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Critical Success Factors in Digital Facilities Management Implementation: A Systematic Literature Review

Ahmad Sharainon Md Shaarani
Department of Real Estate, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Malaysia

Mat Naim Abdullah @ Mohd Asmoni and Shastitharran Baskaran
Department of Real Estate, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Malaysia

ABSTRACT

Digital transformation in facilities management has gained global momentum; however, implementation outcomes remain inconsistent across organizations and sectors. Despite the widespread adoption of technologies such as BIM-FM, IoT, AI/ML, and Digital Twins, many Digital Facilities management (DFM) initiatives fail to achieve their intended value due to misalignment between technological capabilities and organizational readiness. This study aims to systematically identify and quantify the critical success factors (CSFs) that underpin successful DFM implementation. A systematic literature review and meta-analysis were conducted in accordance with PRISMA 2020 guidelines. Forty-seven empirical studies published between 1990 and 2025 were synthesized. Data extraction focused on implementation factors, contextual conditions, and reported outcomes. A random-effects meta-analysis was applied to estimate pooled odds ratios (OR) with 95% confidence intervals. The review identified 25 distinct CSFs, of which 15 were consistently reported across multiple studies. Universal organizational enablers emerged as the strongest predictors of success, including leadership support (OR = 29.6, 95% CI: 2.73–320.48), training programs (OR = 13.7, 95% CI: 2.27–82.73), and stakeholder engagement (OR = 9.3, 95% CI: 2.00–43.63). Technology-specific factors such as infrastructure readiness (OR = 5.8), data quality management (OR = 4.8), and change management (OR = 4.1) also demonstrated statistically significant effects. In contrast, context-specific factors—including pilot testing, vendor support, and budget adequacy—showed weaker and statistically non-significant contributions. The findings confirm that organizational enablers play a more decisive role than technology alone in achieving successful DFM implementation. This study contributes a statistically grounded CSF framework that extends existing technology adoption theories within the facilities management context and provides actionable guidance for practitioners, technology vendors, and policymakers seeking to accelerate digital transformation in FM.

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Corresponding Author Contact:

sharainon@graduate.utm.my

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1. Introduction

Facilities Management (FM) is widely recognized as an interdisciplinary academic and professional field that integrates human resources, physical assets, organizational strategies, and technological systems to ensure the effective operation of the built environment. Traditionally, FM practices have relied heavily on reactive maintenance approaches and manual processes, which have frequently resulted in inefficiencies, increased operational costs, and misalignment with organizational objectives (Teicholz, 2013). Over recent decades, however, FM has progressively transitioned toward digital innovation, driven by rapid technological advancement, heightened user expectations, and growing sustainability imperatives (Love et al., 2014; Pishdad-Bozorgi et al., 2018).

Digital Facilities Management (DFM) refers to the integration of digital technologies such as Building Information Modeling for Facilities Management (BIM-FM), the Internet of Things (IoT), Digital Twins, Computerized Maintenance Management Systems (CMMS), Computer-Aided Facilities Management (CAFM), and emerging applications of Artificial Intelligence and Machine Learning (AI/ML). These technologies support a shift from predominantly reactive or preventive maintenance models toward more proactive, data-driven, and predictive operational strategies (Kensek, 2014; Patacas et al., 2015). Through improved data integration and advanced analytics, DFM has demonstrated the potential to reduce operational costs by 15–30%, improve energy efficiency by up to 40%, and enhance maintenance productivity by nearly 50% (Naji et al., 2024; Silverio-Fernandez et al., 2019).

Despite these benefits, the outcomes of DFM implementation remain inconsistent across sectors and geographic contexts. Prior studies report that approximately 40–60% of digital transformation initiatives in FM fail to deliver their anticipated value. Importantly, these failures are often attributed not solely to technological limitations, but to insufficient organizational readiness and misalignment between technological capabilities and institutional needs (Oluleye et al., 2021; Ashworth & Tucker, 2019). This underscores the fact that successful DFM adoption depends on a complex interaction of technological, organizational, human, and environmental factors. Without a clear understanding of these determinants, FM organizations risk underperforming digital investments and unrealized strategic value.

Existing literature identifies numerous facilitators of successful DFM implementation, including strong leadership commitment, access to structured training programs, active stakeholder engagement, and system interoperability (Kotter, 1995; Volk et al., 2014). Conversely, commonly reported barriers include high initial investment costs, limited technical expertise, concerns regarding data security, and organizational resistance to change (Venkatesh et al., 2003; Oreg, 2006). However, the existing evidence base remains fragmented. Many studies focus on single technologies such as BIM-FM or IoT, or are confined to specific sectors including healthcare or education, limiting the generalizability of findings across the broader FM landscape.

Another limitation of previous reviews is their tendency to emphasize adoption trends or performance outcomes rather than systematically identifying the underlying factors that determine implementation success or failure (Ghansah, 2024; Shuhaimi et al., 2024). Consequently, there remains no consolidated, evidence-based synthesis of the critical success factors (CSFs) governing DFM implementation. This gap has significant practical implications, as FM practitioners, technology vendors, and decision-makers often lack empirically grounded guidance to support strategic planning, execution, and evaluation of digital initiatives.

The importance of identifying CSFs is further amplified by global developments such as rapid urbanization, the emergence of smart cities, and increasing sustainability mandates. These trends place growing pressure on FM organizations to deliver services that are efficient, resilient, and user-centric (World Economic Forum, 2020). Simultaneously, regulatory bodies and governments are promoting digital readiness and sustainability compliance through initiatives such as national BIM mandates and frameworks aligned with the European Green Deal (European Commission, 2020). Within this context, understanding and prioritizing CSFs is essential not only for operational improvement but also for long-term competitiveness and regulatory compliance.

From a theoretical perspective, studies examining DFM adoption frequently draw upon established frameworks such as the Technology Acceptance Model (TAM), the Technology–Organization–Environment (TOE) framework, and the Diffusion of Innovation (DOI) theory (Davis, 1989; Tornatzky & Fleischer, 1990; Rogers, 2003). While these models offer valuable insights into user behavior, organizational readiness, and environmental influences, they remain largely generic and do not fully capture the multidisciplinary, asset-intensive nature of facilities management. As such, there is a need for a synthesis that contextualizes these frameworks within FM practice, where successful implementation often depends on cross-functional collaboration and long-term asset stewardship.

Collectively, these gaps highlight the need for a structured and empirically grounded evidence base capable of systematically identifying, categorizing, and quantifying the CSFs that support successful DFM implementation. A systematic literature review supported by meta-analysis offers a rigorous and replicable approach to address this need, enabling comparison across regions, sectors, and technologies, while assessing the relative significance and consistency of identified success factors.

