Building Information Modelling-Enabled Data Integration and Visual Analytics for Facilities Management: A Systematic Review

Zarith Annisa Idris[1], Mariah Awang[1]*, Nuramidah Hamidon[1], Muhammad Haziq Fitri Hairul[2], Mohd Shahril Abdul Rahman[3] and Zainab Toyin Jagun[4]

[1]Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia (UTHM), Higher Education Hub, Pagoh, 84600 Johor, Malaysia.

[2]IAQ Solutions Sdn. Bhd., No. 9, Jalan Sungai Jeluh 32/192, Kawasan Perindustrian Kemuning, Seksyen 32, 40460 Shah Alam, Selangor, Malaysia.

[3]Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, 81300 Skudai, Johor, Malaysia.

[4]Department of Real Estate, School of Built Environment, Engineering & Computing, Leeds Beckett University, City Campus, Leeds LS1 3HE, United Kingdom.

***Corresponding Author**

DOI: https://doi.org/10.47772/IJRISS.2026.100700466

Received: 20 July 2026; Accepted: 26 July 2026; Published: 04 August 2026

ABSTRACT

Building Information Modelling (BIM) is increasingly positioned as a digital information environment for facilities management (FM), asset management and operation and maintenance (O&M) decision-making. Its operational value, however, remains constrained by fragmented information exchange, incomplete asset information, inconsistent requirements, limited facility manager involvement and weak integration between BIM and FM systems. This paper presents a bounded, corpus-based systematic literature review of 51 documents covering BIM-FM integration, asset information delivery, Industry 4.0 technologies, digital twins and visual analytics. The starting repository was pre-assembled rather than generated through a new bibliographic database search. To improve methodological transparency, the review applies explicit eligibility criteria, a consolidated Boolean verification string, a documented corpus-selection process and qualitative thematic synthesis. Four themes emerged: interoperability and information exchange; asset information quality, data requirements and early FM involvement; BIM convergence with Industry 4.0 technologies and digital twin-enabled FM; and visual analytics, systems-centric modelling and fault diagnosis. The synthesis also distinguishes the implementation emphasis reported in developed-country and developing-country contexts. The paper contributes a provisional, literature-derived seven-stage framework for BIM-enabled data integration and visual analytics in FM. The framework has not yet been validated through practitioner or expert assessment and is therefore presented as a testable conceptual proposition rather than an implementation-ready model. The findings are intended to support bounded theoretical synthesis and future empirical validation, not statistical generalisation across the entire BIM-FM domain.

Keywords: Building Information Modelling; Facilities Management; Asset Management; Digital Twin; Visual Analytics; Interoperability

INTRODUCTION

Facilities management increasingly depends on reliable digital information because O&M decisions require accurate asset location, system relationships, maintenance history, work order information and performance evidence. BIM has been widely discussed as a mechanism for improving FM because it can store geometric and non-geometric information across the building lifecycle and support asset retrieval, maintenance planning and lifecycle decision-making [1-3]. The operational value of BIM is not automatic, however, because many design and construction models are not configured to meet the practical information requirements of facility managers [4-8].

BIM-FM implementation is shaped by technological, organisational and informational constraints. Information exchange between BIM models and FM systems is frequently hindered by software interoperability problems, fragmented databases, inconsistent object naming, incomplete semantic information and weak asset information governance [3-9]. These problems are particularly important during O&M because facility managers depend on asset identity, system membership, location, maintainability information, warranty data, work order records and condition histories to plan and justify maintenance decisions [1,6,8,10].

The scope of BIM-enabled FM is also expanding through Industry 4.0 technologies. BIM is increasingly linked with IoT sensors, digital twins, big data analytics, augmented reality and business intelligence systems to create more dynamic decision-support environments [11-20]. Such integration can transform BIM from a static repository into an operational platform when real-time data, occupant feedback, condition information and maintenance records are connected to spatial and systems-based asset models [11-22].

Existing reviews provide important insights but frequently combine heterogeneous technologies, document types and implementation settings. A synthesis that treats evidence from all contexts as directly transferable may overstate applicability, particularly where digital infrastructure, organisational readiness, contractual arrangements and professional capability differ. This review therefore distinguishes between evidence reported in developed-country, developing-country and non-country-specific settings whenever the source provides sufficient contextual information.

This paper conducts a bounded systematic review of a 51-document, pre-assembled corpus on BIM, advanced technologies and FM. The objectives are to identify overarching thematic patterns, synthesise the main findings, examine contextual applicability and develop a provisional conceptual framework for BIM-enabled data integration and visual analytics in FM. The review addresses five questions: (1) What interoperability issues affect BIM-FM information exchange? (2) What asset information quality issues and information requirements influence BIM use in FM? (3) How do Industry 4.0 technologies extend BIM-enabled FM? (4) How can visual analytics, systems-centric modelling and fault diagnosis support maintenance decision-making? (5) How do reported implementation priorities differ between developed-country and developing-country contexts?

