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Development and evaluation of a maturity assessment tool for integrating building information modelling into operations and maintenance phase of buildings

Dania K. Abideen [a], Akilu Yunusa-Kaltungo [a,*], Clara Cheung [a], Patrick Manu [b]

[a] Department of Mechanical, Aerospace and Civil Engineering (MACE), University of Manchester, UK
[b] School of Architecture and Environment, University of Bristol, UK

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ABSTRACT

The emergence of advanced digital tools such as building information modelling (BIM) has transformed the concept of building management in the construction sector. Despite the promising benefits of BIM in terms of successful project deliveries and enhanced building performance, construction firms struggle to view assets from the perspective of a whole asset life cycle context, and consequently struggle to derive their full potentials via BIM, especially in the operations and maintenance (O&M) phase. One of the fundamental reasons behind this challenge is the lack of empirical understanding of what information should be collected to support efficient and effective operation and maintenance management. Various BIM capability maturity models have been proposed to support BIM integrations into O&M management, but most of these models fail to capture detailed information requirements (IRs). Furthermore, there is limited insights regarding the prioritisations of these IRs to guide construction firms and asset owners towards operational competitiveness and excellence. To address these gaps, this study aims to develop a BIM and O&M maturity assessment model (BIM and O&M MM) by drawing on the capability maturity model integration (CMMI) concept, and utilising Delphi technique and maturity grids. The developed tool enables asset owners and managers to assess BIM and O&M integration maturity of built assets, based on a five-level maturity scheme across 21 IRs. To ensure effectiveness and practicality of the tool, 22 experts assessed the tool, and the results indicate its ability to succinctly measure the maturity level of BIM and O&M integration, thereby enabling construction managers and asset owners to identify areas of strengths and deficiencies for prioritising capital investments. The BIM and O&M MM ensures stakeholder alignment and addresses real-world O&M challenges. It enhances data consistency, optimised long-term asset management, data-driven decision-making, and provides a foundation for future research and technology integration.

1. Introduction

The incorporation of building information modelling (BIM) into the conceptualisation and delivery of built assets continues to grow within the architecture, engineering, and construction (AEC) sector. BIM is known as a centralised data repository that integrates the structural and operational aspects of buildings, thereby facilitating data-driven decision making. BIM offers significant enhancements to effective facilities data management, by enabling a seamless collaboration and coordination among relevant stakeholders from the design to the operations team. Various leading countries in BIM applications have developed sets of specifications and standards for BIM adoption, including USA, Canada, UK, Australia, Finland, Norway and Singapore (Gomes et al., 2013), (RICS, 2011 Building Information Modelling, 2011). For example, the Canadian BIM standards are developed based on the UK BIM specification (NBS). Also, the UK BIM protocols have been integrated to develop preliminary BIM guidelines in Russia, Germany, Hong Kong and Australia (Gomes et al., 2013), (RICS, 2011 Building Information Modelling, 2011). The rate of adopting BIM in UK construction has rapidly increased, making the UK one of the leading nations in implementing BIM technology and processes, especially after the government mandated a minimum requirement of obtaining at least BIM-level 2 to be implemented from 2016 (HM Government, 2012).

While BIM has been extensively adopted in the design-to-

* Corresponding author.
E-mail addresses: dania.abideen@postgrad.manchester.ac.uk (D.K. Abideen), akilu.kaltungo@manchester.ac.uk (A. Yunusa-Kaltungo), clara.cheung@manchester.ac.uk (C. Cheung), patrick.manu@uwe.ac.uk (P. Manu).

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construction phases, its potentials significantly extend to the operations and maintenance (O&M) phase of buildings (Tucker and Masuri, 2018). This emphasises the criticality of integrating BIM with O&M to support long term asset management and sustainability, especially that the O&M phase usually accounts for more than 60% of the total life cycle costs. The integration between BIM and O&M results in faster operational processes, higher productivity, reduced uncertainty, better risk management and informed decision making. In addition, BIM can offer major contributions towards controlling building life cycle costs through prevention of faults and effective waste management.

