ABSTRACT

The lifespan of a building depends not only on the quality of its construction but also on Facilities Management (FM), which is a critical phase in the building lifecycle. FM refers to the coordinated management of building services to ensure the optimal performance, functionality, and sustainability of built assets, thereby enhancing occupant well-being and productivity. Generally, facility managers in healthcare centres rely on conventional Repair and Maintenance (R&M) operations that often require extensive manual intervention, leading to inefficiencies and posing serious risks to patient safety. To overcome this, Building Information Modeling (BIM) has emerged as a solution to centralise information and provide spatial visualisation for facility operations. While BIM has been widely adopted in the Architectural, Engineering, and Construction phases (AEC), its long-term value increasingly lies in its ability to support FM. There are several critical research gaps that remain in the effective implementation of BIM within FM, particularly in healthcare environments.

While previous studies acknowledge the potential of BIM, these are often examined in isolation, with limited empirical investigation into the organisational and managerial conditions required for their effective realisation. The BIM adoption is not solely a technological issue but is influenced by the alignment of people, processes, place, technology, and information management domains. Existing BIM–FM studies rarely examine how the organisational and operational constructs collectively influence the realisation of BIM benefits in healthcare FM environments. Furthermore, the perspectives of maintenance professionals, who directly interact with building systems during daily R&M operations, remain underrepresented in empirical investigations. Additionally, existing BIM model development approaches do not adequately prioritise maintenance-oriented applications, particularly in healthcare environments, where Mechanical, Electrical, and Plumbing (MEP) systems account for a substantial proportion of capital and operational costs. Therefore, a key limitation is the lack of validation of HVAC-centric BIM models within operational workflows, leading to solutions that are theoretically sound but not adopted in practice. Furthermore, existing literature on BIM in FM predominantly emphasises the benefits of BIM adoption while paying limited attention to its operational constraints. This limits their effectiveness when integrated with FM systems and hinders their ability to support real-time maintenance decision-making. Consequently, recent research has increasingly explored Digital Twin (DT) technologies as a potential approach to overcome the BIM constraints. Several review studies have attempted to synthesise BIM–DT developments; however, many rely on bibliometric mapping rather than conceptual analysis, and focus primarily on construction processes rather than operational FM workflows. Consequently, the literature lacks a framework that explains how specific BIM constraints in FM can be conceptually transformed through DT integration, thereby limiting both theoretical clarity and practical guidance for organisations navigating digital transformation in FM.

These challenges constrain the effective application of digital solutions for R&M operations within healthcare FM. Therefore, the aim of this study is to advance the BIM-enabled digital transformation of R&M practices in healthcare centres by investigating the organisational and operational factors that influence BIM benefits, developing and validating an HVAC-centric BIM model, and establishing pathways to address BIM constraints through DT capabilities. To achieve this aim, the study investigates how integrated FM constructs influence the realisation of BIM benefits, develops and validates an HVAC-centric BIM model tailored to Asset Information Requirements (AIRs) of R&M, and critically examines how BIM constraints can be conceptually transformed into DT capabilities.

This study adopts a multi-method research approach that integrates quantitative and qualitative techniques and employs a Design Science Research (DSR) framework. Initially, for objective 1, Integrated FM constructs were identified through a Systematic Literature Review (SLR) of BIM articles on FM and a qualitative thematic content analysis. A conceptual model grounded in the Technology Acceptance Model (TAM) was then developed, followed by the formulation of hypotheses. Subsequently, to achieve objective 2, a structured questionnaire survey was conducted among healthcare maintenance professionals to analyse the relationships between the integrated FM constructs and BIM benefits using Covariance-Based Structural Equation Modeling (CB-SEM). Further, to achieve objective 3, a DSR framework was employed to develop an HVAC-centric BIM model aligned with the AIRs for R&M. The developed model was demonstrated through a case study in a healthcare centre and evaluated using semi-structured interviews with maintenance professionals to assess its perceived usability, practical relevance and potential applicability to R&M operations. The demonstration and evaluation of the BIM model also highlighted certain operational constraints. These observations, together with the constraints identified in the literature, provided the motivation for Objective 4. To achieve Objective 4, a combination of qualitative and quantitative content analyses of the literature was carried out using SLR and Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), this time including both BIM and DT studies in FM, to delve deeper into the constraints of the BIM model. A multi-stage qualitative coding process was used to derive constraint categories, followed by quantitative analysis. The identified constraints were thematically clustered and systematically linked to DT capabilities to develop structured BIM–DT transformation pathways.

The findings indicate that maintenance effectiveness and critical building systems have significant positive relationships with the realisation of BIM benefits. The HVAC-centric BIM model was evaluated through expert feedback, which identified seven perceived benefits, including manufacturer collaboration, fault diagnosis, preventive maintenance and workforce planning, decision-making, cost-related support, and inspection and audit. The literature analysis of 285 peer-reviewed journal articles identified 24 BIM constraints, which were

consolidated into five thematic clusters. These constraints were systematically mapped to DT capabilities to establish conceptual BIM–DT transformation pathways for FM.

This study contributes to FM research and practice by providing an integrated perspective on BIM-enabled digital transformation for R&M in healthcare facilities. Theoretically, it brings together the organisational and operational dimensions of Integrated FM to explain the factors that influence the realisation of BIM benefits. Methodologically, it combines quantitative analysis, case-based BIM artefact development and evaluation, and literature-based conceptual synthesis to examine BIM applications and their progression towards DT-enabled FM. In practice, the study provides an HVAC-centric BIM model structured around AIRs for R&M and identifies conceptual pathways to extend BIM capabilities through DT integration. Collectively, these contributions provide a basis for understanding how digital technologies can be aligned with the information and operational requirements of healthcare maintenance.

Overall, the study highlights that effective digital transformation in FM requires not only BIM implementation but also reliable information management, interoperability, and staged DT integration strategies that align with operational maintenance requirements in healthcare centres.

Keywords: Healthcare FM, Repair and Maintenance, Building Information Modeling (BIM), BIM Constraints, Digital Twin Capabilities.