LITERATURE REVIEW

BIM for FM has evolved from a model-viewing concept into a lifecycle information management approach. Early BIM-FM research identified application areas such as locating building components, checking maintainability, accessing real-time data, facilitating maintenance management and supporting digital updates to asset information [1]. Subsequent reviews emphasised that BIM adoption in FM depends on technical interoperability and the maturity of organisational information processes [2-4,34]. Studies on FM-enabled BIM further argue that the model must be planned from the beginning of the project if it is to support O&M rather than only design coordination and construction delivery [7].

A core issue is the distinction between geometric and non-geometric information. While BIM is often valued for its three-dimensional representation, facility managers require structured semantic information, including asset type, location, classification, specification, maintenance frequency, warranty data, spare parts, access requirements and system dependencies [1,6,8,10,35]. Research on asset information requirements and information commissioning therefore positions information quality as a prerequisite for BIM-FM value realisation [8-10,30,35]. Without validated and operationally relevant data, BIM may produce visually rich models that remain underused by FM teams [8,9,22].

The literature also connects BIM-FM with smart and data-driven technologies. BIM-IoT integration can link static building models with live operational data, while digital twin approaches extend this concept by synchronising physical assets, virtual representations and time-based information flows [13-20]. Big data analytics and business intelligence can support FM by converting distributed operational data into decision-ready information, although the literature stresses challenges related to data volume, veracity, interoperability and analytical capability [22-25]. Visual analytics and augmented reality further support field-level decision-making by displaying maintenance instructions, fault locations and system relationships within spatial or mixed-reality environments [21,26-28].

Context also affects the sequence and feasibility of BIM-FM implementation. Studies from technologically mature settings frequently focus on information commissioning, semantic interoperability, digital twins and advanced visual analytics [8-10,17,18,27-30,33,38]. Studies associated with developing-country or emerging-market settings more often emphasise readiness, skills, contractual clarity, cost, data standardisation and staged technology integration [14,36,39]. These differences do not imply separate technical principles. They indicate that the same BIM-FM architecture may require different implementation priorities and governance arrangements.

MATERIALS AND METHODS

Review Design and Corpus Provenance

This study adopted a corpus-based systematic literature review supported by qualitative thematic analysis. The initial source set was a pre-assembled PDF repository containing literature related to BIM, FM, asset management, information requirements, IoT, digital twins, big data, visual analytics, augmented reality and maintenance decision support. The repository was not produced through a new database search undertaken specifically for this article. This distinction is stated explicitly because the review can reproduce the screening and synthesis applied to the repository, but it cannot independently reproduce the historical process through which every source first entered that repository.

The repository contained 60 PDF files. Fifty-one documents were retained after duplicate, non-target and supporting-only files were removed. The review is therefore designed as a bounded qualitative synthesis rather than an exhaustive or bibliometrically representative account of the complete BIM-FM literature. Broad claims were avoided and conclusions were restricted to patterns supported by the retained corpus.

Search Logic and Reproducibility

To make the corpus-verification process transparent, the concept blocks previously used to organise the repository were consolidated into a full Boolean expression. The expression was applied to document titles, abstracts and keywords to verify topical relevance within the existing corpus. It should not be interpreted as the original database retrieval string because the original database names, field tags, search dates and retrieval history were not available.

Consolidated Boolean verification string: ("Building Information Modelling" OR "Building Information Modeling" OR BIM) AND ("facilities management" OR "facility management" OR FM OR "facility maintenance" OR "operation and maintenance" OR O&M) AND ("asset management" OR "asset information" OR AIR OR EIR OR COBie OR IFC OR interoperability OR "information requirements" OR IoT OR "Internet of Things" OR "digital twin" OR "big data" OR "business intelligence" OR dashboard OR analytics OR "visual analytics" OR "fault diagnosis" OR "fault tree" OR "augmented reality" OR "work order" OR "predictive maintenance").

Concept block	Terms used for corpus verification
BIM and FM	"Building Information Modelling" OR "Building Information Modeling" OR BIM, combined with "facilities management", "facility management", FM, "facility maintenance", "operation and maintenance" or O&M.
Asset information and interoperability	"asset management" OR "asset information" OR AIR OR EIR OR COBie OR IFC OR interoperability OR "information requirements".

Digital integration	IoT OR "Internet of Things" OR "digital twin" OR "big data" OR "business intelligence" OR dashboard OR analytics.
Visual analytics and maintenance	"visual analytics" OR "fault diagnosis" OR "fault tree" OR "augmented reality" OR "work order" OR "predictive maintenance".

Table 1. Consolidated search logic used to verify and organise the pre-assembled corpus.

Screening and Eligibility

Screening focused on documents that contributed directly to BIM-FM integration, BIM-enabled asset management, information quality, digital technologies for FM, systems-based visualisation or maintenance decision support. Each full text was assessed against the criteria in Table 2. Documents were excluded when they were duplicate records, outside the BIM-FM scope, incomplete supporting files or unsuitable for thematic synthesis.