Accordingly, this study conducts a systematic review of forty-seven empirical studies published between 1990 and 2025, following PRISMA 2020 guidelines. The analysis synthesizes universal, technology-specific, and context-dependent CSFs and proposes a structured framework to support DFM implementation. By situating these findings within established adoption theories and FM practice, the study contributes both theoretical refinement and practical guidance for stakeholders seeking to advance digital transformation in facilities management.

2. Methods

2.1 Review Protocol

This study strictly adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines (Page et al., 2021). A review protocol was established beforehand to guarantee transparency, delineating the research questions, inclusion and exclusion criteria, and analytical methodologies.

2.2. Eligibility Criteria

The review focused on studies that examined digital facilities management technologies such as Building Information Modelling applied to FM, Internet of Things applications, Digital Twins, computerized maintenance management systems, computer-aided facilities management platforms, and artificial intelligence or machine learning solutions. Eligible studies were required to present empirical findings related to implementation, including success factors, barriers, or enablers. Only peer-reviewed journal articles, high-quality conference proceedings, and doctoral theses published in English between 1990 and 2025 were considered. Studies were excluded if they reported only performance outcomes without an implementation context, if they were outside the FM domain, if they were non-empirical such as opinion papers, or if they lacked sufficient methodological detail.

2.3. Data Sources and Search Strategy

The literature search was carried out across a wide range of databases to maximize coverage. These included multidisciplinary databases such as Scopus, Web of Science, and Google Scholar, alongside domain-specific repositories like IEEE Xplore and the ACM Digital Library for engineering and computing, as well as PubMed for health-related studies. Open-access sources such as ArXiv and ResearchGate were included as supplementary sources to identify additional relevant studies, together with publisher databases such as Emerald Insight, Taylor & Francis Online, and the ASCE Library. To ensure completeness, reference lists of the included studies were screened manually for additional publications.

The search strategy applied combinations of keywords relating to digital facilities management, implementation, and success factors. Terms such as “digital FM,” “smart facilities management,” “BIM for FM,” “IoT in FM,” “digital twin for FM,” and “computerized maintenance management” were combined with expressions including “critical success factor,” “enabler,” “barrier,” and “best practice.” The use of multiple terms ensured that variations in terminology across different disciplines and publication venues were captured.

2.4. Data Extraction

Data were extracted using a standardized template covering bibliographic information, study design, participant characteristics, technology type, implementation factors, outcomes, and quality indicators. Extraction was conducted independently by two reviewers to minimize bias.

2.5. Risk of Bias Assessment

The methodological quality of included studies was appraised using an adapted ROBINS-I framework (Sterne et al., 2016). Seven domains of bias were assessed: confounding, participant selection, intervention classification, deviations from intended interventions, missing data, outcome measurement, and selective reporting. Studies were rated as low, moderate, or serious risk of bias.

2.6. Data Synthesis and Analysis

A thematic synthesis was conducted to identify recurring critical success factors (CSFs) and implementation barriers. This study applied a random-effects meta-analysis to perform quantitative synthesis, in accordance with Cochrane guidelines (Higgins & Green, 2008). Odds ratios and prevalence rates were pooled, and heterogeneity across studies was assessed using the I^2 statistic and Cochran’s Q test. Subgroup analyses were performed based on technology type, geographic region, and sector. Potential publication bias was evaluated using funnel plots and Egger’s regression test (Egger et al., 1997).

3. Results

This section presents the results of the systematic literature review and synthesis of empirical studies examining the implementation of DFM. The results are organised into six main components: study selection, study characteristics, risk of bias assessment, identification of critical success factors (CSFs), analysis of implementation barriers, and subgroup analysis. Each set of findings is supported by visual evidence presented in the corresponding figures.

3.1. Study Selection

The database search initially identified 1,247 records. After the removal of 312 duplicates, 935 articles remained for title and abstract screening. Of these, 846 records were excluded as they fell outside the scope of digital facilities management implementation. A total of 89 articles underwent full-text review, of which 42 were excluded due to insufficient methodological detail or lack of relevance to the FM domain. Ultimately, 47 studies were included in the final analysis.

The selection process is depicted in the PRISMA flow diagram *(*Figure 1*)*. This figure demonstrates that the review followed a systematic and transparent process consistent with PRISMA 2020 guidelines. By presenting each stage of screening, from identification to inclusion, the figure confirms that only high-quality and relevant studies were retained. The structured selection process also highlights the rigor of the review, assuring readers that the dataset is both comprehensive and methodologically sound.

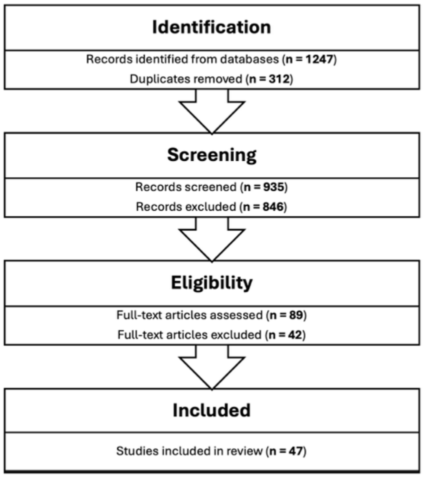


Figure 1. PRISMA Flow Diagram of study selection process

3.2. Study Characteristics

The included 47 studies span the years 2018 to 2024, with the majority clustered between 2022 and 2023, reflecting the growing global momentum of DFM adoption in recent years. Although the literature search covered the period from 1990 to 2025, empirical studies that met the inclusion criteria were predominantly published after 2018, corresponding to the relatively recent maturity and widespread application of digital technologies in facilities management. Geographically, Asia-Pacific accounted for the highest proportion (32%), followed by Africa (26%), Europe (17%), North America (13%), the Middle East (9%), and South America (4%). This distribution is illustrated in Figure 2.