The cost savings through BIM mainly come from the elimination of wastes, energy efficiency analysis, facilities maintenance, elimination of clashes and avoidance of rework costs (Walasek and Barszcz, 2017). These savings will eventually enhance the return on investment (ROI) through optimisation of resource allocations, which will benefit all stakeholders across the entire supply chain and consequently the asset owners (Crawford). Recent studies have started to address the potential of cost saving from BIM in O&M, and proposed means to facilitate the integration with facilities management and the O&M phase (Cheng et al., 2020)– (Ma et al., 2020). Many contractors have reported positive ROI through BIM integration in facilities management. Some examples in the literature include:

- The full integration of BIM into construction projects is expected to almost double ROI and increase labour productivity by approximately 10% (Carbasho, 2008).
- The productivity of designers and architects can rise by up to 30% through BIM adoption (Achieving Strategic ROI MEASURING THE).
- Engineers (structural, mechanical, electrical and plumbing MEP) can decrease man-hours by 47% (Abdulrahman and Naim, 2018).
- Construction projects can increase productivity by 15%–30% by incorporating BIM into their projects (Abdulrahman and Naim, 2018).

Despite the success of BIM and its popularity, several barriers and challenges continue to limit its adoption in facilities management especially in the O&M stage. The key barriers include interoperability challenges due to the complex and extensive nature of the competing software during building life cycle, which further complicates the seamless integrations between systems, resulting in poor and fragmented data. Additionally, the absence of a standardised framework to guide this integration makes it difficult for building owners to establish consistent approaches or practices. Moreover, the reluctance to change from legacy systems and methods and the unfamiliarity with BIM potentials in O&M further de-motivates the integration (Kensek, 2015). These barriers complicate the process of aligning BIM with the various O&M practices, due to the absence of unified frameworks, priorities and data standards among construction stakeholders. This often leads to misalignment between BIM and O&M objectives, thereby hindering their integration.

The importance of adopting BIM in O&M, has created the need to evaluate and improve BIM integration with O&M. Performance enhancements for BIM in O&M and efforts to achieve business excellence is dependent on the application and effectiveness of process improvement techniques. The Capability Maturity Model (CMM) is a well-recognised process improvement technique that is highly flexible and practical (Henriques and Tanner, 2017).

Maturity models (MMs) are a systematic approach aiming toward measuring and assessing different areas of a certain system in an organisation (Henriques and Tanner, 2017). The fundamental theory of MMs is based on progression. Different processes, individuals, activities, organisations, and other elements advance from a preliminary phase to more sophisticated and mature phases, transitioning through several intermediate phases (Henriques and Tanner, 2017).The application of Capability Maturity Model (CMM) provides a structured framework to assess the maturity of BIM integration with O&M by evaluating various processes and attributes at defined stages. This is accomplished through (1) improving productivity; (2) enabling decision-makers to justify the significant amount of capital and time investments to achieve a positive return on investment (ROI), especially in the O&M stage since it typically spans over 20 years of the building life cycle (Kensek, 2015); and (3) enabling building owners through identifying weaknesses, setting specific targets and deliverables, and advancing their capabilities in a systematic and quantified manner (Mahamadu et al., 2020).

Several models have been proposed for assessing the BIM maturity levels in construction for different purposes. While some models aim to benchmark BIM practices against best practice, others focus on organisational assessment. Although many researchers addressed the criticality of assessing BIM capability in construction (Prabhakaran et al., 2021)– (Haji et al., 2021), the majority of these models are centred on the initial stages of the life cycle. For example, the BIM-CAREM reference model for BIM capability assessments was proposed by Yilmaz et al. (2019) to classify FM attributes into process, technical, organisational, human aspect and BIM standards. This comprehensive categorisation offers valuable insights into the critical components required for effective BIM adoption in O&M. Edirisinghe et al. (2021) presented the life cycle BIM maturity model (LCBMM) which emphasises asset life cycle, including the operations phase. The LCBMM offers a structured approach to evaluating BIM maturity across various stages of an asset's lifecycle, highlighting the criticality of seamless data continuity and alignment in the operations phase.