Criterion	Inclusion	Exclusion
Topic	BIM, FM, asset management, O&M, information requirements, IoT, digital twin, big data, visual analytics or maintenance decision support.	Studies unrelated to building assets, FM, O&M or digital information integration.
Document type	Journal articles, conference papers, theses, dissertations, review papers and technical studies relevant to the review topic.	Duplicate files, incomplete supporting files or non-target documents.
Language	English-language documents.	Documents not available in English.
Analytical relevance	Documents reporting findings, frameworks, barriers, requirements, applications or implementation challenges.	Documents with no transferable relevance to BIM-FM integration or FM decision-making.
Full-text availability	Complete documents that could be examined and coded.	Records without usable full text.

Table 2. Inclusion and exclusion criteria.

Data Abstraction, Context Coding and Thematic Synthesis

Data abstraction was conducted using a thematic matrix. Each document was examined for author and year, study setting, country context, research focus, methodology, reported findings, technological focus, implementation barriers and implications for FM. Sources were coded as developed-country, developing-country or non-country-specific only when the reported study setting permitted that distinction. Review papers, conceptual papers and globally framed studies without an explicit empirical country setting were retained as non-country-specific rather than assigned retrospectively.

The corpus contained mixed document types and diverse study designs, so an integrative qualitative synthesis was used. Similar findings were compared, grouped and synthesised into higher-order themes rather than counted as statistically equivalent observations. Four themes were finalised after repeated coding: interoperability and information exchange; asset information quality and FM requirements; Industry 4.0 and digital twin-enabled FM; and visual analytics, systems-centric modelling and fault diagnosis. Cross-context observations were treated as interpretive patterns, not as a balanced comparative meta-analysis.

The file-level screening decisions and thematic matrix provide the audit trail for the review and may be made available by the corresponding author on reasonable request. Because the original repository acquisition history was incomplete, the procedure supports reproducibility from the 60-file starting corpus onward, but not independent recreation of the initial repository from bibliographic databases.

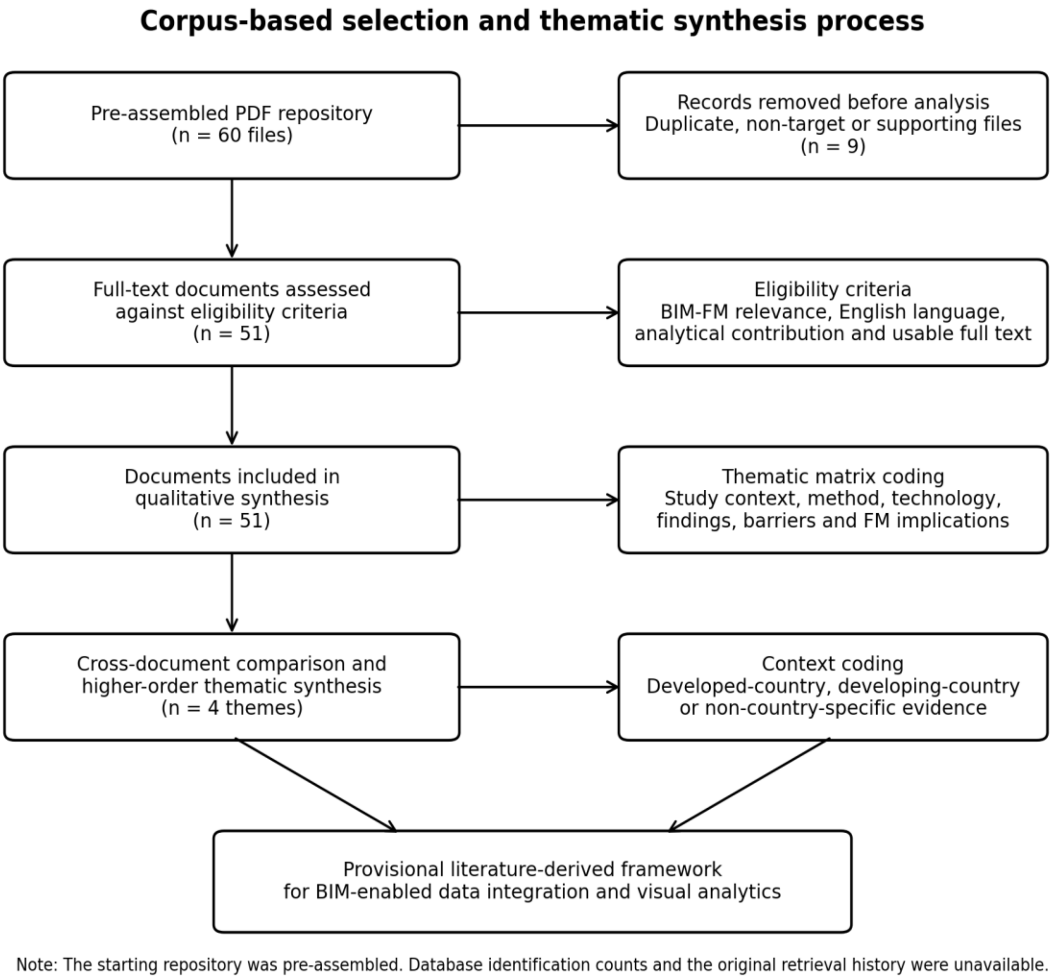

Fig. 1. Corpus-based selection, context coding and thematic synthesis process.