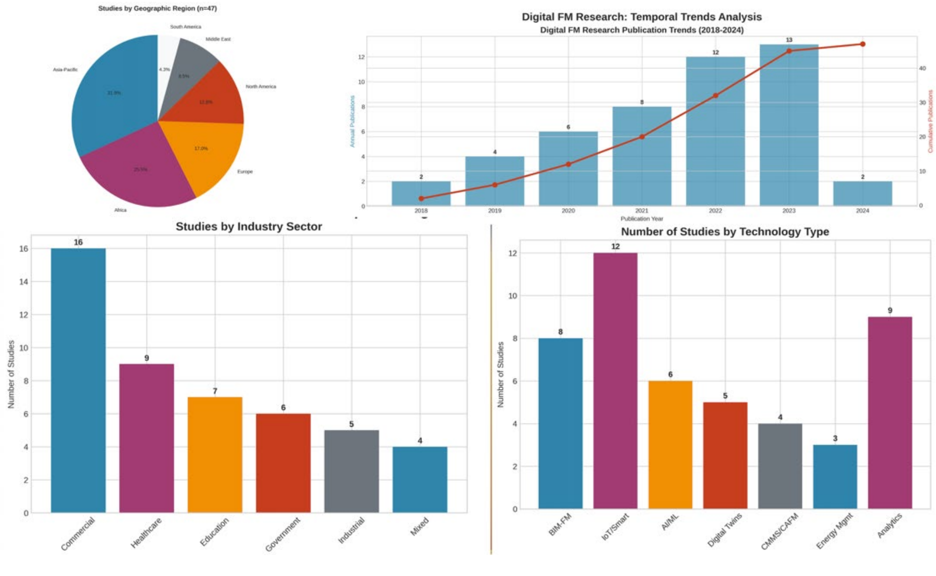


Figure 2. Distribution of included studies by technology type and region

The figure shows not only the geographic spread but also the concentration of research in emerging economies where digital adoption in FM is gaining traction. For instance, Asia-Pacific and African studies often highlighted cost-effectiveness and infrastructure readiness, while European studies emphasized regulatory compliance and sustainability. North American publications were fewer in number but tended to focus on innovation and scalability. This variation suggests that contextual drivers strongly shape research priorities in different regions.

From a technological perspective, IoT and smart building systems dominated (26%), followed by data analytics (19%), BIM-FM (17%), AI/ML (13%), Digital Twins (11%), CMMS/CAFM (9%), and energy management systems (6%). As seen in Figure 2, IoT has become the leading research domain because of its real-time monitoring capabilities and applicability across multiple sectors. In contrast, AI/ML and Digital Twin technologies, while less frequent, reflect cutting-edge innovations that may represent the future trajectory of FM research.

3.3. Risk of Bias Assessment

The methodological quality of the included studies was evaluated using an adapted ROBINS-I framework. As shown in Figure 3, 17% of the studies were categorized as low risk of bias, 66% as moderate, and 17% as serious.

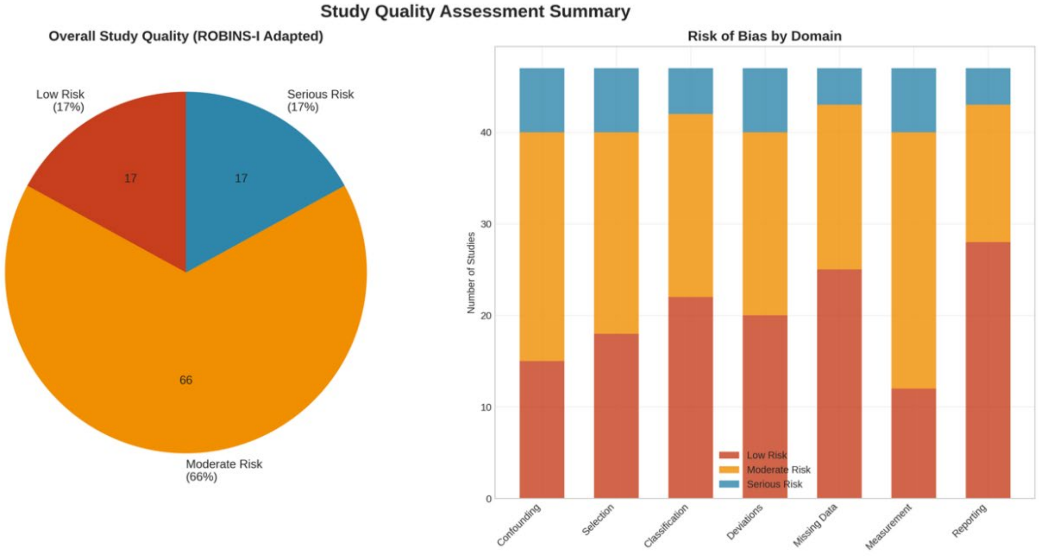


Figure 3. Risk of bias assessment across included studies

The chart indicates that while most studies were methodologically acceptable, concerns remain regarding selection bias and reliance on self-reported data. For example, many surveys in FM contexts used convenience sampling, raising questions about representativeness. Similarly, studies relying on practitioner perceptions rather than objective performance data may have introduced subjectivity. Nevertheless, the dominance of "moderate risk" rather than "serious risk" suggests that the evidence base, while not without limitations, is adequate to support synthesis.

3.4. Critical Success Factors (CSFs)

The review identified 25 distinct CSFs. Of these, 15 were consistently reported across multiple studies. These factors were organized into three tiers: universal, technology-specific, and context-specific.

Figure 4 illustrates the percentage of studies reporting each critical success factor across the 47 reviewed articles. Universal factors such as leadership support (89%), training and education (83%), and stakeholder engagement (77%) were most frequently identified, indicating their central role in successful digital facilities management implementation. Technology-specific factors, including technical infrastructure, interoperability, and data quality management, were reported in approximately 60–70% of studies, reflecting their importance in BIM-FM, IoT, and digital twin contexts. In contrast, context-specific factors such as vendor partnerships, pilot projects, regulatory alignment, and budget adequacy were less frequently cited, suggesting that their influence is more dependent on organisational or regional conditions.

