *International Journal of Innovation Science, 11*(1), 139–160. Emerald Group Holdings Ltd. https://doi.org/10.1108/IJIS-07-2018-0068.

Ferreira, J., Mueller, J., & Papa, A. (2020). Strategic Knowledge Management: Theory, Practice And Future Challenges. *Journal of Knowledge Management, 24*(2), 121–126. Emerald Group Holdings Ltd. https://doi.org/10.1108/JKM-07-2018-0461.

Fischer, G., & Herrmann, T. (2011). Socio-Technical Systems: A Meta-Design Perspective. *International Journal of Sociotechnology and Knowledge Development, 3*(1). https://doi.org/10.4018/jskd.2011010101.

Geels, F. W. (2011). The Multi-Level Perspective On Sustainability Transitions: Responses To Seven Criticisms. *Environmental Innovation and Societal Transitions, 1*(1), 24–40. https://doi.org/10.1016/j.eist.2011.02.002.

Ghansah, F. A., Lu, W., Chen, J., & Peng, Z. (2022). A Socio-Technical System (STS) Framework for Modular Construction of Cognitive Buildings. *IOP Conference Series: Earth and Environmental Science*, 1101(7). https://doi.org/10.1088/1755-1315/1101/7/072012.

Ghosh, A., Chasey, A. D., & Mergenschroer, M. (2015). *Building Information Modeling For Facilities Management: Current Practices And Future Prospects.* Building Information Modeling: Applications and Practices, 223–253. https://doi.org/10.1061/9780784413982.ch09.

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.

Hult, G. T. M., Ketchen Jr, D. J., Cavusgil, S. T., & Calantone, R. J. (2006). Knowledge As A Strategic Resource In Supply Chains. *Journal of Operations Management, 24*(5), 458–475. https://doi.org/10.1016/j.jom.2005.11.009.

Jashapara, A. (2003). Cognition, Culture And Competition: An Empirical Test Of The Learning Organization. *The Learning Organization, 10*(1), 31–50. https://doi.org/10.1108/09696470310457487.

Kouchaksaraei, H. R., & Karl, H. (2019). Procedures for Performing Systematic Review. DEBS 2019 - *Proceedings of the 13th ACM International Conference on Distributed and Event-Based Systems,* 240–243.

Liu, R., & Issa, R. R. A. (2014). Design For Maintenance Accessibility Using BIM Tools. *Facilities, 32*(3), 153–159. https://doi.org/10.1108/F-09-2011-0078.

Love, P. E. D., Matthews, J., Simpson, I., Hill, A., & Olatunji, O. A. (2014). *A Benefits Realization Management Building Information Modelling Framework For Asset Owners*. Automation in Construction, 37, 1–10. https://doi.org/10.1016/j.autcon.2013.09.007.

Lyytinen, K., & Newman, M. (2008). Explaining Information Systems Change: A Punctuated Socio-Technical Change Model. *European Journal of Information Systems, 17*(6), 589–613. https://doi.org/10.1057/ejis.2008.50.

Martins, V. W. B., Rampasso, I. S., Anholon, R., Quelhas, O. L. G., & Leal Filho, W. (2019). Knowledge Management In The Context

Of Sustainability: Literature Review And Opportunities For Future Research. *Journal of Cleaner Production*, 229, 489–500. https://doi.org/10.1016/j.jclepro.2019.04.354.

Marmo, R., Nicolella, M., Polverino, F., & Tibaut, A. (2019). *A Methodology For A Performance Information Model To Support Facility Management*. Sustainability (Switzerland), 11(24), 1–25.

McArthur, J. J. (2015). A Building Information Management (BIM) Framework and Supporting Case Study for Existing Building Operations, Maintenance and Sustainability. *Procedia Engineering,* 118, 1104–1111. https://doi.org/10.1016/j.proeng.2015.08.450.

McArthur, J. J., & Bortoluzzi, B. (2018). Lean-Agile FM-BIM: A Demonstrated Approach. *Facilities, 36*(13–14), 676–695. https://doi.org/10.1108/F-04-2017-0045.

Motawa, I., & Almarshad, A. (2013). A Knowledge-Based BIM System For Building Maintenance. *Automation in Construction*, 29, 173–182. https://doi.org/10.1016/j.autcon.2012.09.008.

Nicał, A. K., & Wodyński, W. (2016). Enhancing Facility Management Through BIM 6D. *Procedia Engineering,* 164, 299–306. https://doi.org/10.1016/j.proeng.2016.11.623.

Nonaka, I. (2009). *The Knowledge-Creating Company.* In The Economic Impact Of Knowledge (pp. 175–187). Routledge.

Pavón, R. M., Alberti, M. G., Álvarez, A. A. A., & Del Rosario Chiyón Carrasco, I. (2021). Use of BIM-FM To Transform Large Conventional Public Buildings Into Efficient And Smart Sustainable Buildings. *Energies, 14*(11), 1–22. https://doi.org/10.3390/en14113127.