While both, the BIM-CAREM and LCBMM offers valuable insights into BIM maturity from a life cycle perspective, their primary focus lies in the high-level assessment of current BIM capabilities. Both models do not explicitly address the appropriate level of details or the progressive nature of integrating BIM with O&M. These models lack comprehensiveness in their defined measures and therefore fail to capture/assess actual BIM integration with O&M maturity and readiness. Additionally, they lack flexibility when it comes to advancing maturity levels in the context of O&M over time and often fail to account for the dynamic nature of O&M processes as well as their relative importance. By overlooking this dynamic phenomena, the models lack flexibility and real-time responsiveness that are essential to modernised facility management, leading to inefficiencies and increased operational risks. These limitations underscore a noteworthy gap regarding providing actionable pathways to enhance BIM integration with O&M.

Despite the widespread use of CMMs in various industries, there is currently no universally accepted model specifically tailored to accommodate the key information requirements (IRs) for BIM integration with O&M. The absence of a standardised framework hinders building and asset owners from advancing and enhancing their current capabilities in aligning BIM with O&M processes. Although BIM has proven beneficial in enhancing operational efficiency, this work identifies a critical research gap regarding the absence of a holistic CMM specifically designed to enable objective assessments of BIM and O&M integration. This gap prevents building owners from objectively assessing BIM and O&M maturity. Furthermore, the lack of detailed IRs for BIM in O&M further limits the ability to systematically identify operational inefficiencies, evaluate current capabilities, and implement targeted and practical improvements with responsiveness to real life operational needs, to leverage and advance BIM performance in O&M. Therefore, there is a need for the development of a CMM that facilitates comprehensive evaluation and progressive enhancement of BIM and O&M integration.

Building on the foundational concepts introduced by Yilmaz et al. (2019) and the principles of the LCBMM (Edirisinghe et al., 2021), this research aims to develop a novel CMM framework specifically designed to evaluate and improve BIM and O&M integration, addressing both the detailed assessment and improvement dimensions of BIM and O&M maturity.

The developed tool enables construction stakeholders and built asset owners and managers to assess their current operational preparedness, highlight room for improvements and thus, prioritise investments and capital expenditures to address maintenance issues. The proposed model serves as a benchmark for continuous improvement and enables policymakers and decision-makers to optimise and standardise their maintenance practices. Section 2 of this study provides a thorough and systematic literature review, followed by an outline of the research methodology. Subsequently, the BIM and O&M maturity assessment tool is presented, followed by a discussion of the evaluation process and concluding remarks.

2. Literature review

The literature review examines historical and current trends of the applications of capability maturity models in construction, and BIM and O&M maturity. The research employed the preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) as highlighted by (Moher et al., 2015), (Okoli, 2015).

2.1. Systematic literature review (SLR) approach

2.1.1. Review question

The SLR was conducted with the aim of critically reviewing, highlighting and comparing the contemporary state of BIM maturity models in the O&M stage. Thus, the subsequent review question is:

What is the status of BIM maturity models, and how extensively are they incorporated with the O&M stage?

2.1.2. Inclusion guidelines

A key aspect of SLRs is the rationale behind selecting each primary article, typically demonstrated through inclusion and exclusion criteria. As such, the inclusion criteria for this SLR are presented in Table 1 below.

2.1.3. Search strategy

The selected database was Scopus, owing to its size and multidisciplinary contents. Therefore, Scopus provides an opportunity to effectively capture articles representing the views, focus, and methods used by experts from diverse disciplines through a single database. The methodology comprises five stages: scoping, identification of review question, screening of initially generated articles, determining eligibility and selecting final sample. Advanced keyword search option was employed using the phrases; TITLE-ABS-KEY (*"BIM" AND "maturity model")*. Following the initial search, a manual filtering process was applied based on the previously defined inclusion criteria, to focus on studies explicitly related to BIM maturity models within O&M. This approach captured key developments in the field, with most relevant studies concentrated in recent years, evolving from 2018, thereby reflecting a period of significant advancement and adoption of BIM focusing on actual O&M phase/facilities management as previously emphasised by Abideen et al. (2022), (Abideen et al., 2020; Al Rahhal Al Orabi and Al-Gahtani, 2022). There were initially 61 articles identified, which were subsequently narrowed down according to the implementation of inclusion and exclusion criteria. Ultimately, 25 publications were excluded due to their irrelevance to the filed. The remaining 36 papers were manually filtered through title and abstract assessment. Ultimately, the suitability of the remaining papers was assessed based on availability of full text. Finally, the 13 articles that met the inclusion criteria were retained for full review. Fig. 1 below demonstrates the different stages of the SLR process implemented here.