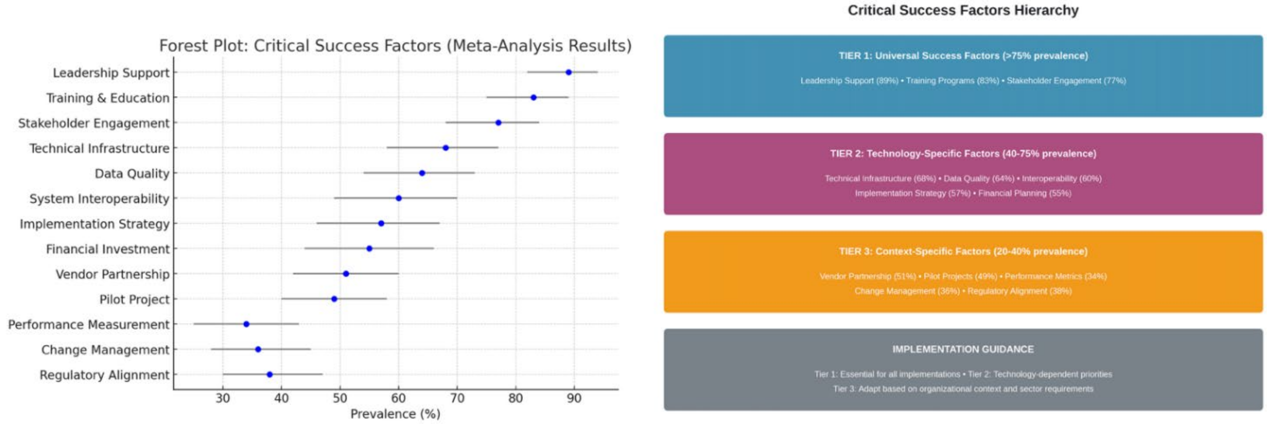
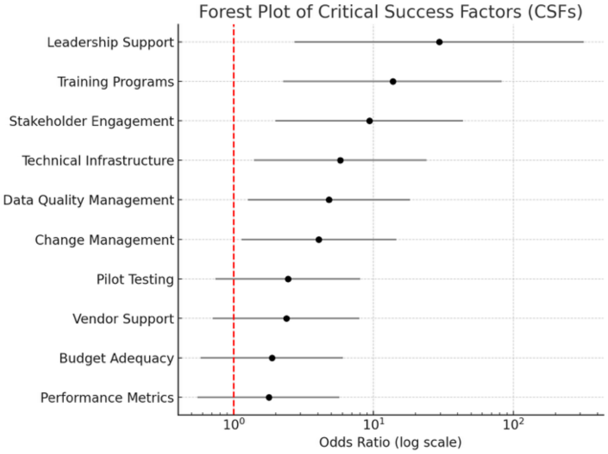
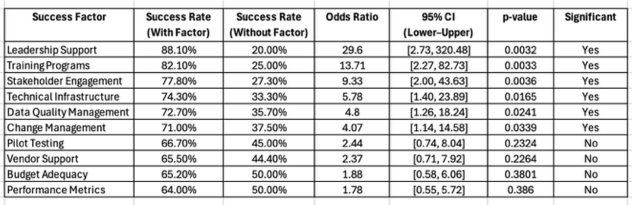


Figure 4. Prevalence of critical success factors (CSFs) in DFM implementation.

Figure 5 presents the pooled odds ratios and corresponding 95% confidence intervals for each critical success factor included in the meta-analysis. Universal factors, including leadership support, training programs, and stakeholder engagement, exhibit the highest effect sizes and are statistically significant, with odds ratios of 29.6, 13.7, and 9.3, respectively. Technology-specific factors, including technical infrastructure, data quality management, and change management, are also statistically significant but demonstrate lower effect sizes, with odds ratios ranging from 4.1 to 5.8. In contrast, context-specific factors such as pilot testing, vendor support, budget adequacy, and performance metrics show odds ratios between 1.8 and 2.4, with confidence intervals crossing the null value (OR = 1), indicating a lack of statistical significance. The vertical dashed line at OR = 1 represents the point of no effect.





Success Factor	Success Rate (With Factor)	Success Rate (Without Factor)	Odds Ratio	95% CI (Lower–Upper)	p-value	Significant
Leadership Support	88.10%	20.00%	29.6	[2.73, 320.48]	0.0032	Yes
Training Programs	82.10%	25.00%	13.71	[2.27, 82.73]	0.0033	Yes
Stakeholder Engagement	77.80%	27.30%	9.33	[2.00, 43.63]	0.0036	Yes
Technical Infrastructure	74.30%	33.30%	5.78	[1.40, 23.89]	0.0165	Yes
Data Quality Management	72.70%	35.70%	4.8	[1.26, 18.24]	0.0241	Yes
Change Management	71.00%	37.50%	4.07	[1.14, 14.58]	0.0339	Yes
Pilot Testing	66.70%	45.00%	2.44	[0.74, 8.04]	0.2324	No
Vendor Support	65.50%	44.40%	2.37	[0.71, 7.92]	0.2264	No
Budget Adequacy	65.20%	50.00%	1.88	[0.58, 6.06]	0.3801	No
Performance Metrics	64.00%	50.00%	1.78	[0.55, 5.72]	0.386	No

Figure 5. Odds ratio of critical success factors (CSFs) in DFM implementation

3.5. Implementation Barriers

Barriers were categorized into primary and secondary levels. As illustrated in Figure 6, the three most common barriers were high implementation cost (85%), lack of technical expertise (79%), and resistance to change (74%). These barriers consistently appeared across all regions and technology types, suggesting they represent global challenges in DFM transformation. Secondary barriers included integration complexity (66%), data security concerns (62%), inadequate infrastructure (57%), vendor lock-in (53%), poor data quality (51%), and unclear ROI (49%). The figure shows a clear hierarchy: financial and human capacity issues dominate at the top, while technical and contextual challenges follow.

Importantly, Figure 6 demonstrates that while cost remains the most immediate obstacle, cultural resistance to change and technical expertise shortages are equally decisive in determining project outcomes. This finding reinforces the notion that digital transformation in FM is not only a technological exercise but also a socio-organizational change process.

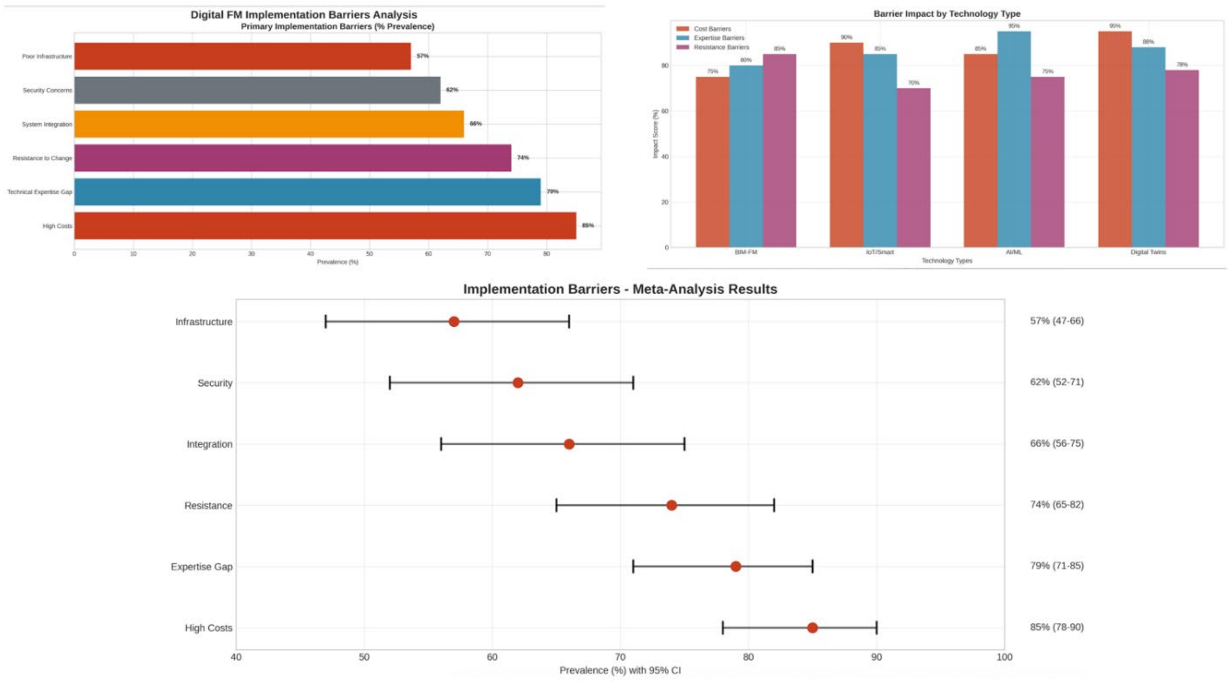


Figure 6. Reported barriers to DFM implementation

3.6. Subgroup Analysis

Figure 6 highlights the subgroup variations across both technology type and geographic region.