RESULTS

The thematic analysis generated four overarching themes. Table 3 summarises the scope of each theme and representative sources. The findings indicate that BIM-enabled FM is not a single software problem. It is a lifecycle information management issue connecting interoperability, information quality, technological integration and decision-oriented visualisation.

Theme	Scope of synthesis	Representative sources
Theme 1: Interoperability and information exchange	Technical, syntactic and semantic barriers affecting transfer of asset data between BIM authoring tools, CMMS, CAFM, databases and FM platforms.	[2-7,29,34,39]
Theme 2: Asset information quality, data requirements and early FM involvement	Completeness, accuracy, consistency and operational relevance of asset information, including information commissioning and FM participation during early project stages.	[1,5,6,8-10,30,35]
Theme 3: BIM, Industry 4.0 technologies and digital twin-enabled FM	Integration of BIM with IoT, big data, business intelligence, digital twins and predictive analytics for smart and data-driven FM.	[11-20,22-25,31]
Theme 4: Visual analytics, systems-centric modelling and fault diagnosis	BIM-based visualisation, IFC relationships, augmented reality, work order scheduling and fault-tree reasoning for maintenance decisions.	[21,26-28,32,33]

Table 3. Thematic findings from the systematic literature review.

Theme 1: Interoperability and Information Exchange in BIM-FM Integration

Interoperability remains a persistent barrier in BIM-enabled FM because asset information generated during design and construction is often not transferred efficiently into the systems used during O&M [2-5,34]. BIM authoring tools, CMMS and CAFM systems commonly operate with different schemas, data structures and software logics, creating fragmentation between project information and operational information [3-5]. This fragmentation weakens information continuity and limits the ability of owners and facility managers to use BIM as a reliable operational information environment [2,3,7].

Open data standards, particularly IFC and COBie, are repeatedly identified as mechanisms for improving BIM-FM information exchange [2,6,7]. IFC supports vendor-neutral object representation and can describe building components, spatial structures and system relationships, while COBie structures handover data in a form that can support asset management workflows [6,7]. These standards do not automatically solve FM information problems because they do not fully define which data should be delivered, when they should be validated, who is responsible for producing them or how they should be maintained after handover [4,5,8].

Interoperability is therefore a governance and semantic issue as much as a technical one. Effective exchange requires consistent object naming, parameter mapping, classification rules, application programming interfaces, model delivery protocols, contractual clarity and explicit information ownership [5,6,9,29,39]. BIM-FM integration requires standards, modelling protocols and validated information requirements rather than reliance on file exchange alone [6-9].

Theme 2: Asset Information Quality, Data Requirements and Early FM Involvement

BIM-FM implementation is frequently undermined by poor asset information quality at handover [8-10,30,35]. Although BIM models may contain extensive geometric information, they often lack the non-geometric and asset-specific information required for O&M, including maintenance procedures, warranty information, accessibility, spare parts, condition data, inspection records and equipment service relationships [1,6,8]. This creates an information mismatch in which models may be data-rich for design coordination but operationally incomplete for facility managers [8,9,22].

Asset Information Requirements and Exchange Information Requirements are central to resolving this mismatch because they define the operational information needed to support asset management decisions [5,10]. BIM-FM value depends not merely on delivering a 3D model, but on delivering a verified information model aligned with FM tasks, classification structures and lifecycle responsibilities [1,6,8,10,35].

Early FM involvement is consistently presented as a strategy for improving information quality [4,7,8]. When facility managers are excluded from planning and design, operational requirements tend to be defined too late, causing manual re-entry, post-handover checking and information loss [4,8]. Early FM participation allows maintenance needs, data fields, handover milestones and model-development requirements to be embedded before the model is finalised [7,10]. Information commissioning strengthens this process by treating asset information as a deliverable that must be checked for completeness, accuracy and usability before acceptance for O&M [10].

Theme 3: BIM, Industry 4.0 Technologies and Digital Twin-Enabled FM

BIM is increasingly extended through Industry 4.0 technologies such as IoT, digital twins, big data analytics, cloud platforms, business intelligence and machine learning [11-20]. Traditional BIM provides a structured representation of building geometry and semantic asset data, but it remains largely static unless connected to live operational sources [13,14,16]. IoT-BIM integration can add real-time information on indoor environmental conditions, equipment performance, occupancy and energy-related behaviour, enabling more responsive FM processes [13,14,17,31].