Rashed, M. S. , & N. A. U. (2016). *The Readiness of Banks for Implementation of Knowledge Management: A Study on Commercial Banks of Bangladesh.* The Chittagong University Journal of Business Administration. Bangladesh. http://dx.doi.org/10.4172/2167-0234.1000181.

Rezgui, Y. (2001). Review Of Information And The State Of The Art Of Knowledge Management Practices In The Construction Industry.

The Knowledge Engineering Review, 16(3), 241–254. https://doi.org/10.1017/S026988890100008X.

Rezgui, Y., & Miles, J. (2011). *Harvesting And Managing Knowledge In Construction: From Theoretical Foundations To Business Applications*. Routledge.

Sabol, L. (2008). *Challenges in Cost Estimating With Building Information Modelling.* IFMA World Workplace, 1, 1–16.

Santini, A. (2018). The Importance of Referencing. *The Journal of Critical Care Medicine, 4*(1), 3–4. https://doi.org/10.2478/jccm-2018-0002.

Santos, R., Costa, A. A., & Grilo, A. (2017). Bibliometric Analysis And Review Of Building Information Modelling Literature Published Between 2005 and 2015. *Automation in Construction,* 80, 118–136. http://dx.doi.org/10.1016/j.autcon.2017.03.005.

Sik-wah Fong, P., & Chu, L. (2006). Exploratory Study Of Knowledge Sharing In Contracting Companies: A Sociotechnical Perspective. *Journal of Construction Engineering and Management, 132*(9), 928–939. http://dx.doi.org/10.1061/(ASCE)0733-9364(2006)132:9(928).

Solihin, W., & Eastman, C. (2015). Classification Of Rules For Automated BIM Rule Checking Development. *Automation in Construction,* 53, 69–82. https://doi.org/10.1016/j.autcon.2015.03.003.

Succar, B. (2009). Building Information Modelling Framework: A Research And Delivery Foundation For Industry Stakeholders. *Automation in Construction, 18*(3), 357–375. https://doi.org/10.1016/j.autcon.2008.10.003.

Sunil Luthra, Sanjay Kumar, Ravinder Kharb, Md. Fahim Ansari, & S.L. Shimmi. (2014). *Adoption Of Smart Grid Technologies: An Analysis Of Interactions Among Barriers.* Renewable and Sustainable Energy. https://doi.org/10.1016/j.rser.2014.02.030.

Tan, H. C., Carrillo, P., Anumba, C., Kamara, J. M., Bouchlaghem, D., & Udeaja, C. (2006). Live Capture And Reuse Of Project Knowledge In Construction Organisations. *Knowledge Management Research and Practice, 4*(2), 149–161. https://doi.org/10.1057/palgrave.

kmrp.8500097.

Tezel, E., Giritli, H., Tezel, E., Alatli, L., & Giritli, & H. (2022). Barriers for Efficient Facility Management: Perspectives of BIM-users And Non-BIM-Users. *Journal for Facility Management,* 2022, 41–51. https://www.researchgate.net/publication/365787791.

Tzortzaki, A. M., & Mihiotis, A. (2014). A Review of Knowledge Management Theory and Future Directions. *Knowledge and Process Management, 21*(1), 29–41. https://doi.org/10.1002/kpm.1429.

Underwood, J., & Isikdag, U. (2011). *Emerging technologies for BIM 2.0*. Construction Innovation, 11(3), 252–258.

Valerie Leonard Doudilim, Y., Asrul Nasid bin Masrom, M., binti Ahmad Latiffi, A., & binti Kasim, N. (2021). *Building Information Modeling (BIM) Implementation Towards Improving Collaborative Communication in Construction Projects.* 2(2), 395–414. https://doi.org/10.30880/rmtb.2021.02.02.030.

Villani, V., Pini, F., Leali, F., & Secchi, C. (2018). Survey On Human–Robot Collaboration In Industrial Settings: Safety, Intuitive Interfaces And Applications. *Mechatronics,* 55, 248–266.https://doi.org/10.1016/j.mechatronics.2018.02.009.

Volk, R., Stengel, J., & Schultmann, F. (2014a). Building Information Modeling (BIM) For Existing Buildings—Literature Review And Future Needs. *Automation in Construction,* 38, 109–127. http://dx.doi.org/10.1016/j.autcon.2013.10.023.

Wong, K., & Fan, Q. (2013). Building Information Modelling (BIM) For Sustainable Building Design. *Facilities, 31*(3/4), 138–157.https://doi.org/10.1108/02632771311299412.

Zhang, P., & Ng, F. F. (2013). Explaining Knowledge-Sharing Intention In Construction Teams In Hong Kong. *Journal of Construction Engineering and Management, 139*(3), 280–293. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000607.