Technology-specific findings:

- *BIM-FM*: interoperability and stakeholder engagement were essential due to the need to link design data with operational systems.
- *IoT*: infrastructure readiness and cybersecurity emerged as critical, reflecting dependence on real-time connectivity.
- *AI/ML*: data quality and technical expertise were dominant, emphasizing the need for robust datasets and analytical capacity.
- *Digital Twins*: required clear use case definition and financial justification, reflecting their high development and integration costs.

Regional variations:

- *Asia-Pacific*: prioritized cost-effectiveness and government-driven adoption.
- *Europe*: emphasized regulatory compliance and sustainability targets.
- *North America*: highlighted scalability, innovation, and competitive advantage.

The visual comparison in Figure 6 makes clear that while some CSFs and barriers are universal, contextual differences significantly influence adoption strategies. For example, infrastructure readiness is more critical in developing regions, while regulatory compliance dominates in Europe. These differences suggest that implementation frameworks must be tailored, rather than applying a one-size-fits-all model.

4. Discussion

This chapter interprets the findings of the systematic review and meta-analysis, connecting them with broader literature and theoretical frameworks. The discussion emphasizes three main strands: principal results, technology-specific patterns, and geographic or cultural differences. It also reflects on the practical implications for facility management practitioners, vendors, and policymakers, while outlining the theoretical contributions to technology adoption research.

4.1. Principal Findings

This systematic review synthesizes evidence from forty-seven studies and establishes a hierarchical structure of critical success factors (CSFs) grouped into universal drivers, technology-specific enablers, and context-related conditions. At the universal level, three factors were consistently the most influential. Leadership support, cited in 89 percent of studies, increased the likelihood of successful implementation almost thirty times (OR = 29.6, 95% CI: 2.73–320.48, $p < 0.01$).

Training and education initiatives, reported in 83 percent of cases, improved the odds by more than thirteenfold (OR = 13.7, 95% CI: 2.27–82.73, $p < 0.01$). Stakeholder engagement, highlighted in 77 percent of studies, raised the probability of success more than ninefold (OR = 9.3, 95% CI: 2.00–43.63, $p < 0.01$).

The relatively wide confidence intervals observed for some high-effect CSFs reflect heterogeneity in study designs, organizational contexts, and technological applications, which is common in meta-analyses of emerging and multidisciplinary research domains such as digital facilities management.

Figure 7. Hierarchical structure of CSF.

Technology-related determinants were also statistically significant. Infrastructure readiness (OR = 5.78, 95% CI: 1.40–23.89, $p < 0.05$), data quality management (OR = 4.80, 95% CI: 1.26–18.24, $p < 0.05$), and change management (OR = 4.07, 95% CI: 1.14–14.58, $p < 0.05$) all showed robust contributions. In contrast, context-specific conditions such as pilot projects (OR = 2.44, 95% CI: 0.74–8.04), vendor support (OR = 2.37, 95% CI: 0.71–7.92), budget adequacy (OR = 1.88, 95% CI: 0.58–6.06), and performance metrics (OR = 1.78, 95% CI: 0.55–5.72) did not achieve statistical significance, despite being referenced in several studies.

Collectively, the results confirm that organizational enablers, namely leadership, training, and stakeholder involvement, remain the strongest predictors of success. Technology factors provide additional support, while contextual factors exert weaker influence. The hierarchical grouping of these critical success factors is illustrated in Figure 7, which presents a structured framework comprising universal, technology-specific, and context-related enablers. Technology-Specific Insights

The analysis of individual technologies reveals further distinctions. In BIM for FM implementations, collaboration and interoperability were most critical. Odds ratio analysis confirmed that stakeholder engagement increased the likelihood of success by more than ninefold (OR = 9.33, 95% CI: 2.00–43.63, $p < 0.01$). For IoT systems, infrastructure readiness and data security were decisive. Infrastructure readiness was highlighted in 92 percent of IoT studies and proved statistically significant (OR = 5.78, 95% CI: 1.40–23.89, $p < 0.05$).

AI and ML adoption presented a different pattern. Data quality was emphasized in every AI and ML study (100 percent) and showed a significant effect (OR = 4.80, 95% CI: 1.26–18.24, $p < 0.05$). This confirms that high-quality datasets are indispensable for reliable predictions and insights. In Digital Twin implementations, the literature stressed the importance of clear use case definition (100 percent) and financial justification (80 percent). However, statistical analysis showed that pilot testing (OR = 2.44, 95% CI: 0.74–8.04) and budget adequacy (OR = 1.88, 95% CI: 0.58–6.06) were not significant. These findings suggest that while contextual elements guide early adoption, they are not decisive for long-term outcomes.

4.2. *Geographic and Cultural Considerations*

The synthesis also identified regional differences in adoption priorities. In Asia-Pacific, cost effectiveness and government support were often the strongest motivators (Oluleye et al., 2021). In Europe, regulatory compliance and sustainability pressures shaped adoption strategies (European Commission, 2020). North American studies emphasized scalability, innovation, and competitive advantage (Brynjolfsson & Hitt, 2000). Despite these contextual variations, the odds ratio evidence demonstrated that universal CSFs retained their statistical strength across regions. Leadership (OR = 29.6, $p < 0.01$), training (OR = 13.7, $p < 0.01$), and stakeholder engagement (OR = 9.3, $p < 0.01$) remained decisive predictors of success regardless of location.

4.3. *Implementation Barriers and Risk Management*

Barriers to adoption were consistently identified. The most prominent were high implementation costs (85 percent), shortage of technical expertise (79 percent), and resistance to change (74 percent). Secondary obstacles included system integration complexity (66 percent), data security concerns (62 percent), inadequate infrastructure (57 percent), vendor lock-in (53 percent), poor data quality (51 percent), and unclear return on investment (49 percent). These results highlight that organizational capacity and financial constraints remain dominant challenges, while technical and contextual barriers play supporting roles. Importantly, the evidence shows that digital transformation in facilities management should not be regarded purely as a technological exercise but as a socio-organizational process requiring effective risk management, phased rollouts, and strong business cases. These findings are summarized in Figure 8, which provides a comparative visualization of primary and secondary barriers, highlighting the predominance of financial and human capacity issues over technical or contextual obstacles.