Digital twins connect physical assets, virtual models and operational data in a continuously updated environment [15-20]. BIM can act as the spatial and semantic backbone of a digital twin, while IoT sensors, data mining, concept networks and machine learning contribute temporal and performance intelligence [15-18]. This combination can support trend detection and predictive maintenance by linking historical and real-time asset data to building spaces and systems [15,16,18].

Big data and business intelligence are relevant because operational datasets are becoming larger, more varied and more time-sensitive [22-25]. Dashboards and analytics platforms can improve decision-making only when data are accurate, integrated and interpreted within a clear asset management context [8,10,22-25]. Advanced technology therefore extends, rather than replaces, the need for reliable information governance.

Theme 4: Visual Analytics, Systems-Centric Modelling and Fault Diagnosis

Visual analytics transforms fragmented asset records, work orders and fault information into spatially contextualised decision support [21,26,27]. BIM-based visual analytics allows facility managers to locate assets, examine system relationships and interpret failures within the physical and functional context of a building [26,27]. This is particularly valuable for complex building services systems where one component failure may affect multiple spaces and connected assets [26-28].

Systems-centric BIM configuration is important because facility managers often reason through systems rather than isolated model objects [27,28]. IFC relationship structures can represent containment, connectivity, grouping, spatial structure and service relationships between assets and spaces [6,26,27]. BIM can therefore be used not only to visualise objects but also to understand consequences of equipment failure, shutdown or maintenance intervention [26,27].

Fault Tree Analysis strengthens diagnostic reasoning by linking expert knowledge about failure causes with asset-specific BIM and CMMS data [26]. Related studies indicate that BIM can support maintenance work-order scheduling, safer maintenance processes and post-occupancy feedback analysis when spatial data are linked to time-based records [11,12,21,28,32,33]. Augmented reality can present maintenance instructions and asset information at the physical point of work [21].

Contextual Applicability in Developed and Developing Country Settings

Country context was explicit in only part of the corpus. Review papers, conceptual studies and internationally framed sources were therefore coded as non-country-specific. The comparison below is interpretive and does not represent a statistically balanced cross-country analysis.

In developed-country settings, the literature commonly assumes a comparatively mature digital infrastructure and focuses on semantic interoperability, information commissioning, asset data quality, systems-centric modelling, digital twins and advanced analytics [8-10,17,18,27-30,33,38]. Persistent problems nevertheless remain, particularly legacy-system integration, inconsistent information requirements, incomplete handover data and weak post-handover updating.

In developing-country and emerging-market settings, studies more often emphasise uneven BIM maturity, limited standardisation, skills and training needs, cost, fragmented contractual responsibilities and the need for staged integration [14,36,39]. The immediate priority may therefore be a reliable asset register, common naming conventions, minimum information requirements, governance roles and basic BIM-CMMS exchange before digital-twin or predictive-analytics functions are introduced.

The core technical principles are transferable across contexts, but the implementation sequence is not necessarily identical. Applicability claims should therefore be conditioned by organisational capability, data maturity, procurement arrangements, available infrastructure and the operational criticality of the facility.

DISCUSSION

The synthesis demonstrates that BIM-enabled FM should be understood as a socio-technical information system rather than a modelling tool alone. Technically, it requires interoperable data exchange, semantic mapping, information standards, systems relationships, validated asset data and integrated digital platforms [3,6,8,10,27]. Organisationally, it requires early FM involvement, information governance, clearly defined owner requirements, post-handover updating processes and a shared understanding of how model-based data will support operational decisions [4,7-10].

The four themes are mutually reinforcing. Interoperability enables asset information to move between BIM and FM systems, while information quality determines whether the transferred information is useful [5,6,8]. Industry 4.0 technologies extend BIM by linking static asset data with real-time and historical information streams [13-20]. Visual analytics then converts these integrated datasets into practical maintenance intelligence by linking assets, spaces, systems, work orders, fault histories, occupant feedback and performance indicators [11,12,21,26,27,33].

For building services assets such as HVAC and air-conditioning and mechanical ventilation systems, a BIM-enabled FM environment should include asset identity, equipment type, service zone, system membership, connected components, warranty details, maintenance frequency, work-order history, fault patterns, inspection records and performance readings [1,6,8,27]. Without early specification and handover validation, BIM dashboards or 3D views may remain visually attractive but operationally weak [8-10].

Provisional Literature-Derived Conceptual Framework

Based on the thematic synthesis, this paper proposes a seven-stage framework for BIM-enabled data integration and visual analytics in FM. The framework is provisional and literature-derived. It organises the relationships identified across the corpus into a lifecycle-oriented workflow, but it has not been validated through practitioner interviews, expert review, a Delphi process or operational case testing. It should therefore be treated as a testable conceptual proposition rather than an implementation-ready standard.