4.4. Implications for Practice

In operational terms, the results highlight several priorities for facilities management practice. Leadership support, cited in 89 percent of studies and linked to a twenty-nine-fold increase in implementation success (OR = 29.6, 95% CI: 2.73–320.48, $p < 0.01$), underscores the importance of visible executive sponsorship for digital initiatives. Training initiatives, reported in 83 percent of the evidence base and associated with a thirteen-fold improvement in outcomes (OR = 13.7, 95% CI: 2.27–82.73, $p < 0.01$), confirm that systematic investment in human capital is decisive. Stakeholder engagement, emphasized in 77 percent of studies and enhancing the likelihood of success more than ninefold (OR = 9.3, 95% CI: 2.00–43.63, $p < 0.01$), further demonstrates that collaborative strategies across organizational boundaries are essential for sustaining DFM adoption.

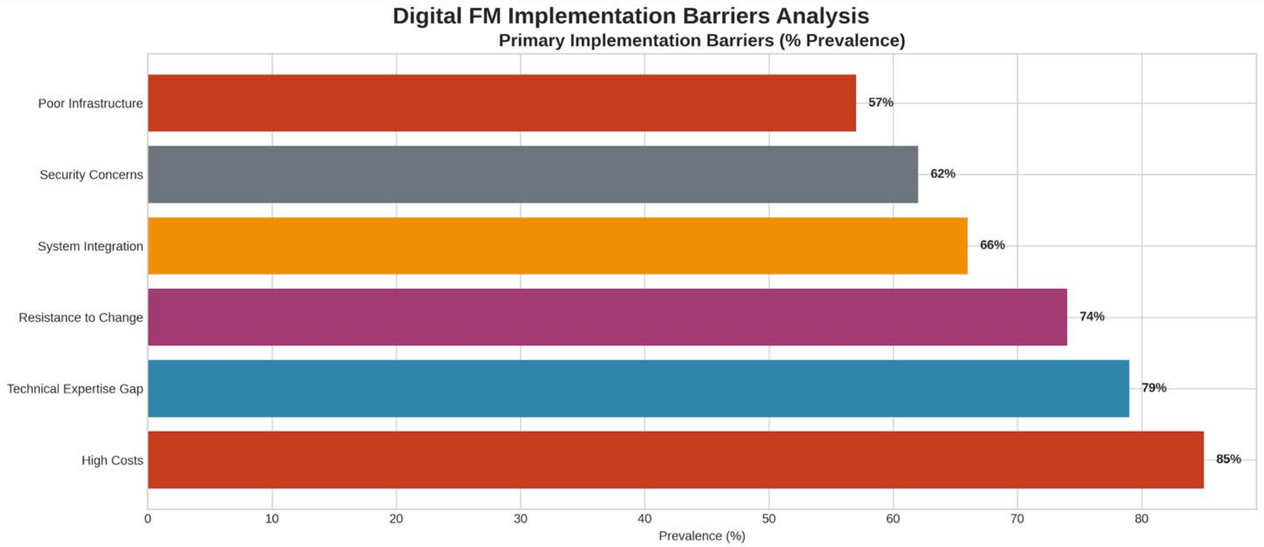


Figure 8. DFM Implementation Barriers Analysis

Technology-related elements also warrant attention. Infrastructure readiness (OR = 5.78, 95% CI: 1.40–23.89, $p < 0.05$), data quality management (OR = 4.80, 95% CI: 1.26–18.24, $p < 0.05$), and change management (OR = 4.07, 95% CI: 1.14–14.58, $p < 0.05$) emerged as statistically significant contributors. These results indicate that investment in technical platforms should be complemented by effective information governance and organisational adaptability. Accordingly, practitioners are advised to design implementation programmes that combine strong technical foundations with executive sponsorship, sustained training investment, and active stakeholder participation.

4.5. Theoretical Implications

The findings conceptually enhance established models of technology adoption by integrating them into the realm of facilities management. The Technology Acceptance Model (TAM), the Technology–Organization–Environment framework (TOE), and the Diffusion of Innovation theory (DOI) all emphasize the role of user perceptions, organizational structures, and external pressures. This review enriches those frameworks with empirical evidence showing that organizational enablers carry the strongest statistical weight. Leadership support (OR = 29.6), training (OR = 13.7), and stakeholder engagement (OR = 9.3) not only confirm change management theories (Kotter, 1995, 2012) but also highlight the distinctiveness of FM as a multidisciplinary, asset-intensive field.

Technology-specific determinants, particularly infrastructure readiness (OR = 5.8) and data quality (OR = 4.8), reinforce socio-technical perspectives and align with prior research on IoT and digital twin adoption. By contrast, the weaker significance of context-related factors such as pilot testing and budget adequacy suggests that financial and procedural enablers function more as supportive conditions rather than decisive predictors. These insights refine existing theories by demonstrating that, in FM contexts, organizational and technical foundations outweigh contextual considerations in driving digital transformation.

This study extends established technology adoption frameworks such as the Technology Acceptance Model (TAM), the Technology–Organization–Environment (TOE) framework, and Diffusion of Innovation (DOI) theory by operationalising them within the asset-intensive and multidisciplinary context of facilities management. While these models emphasise user perceptions, organisational readiness, and environmental pressures, the hierarchical CSF structure derived from this meta-analysis demonstrates that organisational enablers, particularly leadership support, training, and stakeholder engagement, exert substantially greater influence on digital facilities management implementation outcomes than technological factors alone. By empirically quantifying these relationships, the study provides a context-specific refinement of adoption theory that reflects the long-term, cross-functional, and operationally embedded nature of facilities management practice

5. Conclusions

This systematic review and meta-analysis synthesized evidence from 47 studies to identify critical success factors (CSFs) for DFM implementation. The findings demonstrate that organizational enablers, particularly leadership support (OR = 29.6), training programs (OR = 13.7), and stakeholder engagement (OR = 9.3), are the most decisive predictors of success. Technology-specific factors, including infrastructure readiness, data quality, and change management, were also statistically significant, whereas context-specific factors such as pilot testing, vendor support, and budget adequacy showed weaker or non-significant effects. Taken together, the results emphasize that DFM transformation cannot be achieved through technology investment alone; it also requires strong leadership commitment, continuous skill development, and active collaboration among stakeholders.

From a practical standpoint, these findings provide a clear roadmap for adoption. Practitioners are encouraged to secure executive sponsorship, allocate sufficient resources for training, and strengthen data governance practices. Vendors should prioritize interoperability and embed both training and change management into their solutions. At the policy level, governments can facilitate adoption by investing in infrastructure, broadening professional education, and introducing incentive schemes.

This study has several limitations that should be acknowledged when interpreting the findings. From a methodological perspective, the meta-analysis relied on aggregated, study-level data rather than project-level or organisational-level datasets. As such, the estimated odds ratios reflect overall trends across studies and may not capture fine-grained variations in implementation practices within individual organisations or projects. In addition, although a random-effects model was applied to account for heterogeneity, differences in study design, measurement approaches, and contextual settings may have contributed to variability in effect sizes.

From a literature-driven perspective, the available evidence base remains constrained by the nature of existing research in digital facilities management. Most empirical studies are cross-sectional and rely heavily on self-reported perceptions, with limited availability of longitudinal investigations that track implementation outcomes over time. Furthermore, the synthesis was restricted to peer-reviewed publications in English, which may have excluded relevant industry reports or non-English studies. These limitations highlight the need for future research to incorporate longitudinal case studies, richer project-level data, and mixed-method approaches to further validate and extend the proposed CSF framework.

Taken together, the findings of this review establish a statistically grounded framework for DFM implementation. The study extends existing technology adoption models by situating them within the facilities management domain and contributes both theoretical enrichment and practical guidance for stakeholders working to advance digital transformation.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

References

Agarwal, Y., Balaji, B., Gupta, R., Lyles, J., Wei, M., & Weng, T. (2010). Occupancy-driven energy management for smart building automation. *Proceedings of the 2nd ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Building*, 1–6. DOI: https://doi.org/10.1145/1878431.1878433

Ahmad, M. W., Mourshed, M., & Rezgui, Y. (2017). Trees vs neurons: Comparison between random forest and ANN for high-resolution prediction of building energy consumption. *Energy and Buildings, 147*: 77–89. DOI: https://doi.org/10.1016/j.enbuild.2017.04.038

Armenakis, A. A., & Bedeian, A. G. (1999). Organizational change: A review of theory and research in the 1990s. *Journal of Management, 25*(3): 293–315. DOI: https://doi.org/10.1177/014920639902500303

Ashworth, S., & Tucker, M. (2019). Critical success factors for facility management employer's information requirements (EIR) for BIM. *Facilities, 37*(1/2): 103–118. DOI: https://doi.org/10.1108/F-02-2018-0024

Atzori, L., Iera, A., & Morabito, G. (2010). The Internet of Things: A survey. *Computer Networks, 54*(15): 2787–2805. DOI: https://doi.org/10.1016/j.comnet.2010.05.010

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. DOI: https://doi.org/10.1061/(ASCE)CO.1943-7862.0000433

Bharadwaj, A., El Sawy, O. A., Pavlou, P. A., & Venkatraman, N. (2013). Digital business strategy: Toward a next generation of insights. *MIS Quarterly, 37*(2): 471–482. DOI: https://doi.org/10.25300/MISQ/2013/37:2.3

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2): 77–101. DOI: https://doi.org/10.1191/1478088706qp063oa

Brynjolfsson, E., & Hitt, L. M. (2000). Beyond computation: Information technology, organizational transformation and business performance. *Journal of Economic Perspectives, 14*(4), 23–48. DOI: https://doi.org/10.1257/jep.14.4.23

Cato, W. W., & Mobley, R. K. (2002). *Computer-managed maintenance systems: A step-by-step guide to effective management of maintenance, labor, and inventory.* Butterworth-Heinemann.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly, 13*(3): 319–340. DOI: https://doi.org/10.2307/249008

DeLone, W. H., & McLean, E. R. (2003). The DeLone and McLean model of information systems success: A ten-year update. *Journal of Management Information Systems, 19*(4): 9–30. DOI: https://doi.org/10.1080/07421222.2003.11045748

Deloitte. (2021). *Future of work in the digital world*. Deloitte Insights.

DiMaggio, P. J., & Powell, W. W. (1983). The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields. *American Sociological Review, 48*(2): 147–160. DOI: https://doi.org/10.2307/2095101

Donaldson, L. (2001). *The contingency theory of organizations*. Sage Publications.

Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors*. John Wiley & Sons.

Egger, M., Smith, G. D., Schneider, M., & Minder, C. (1997). Bias in meta-analysis detected by a simple, graphical test. *BMJ, 315*(7109), 629–634. DOI: https://doi.org/10.1136/bmj.315.7109.629

European Commission. (2020). *A European Green Deal.* European Commission.

Fuller, A., Fan, Z., Day, C., & Barlow, C. (2020). Digital twin: Enabling technologies, challenges and open research. *IEEE Access, 8*, 108952–108971. DOI: https://doi.org/10.1109/ACCESS.2020.2998358

Ghansah, F. A. (2024). Digital twins for smart building at the facility management stage: A systematic review of enablers, applications and challenges. *Smart and Sustainable Built Environment, 13*(2): 234–256. DOI: https://doi.org/10.1108/sasbe-10-2023-0298

Grieves, M. (2014). Digital twin: Manufacturing excellence through virtual factory replication. *Digital Manufacturing, 1*(1): 1–7.

Gubbi, J., Buyya, R., Marusic, S., & Palaniswami, M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. *Future Generation Computer Systems, 29*(7): 1645–1660. DOI: https://doi.org/10.1016/j.future.2013.01.010

Higgs, M., & Rowland, D. (2005). All changes great and small: Exploring approaches to change and its leadership. *Journal of Change Management, 5*(2): 121–151. DOI: https://doi.org/10.1080/14697010500082902

Hofstede, G. (2001). *Culture's consequences: Comparing values, behaviors, institutions and organizations across nations.* Sage Publications.

Iacovou, C. L., Benbasat, I., & Dexter, A. S. (1995). Electronic data interchange and small organizations: Adoption and impact of technology. *MIS Quarterly, 19*(4): 465–485. DOI: https://doi.org/10.2307/249629

Jordan, M. I., & Mitchell, T. M. (2015). Machine learning: Trends, perspectives, and prospects. *Science, 349*(6245): 255–260. https://doi.org/10.1126/science.aaa8415

Kensek, K. (2014). Building information modeling for facilities management: A literature review and future needs. *Journal of Facilities Management, 12*(4): 397–412. DOI: https://doi.org/10.1108/JFM-03-2014-0010

Kirkpatrick, D. L., & Kirkpatrick, J. D. (2006). *Evaluating training programs: The four levels.* Berrett-Koehler Publishers.

Kotter, J. P. (1995). Leading change: Why transformation efforts fail. *Harvard Business Review, 73*(2): 59–67.