The framework begins with the definition of FM information requirements and progresses through FM-capable model preparation, data-quality validation, operational-system integration, analytical and diagnostic logic, visualisation and continuous updating. The sequence reflects the finding that advanced analytics cannot compensate for missing asset identities, inconsistent naming or unreliable handover information.

Stage	Process	Expected output
1. Define FM information requirements	Specify asset identity, location, classification, system membership, maintenance tasks, documents, performance indicators and operational data needs [1,5-8,10].	Asset Information Requirements and Exchange Information Requirements.
2. Prepare an FM-capable BIM model	Embed shared parameters, naming conventions, spatial hierarchy, systems relationships and classification rules [1,5-7,29].	Structured BIM model containing geometric and non-geometric asset information.
3. Validate asset information quality	Check completeness, accuracy, consistency, duplicate IDs, missing attributes and handover compliance [8-10,30,35].	Verified asset information dataset.
4. Integrate BIM with operational systems	Connect BIM with CMMS, CAFM, databases, IoT streams, GIS, business intelligence platforms or middleware [2,3,6,13-17,31,36,39].	Integrated information environment for FM.
5. Apply analytical and diagnostic logic	Use fault trees, maintenance rules, work-order histories, time-series analysis, sensor data and occupant feedback [11,12,15,18,26,32].	Fault diagnosis, trend detection and predictive-maintenance insights.
6. Visualise operational intelligence	Display assets, systems, affected zones, work orders, condition histories and KPIs using BIM, dashboards or augmented reality [21,26-28,32,33].	Contextual visual analytics for FM decision-making.
7. Update the asset information model	Feed inspections, repairs, replacements, condition changes, feedback and completed work orders back into the asset record [7-10,19,20].	Continuously maintained digital asset information environment.

Table 4. Provisional framework for BIM-enabled data integration and visual analytics in FM.

Required Validation of the Framework

A staged validation programme is required before the framework can be claimed as practically robust. Table 5 specifies a feasible validation route. The activities are proposed future work and were not undertaken in the present review.

Validation stage	Suggested method	Evidence required
Expert content review	Structured assessment by BIM, FM, asset-management and data-analytics specialists. Content Validity Index and qualitative comments may be used to assess relevance, clarity and completeness.	Agreement on stages, definitions, dependencies and missing elements.
Operational case application	Apply the framework to one or more occupied facilities and trace selected assets from information requirements to work-order and dashboard use.	Data completeness, mapping accuracy, integration success and documented workflow performance.
User and usability evaluation	Evaluate facility managers, technicians and system administrators undertaking representative FM tasks.	Task completion, information retrieval time, usability ratings and qualitative feedback.
Cross-context validation	Compare implementation in a developed-country and developing-country setting or in organisations with contrasting digital maturity.	Context-specific enablers, constraints, sequencing requirements and framework refinements.

Table 5. Proposed empirical validation programme for the conceptual framework.

Methodological Limitations

The review has five principal limitations. First, 51 documents constitute a relatively small corpus for claims spanning several technology domains. The findings are therefore thematic and bounded, not statistically generalisable. Second, the starting corpus was pre-assembled and its original database retrieval history was unavailable. Selection bias may consequently have occurred before the present screening process began. Third, the consolidated Boolean expression supports verification of the available corpus but cannot reproduce the original repository from external databases. Fourth, the corpus includes different document types and is not balanced across national contexts, limiting direct comparison between developed and developing countries. Fifth, the proposed framework has not been empirically validated.

These limitations do not invalidate the synthesis, but they define its evidential boundary. A future update should conduct a prospective search in databases such as Scopus and Web of Science using dated, database-specific strings, publish a complete screening log and corpus inventory, assess study quality formally and validate the framework with practitioners and operational case evidence.

CONCLUSION

This bounded, corpus-based systematic literature review synthesised 51 documents on BIM-enabled data integration, advanced technologies and visual analytics for FM. Four major themes were identified: interoperability and information exchange; asset information quality, data requirements and early FM involvement; BIM convergence with Industry 4.0 technologies and digital twin-enabled FM; and visual analytics, systems-centric modelling and fault diagnosis.

The review indicates that BIM can support FM only when asset information is structured, validated, interoperable and aligned with operational needs. IFC and COBie can support exchange, but they must be complemented by semantic mapping, naming conventions, information requirements, data governance and verification procedures. Industry 4.0 technologies can extend BIM into dynamic and predictive FM, but their effectiveness depends on reliable information and organisational readiness.

The developed-country and developing-country comparison suggests that the underlying technical principles are broadly consistent while implementation sequencing differs. Digitally mature organisations may progress towards automated integration and advanced analytics, whereas less mature contexts may first require standardised asset data, governance roles, skills development and basic BIM-FM connectivity.

The seven-stage framework is a provisional literature-derived contribution. It should not be treated as validated until it has undergone expert assessment, operational case testing, usability evaluation and cross-context refinement. Future research should also replace the pre-assembled corpus with a prospectively retrieved and fully reproducible database search.