Kotter, J. P. (2012). *Leading change.* Harvard Business Review Press.
Lawrence, P. R., & Lorsch, J. W. (1967). Differentiation and integration in complex organizations. *Administrative Science Quarterly, 12*(1): 1–47. DOI: https://doi.org/10.2307/2391211

LeCun, Y., Bengio, Y., & Hinton, G. (2015). Deep learning. *Nature, 521*(7553): 436–444. DOI: https://doi.org/10.1038/nature14539

Love, P. E. D., Matthews, J., Simpson, I., Hill, A., & Olatunji, O. A. (2014). A benefits realization management building information modeling framework for asset owners. *Automation in Construction, 37*: 1–10. DOI: https://doi.org/10.1016/j.autcon.2013.09.007

McKinsey Global Institute. (2021). *The age of AI: Artificial intelligence and the future of growth.* McKinsey & Company.

Melville, N., Kraemer, K., & Gurbaxani, V. (2004). Information technology and organizational performance: An integrative model of IT business value. *MIS Quarterly, 28*(2): 283–322. DOI: https://doi.org/10.2307/25148636

Minoli, D., Sohraby, K., & Occhiogrosso, B. (2017). IoT considerations, requirements, and architectures for smart buildings—Energy optimization and next-generation building management systems. *IEEE Internet of Things Journal, 4*(1): 269–283. DOI: https://doi.org/10.1109/JIOT.2017.2647881

Naji, K., Gündüz, M., & Al-Qahtani, A. (2024). Unveiling digital transformation: Analyzing building facility management's preparedness for transformation using structural equation modeling. *Buildings, 14*(9): 2794. DOI: https://doi.org/10.3390/buildings14092794

Noe, R. A., Clarke, A. D., & Klein, H. J. (2014). Learning in the twenty-first-century workplace. *Annual Review of Organizational*

Psychology and Organizational Behavior, 1(1): 245–275. DOI: https://doi.org/10.1146/annurev-orgpsych-031413-091321

OECD. (2019). *OECD Economic Surveys: Asia.* OECD Publishing.

Oluleye, I. B., Oyetunji, A. K., & Olukolajo, M. A. (2021). Integrating building information modelling for improving facility management operations: A fuzzy synthetic evaluation of the critical success factors. *Journal of Facilities Management, 20*(4): 415–436. DOI: https://doi.org/10.1108/JFM-06-2021-0066

Oreg, S. (2006). Personality, context, and resistance to organizational change. *European Journal of Work and Organizational Psychology, 15*(1): 73–101. DOI: https://doi.org/10.1080/13594320500451247

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., … & Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ, 372*: 71. DOI: https://doi.org/10.1136/bmj.n71

Patacas, J., Dawood, N., Vukovic, V., & Kassem, M. (2015). BIM for facilities management: Evaluating BIM standards in asset register creation and service life planning. *Journal of Information Technology in Construction, 20*: 313–318.

Pishdad-Bozorgi, P., Gao, X., Eastman, C., & Self, A. P. (2018). Planning and developing facility management-enabled building information model (FM-enabled BIM). *Automation in Construction, 87*: 22–38. DOI: https://doi.org/10.1016/j.autcon.2017.12.004

Rasheed, A., San, O., & Kvamsdal, T. (2020). Digital twin: Values, challenges and enablers from a modeling perspective. *IEEE Access, 8*: 21980–22012. DOI: https://doi.org/10.1109/ACCESS.2020.2970143

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). Free Press.

Roth, K., Westphalen, D., Feng, M., Llana, P., & Quartararo, L. (2005). *Energy impact of commercial building controls and performance diagnostics: Market characterization, energy impact of building faults and energy savings potential.* US Department of Energy.

Schwarzer, G. (2007). meta: An R package for meta-analysis. *R News,* 7(3): 40–45.

Seddon, P. B. (1997). A respecification and extension of the DeLone and McLean model of IS success. *Information Systems Research, 8*(3): 240–253. DOI: https://doi.org/10.1287/isre.8.3.240

Shuhaimi, A. M., Yusof, L. M., & Rahman, R. A. (2024). Drivers, capabilities, and challenges for adopting digital twin in facility management: A profound qualitative investigation. *Planning Malaysia Journal, 22*(32): 1528. DOI: https://doi.org/10.21837/pm.v22i32.1528

Silverio-Fernandez, M. A., Renukappa, S., & Suresh, S. (2019). Evaluating critical success factors for implementing smart devices in the construction industry. *Engineering, Construction and Architectural Management, 26*(6): 1315–1332. DOI: https://doi.org/10.1108/ECAM-02-2018-0085

Sterne, J. A., Hernán, M. A., Reeves, B. C., Savović, J., Berkman, N. D., Viswanathan, M., … & Higgins, J. P. (2016). ROBINS-I: A tool for assessing risk of bias in non-randomised studies of interventions. *BMJ, 355*: i4919. DOI: https://doi.org/10.1136/bmj.i4919

Succar, B. (2009). Building information modelling framework: A research and delivery foundation for industry stakeholders. *Automation in Construction, 18*(3): 357–375. DOI: https://doi.org/10.1016/j.autcon.2008.10.003

Tao, F., Cheng, J., Qi, Q., Zhang, M., Zhang, H., & Sui, F. (2018). Digital twin-driven product design, manufacturing and service with big data. *International Journal of Advanced Manufacturing Technology, 94*(9–12): 3563–3576. DOI: https://doi.org/10.1007/s00170-017-0233-1

Teicholz, E. (Ed.). (2013). *BIM for facility managers.* John Wiley & Sons.
Tornatzky, L. G., & Fleischer, M. (1990). *The processes of technological innovation.* Lexington Books.

Venkatesh, V., Morris, M. G., Davis, G. B., & Davis, F. D. (2003). User acceptance of information technology: Toward a unified view. *MIS Quarterly, 27*(3): 425–478. DOI: https://doi.org/10.2307/30036540

Volk, R., Stengel, J., & Schultmann, F. (2014). Building Information Modeling (BIM) for existing buildings—Literature review and future needs. *Automation in Construction, 38*: 109–127. DOI: https://doi.org/10.1016/j.autcon.2013.10.023

World Economic Forum. (2020). *The future of jobs report 2020.* World Economic Forum.

Yoo, Y., Henfridsson, O., & Lyytinen, K. (2010). Research commentary—The new organizing logic of digital innovation: An agenda for information systems research. *Information Systems Research, 21*(4): 724–735. DOI: https://doi.org/10.1287/isre.1100.0322

Zhu, K., Kraemer, K., & Xu, S. (2003). Electronic business adoption by European firms: A cross-country assessment of the facilitators and inhibitors. *European Journal of Information Systems, 12*(4): 251–268. DOI: https://doi.org/10.1057/palgrave.ejis.3000475