Data Availability Statement

The file-level screening log and thematic abstraction matrix used for this review may be made available by the corresponding author on reasonable request. The original historical database retrieval record for the pre-assembled repository was not available.

Acknowledgement

This research was supported by Universiti Tun Hussein Onn Malaysia (UTHM) through Tier 1 (Vot Q958) and the Postgraduate Research Grant (Vot J078).

Conflict of Interest

The authors declare no conflict of interest.

REFERENCES

1. 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.
2. Pärn, E. A., Edwards, D. J., & Sing, M. C. P. (2017). The building information modelling trajectory in facilities management: A review. Automation in Construction, 75, 45-55. https://doi.org/10.1016/j.autcon.2016.12.003
3. Matarneh, S. T., Danso-Amoako, M., Al-Bizri, S., Gaterell, M., & Matarneh, R. (2019). Building information modeling for facilities management: A literature review and future research directions. Journal of Building Engineering, 24, 100755. https://doi.org/10.1016/j.jobe.2019.100755
4. Dixit, M. K., Venkatraj, V., Ostadalimakhmalbaf, M., Pariafsai, F., & Lavy, S. (2019). Integration of facility management and building information modeling: A review of key issues and challenges. Facilities, 37(7/8), 455-483.
5. Matarneh, S. T., Danso-Amoako, M., Al-Bizri, S., Gaterell, M., & Matarneh, R. T. (2020). Developing information requirements to support facilities management systems. Facilities, 38(5/6), 378-394. https://doi.org/10.1108/F-07-2018-0084
6. Farghaly, K., Abanda, F. H., Vidalakis, C., & Wood, G. (2018). Taxonomy for BIM and asset management semantic interoperability. Journal of Management in Engineering, 34(4), 04018012. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000610
7. Pishdad-Bozorgi, P., Gao, X., Eastman, C., & Self, A. P. (2018). Planning and developing facility management-enabled building information model. Automation in Construction, 87, 22-38. https://doi.org/10.1016/j.autcon.2017.12.004
8. Tsay, G. S., Staub-French, S., & Poirier, É. (2022). BIM for facilities management: An investigation into the asset information delivery process and the associated challenges. Applied Sciences, 12(19), 9542. https://doi.org/10.3390/app12199542
9. Tsay, G. S., Staub-French, S., Poirier, É., Zadeh, P., & Pottinger, R. (2023). BIM for FM: Understanding information quality issues in terms of compliance with owner's building information modeling requirements. Frontiers in Built Environment, 9, 1117066. https://doi.org/10.3389/fbuil.2023.1117066
10. Kim, S., Poirier, E. A., & Staub-French, S. (2020). Information commissioning: Bridging the gap between

digital and physical built assets. Journal of Facilities Management, 18(3), 231-245. https://doi.org/10.1108/JFM-04-2020-0024

11. Artan, D., Ergen, E., Kula, B., & Guven, G. (2022). RateWorkSpace: BIM integrated post-occupancy evaluation system for office buildings. Journal of Information Technology in Construction, 27, 441-485. https://doi.org/10.36680/j.itcon.2022.022
12. Artan, D., Tekce, I., Yilmaz, N., & Ergen, E. (2024). The contextual information requirements for collection and use of occupant feedback in BIM-enabled FM. Facilities, 42(3/4), 321-341. https://doi.org/10.1108/F-03-2023-0028
13. Tang, S., Shelden, D. R., Eastman, C. M., Pishdad-Bozorgi, P., & Gao, X. (2019). A review of building information modeling and the Internet of Things devices integration: Present status and future trends. Automation in Construction, 101, 127-139. https://doi.org/10.1016/j.autcon.2019.01.020
14. Altohami, A. B. A., Haron, N. A., Ales@Alias, A. H., & Law, T. H. (2021). Investigating approaches of integrating BIM, IoT, and facility management for renovating existing buildings: A review. Sustainability, 13(7), 3930. https://doi.org/10.3390/su13073930
15. Pan, Y., & Zhang, L. (2021). A BIM-data mining integrated digital twin framework for advanced project management. Automation in Construction, 124, 103564. https://doi.org/10.1016/j.autcon.2021.103564
16. Hakimi, O., Liu, H., & Abudayyeh, O. (2024). Digital twin-enabled smart facility management: A bibliometric review. Frontiers of Engineering Management.
17. Roxin, A., Abdou, W., & Derigent, W. (2022). Interoperable digital building twins through communicating materials and semantic BIM. SN Computer Science, 3, 23. https://doi.org/10.1007/s42979-021-00860-w
18. Sobhkhiz, S. (2023). Dynamic integration of textual data in digital twins using concept networks and machine learning. Doctoral thesis, University of Toronto.
19. Lee, J. Y., Irisboev, I. O., & Ryu, Y. S. (2021). Literature review on digitalization in facilities management and facilities management performance measurement: Contribution of Industry 4.0 in the global era. Sustainability, 13(23), 13432. https://doi.org/10.3390/su132313432
20. Nota, G., Peluso, D., & Toro Lazo, A. (2021). The contribution of Industry 4.0 technologies to facility management. Journal of Facilities Management.
21. Palmarini, R., Erkoyuncu, J. A., Roy, R., & Torabmostaedi, H. (2018). A systematic review of augmented reality applications in maintenance. Robotics and Computer-Integrated Manufacturing, 49, 215-228. https://doi.org/10.1016/j.rcim.2017.06.002
22. Ahmed, V., Tezel, A., Aziz, Z., & Sibley, M. (2017). The future of Big Data in facilities management: Opportunities and challenges. Facilities, 35(13/14), 725-745.
23. Ali, S. M., Gupta, N., Nayak, G. K., & Lenka, R. K. (2016). Big data visualization: Tools and challenges. 2016 2nd International Conference on Contemporary Computing and Informatics. https://doi.org/10.1109/IC3I.2016.7918044
24. Khan, R. A., & Quadri, S. M. K. (2012). Business intelligence: An integrated approach. Business Intelligence Journal, 5(1), 64-70.
25. Omoyiola, B. O. (2022). The social implications, risks, challenges and opportunities of big data. Emerald Open Research, 4, 23. https://doi.org/10.35241/emeraldopenres.14646.1
26. Motamedi, A., Hammad, A., & Asen, Y. (2014). Knowledge-assisted BIM-based visual analytics for failure root cause detection in facilities management. Automation in Construction. https://doi.org/10.1016/j.autcon.2014.03.012
27. Ensafi, M., Harode, A., & Thabet, W. (2022). Developing systems-centric as-built BIMs to support facility emergency management: A case study approach. Automation in Construction, 133, 104003. https://doi.org/10.1016/j.autcon.2021.104003
28. Evans, G., Heesom, D., & Oloke, D. (2021). Configuring BIM models to support a systems-driven visualisation approach. IOP Conference Series: Materials Science and Engineering, 1218, 012026. https://doi.org/10.1088/1757-899X/1218/1/012026
29. Foster, J. D. (2022). Using naming conventions to facilitate data transfer between asset management systems and building information models. Master thesis, Rowan University.
30. Fang, Z., Liu, Y., Lu,Q., Pitt, M., Hanna, S., & Tian, Z. (2022). BIM-integrated portfolio-based strategic asset data quality management. Automation in Construction, 134, 104070. https://doi.org/10.1016/j.autcon.2021.104070

31. Chen, W. (2019). Integration of Building Information Modeling and Internet of Things for facility maintenance management. Doctoral dissertation, Hong Kong University of Science and Technology.
32. Chen, W., Chen, K., Cheng, J. C. P., Wang, Q., & Gan, V. J. L. (2018). BIM-based framework for automatic scheduling of facility maintenance work orders. Automation in Construction, 91, 15-30. https://doi.org/10.1016/j.autcon.2018.03.007
33. Wetzel, E. M., & Thabet, W. Y. (2015). The use of a BIM-based framework to support safe facility management processes. Automation in Construction, 60, 12-24.
34. Abideen, D. K., Yunusa-Kaltungo, A., Manu, P., & Cheung, C. (2022). A systematic review of the extent to which BIM is integrated into operation and maintenance. Sustainability, 14(14), 8692. https://doi.org/10.3390/su14148692
35. Chang, J. Y., Merino-Garcia, J., Xie, X., Moretti, N., & Parlikad, A. (2022). Information quality for effective asset management: A literature review. IFAC-PapersOnLine, 55(19), 235-240. https://doi.org/10.1016/j.ifacol.2022.09.213
36. Ismaeil, E. M. H. (2024). Asset information model management-based GIS/BIM integration in facility management contract. Sustainability, 16(6), 2495. https://doi.org/10.3390/su16062495
37. Ismaeel, W. S. E., & Lotfy, R. A. E. (2023). An integrated building information modelling-based environmental impact assessment framework. Clean Technologies and Environmental Policy, 25, 1291-1307. https://doi.org/10.1007/s10098-022-02443-6
38. Santos, R., Costa, A. A., Silvestre, J. D., & Pyl, L. (2020). BIM-based life cycle assessment and life cycle costing of an office building in Western Europe. Building and Environment, 169, 106568. https://doi.org/10.1016/j.buildenv.2019.106568
39. Jamil, A. H. A., & Fathi, M. S. (2020). Enhancing BIM-based information interoperability: Dispute resolution from legal and contractual perspectives. Journal of Construction Engineering and Management. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001868
40. Lovreglio, R., Thompson, P., & Feng, Z. (2021). Automation in fire safety engineering using BIM and generative design. Fire Technology. https://doi.org/10.1007/s10694-021-01153-7
41. Malagnino, A., Mangialardi, G., Corallo, A., & Lazoi, M. (2022). The digital transformation in fire safety engineering over the past decade through building information modelling: A review. Fire Technology. https://doi.org/10.1007/s10694-022-01313-3