Table 1
Inclusion criteria for SLR.

Category	Criteria
Search key words	The initial search phrases using TITLE-ABS-KEY included *("Building information modelling" AND "maturity model" AND "Operations & maintenance")* but no results were found. Then, due to the widespread use and recognition of their acronyms within the academic and professional communities (*"BIM" AND "maturity model" AND "Operations & maintenance")* then (*"BIM" AND "maturity model" AND "O&M")* were used. However, no results were found based on any of the initial search strings. Therefore, the search string was broadened to (*"BIM" AND "maturity model"*).
Publication scope	Publications on BIM CMMs in construction focusing on O&M phase/facilities management.
Publication type	Peer-reviewed journal and conference articles, due to their rigorous research methodologies and reliability of their outcomes (Bronson et al., 2012).
Language	Publications written in English
Time frame	No specific time frame was selected to ensure comprehensive coverage of all relevant literature on BIM maturity models focusing on the O&M phase. By not limiting the search period, the SLR aimed to identify seminal works as well as recent advances, allowing better tracking of the field's evolution.

2.1.4. Screening of articles

The screening process entailed the following steps:

- The inclusion and exclusion guidelines were used to filter the initial search outcomes.
- To determine article relevance, titles and abstracts/full assessment were conducted.
- Relevant publications were then saved in Mendeley software.

2.1.5. Extraction of data

Existing literature was systematically reviewed and analysed by identifying the strengths, weaknesses, and number of maturity levels as well as the models' descriptors and their definitions. In addition, the items/attributes of each CMM were investigated to have a deeper understanding of the BIM CMMs in O&M.

Table 2 shows a summary of previous BIM capability maturity models in the construction domain. The analysis presents the name of maturity models, aim, number of levels, descriptors as well as their descriptions or definitions and strengths and weaknesses. Furthermore, the analysis captures the various attributes/categories/factors of each framework/CMM. Sections 2.2-2.4 summarise the key findings and

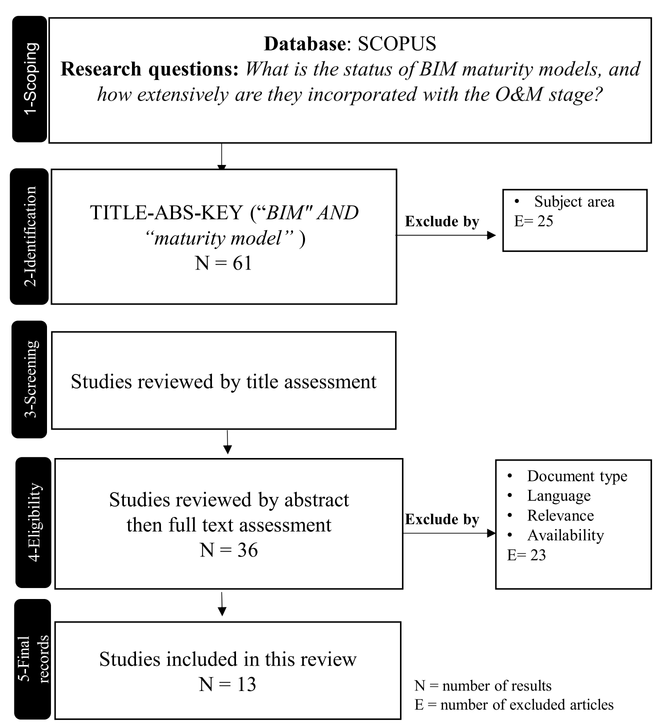

Fig. 1. Detailed flowchart for SLR.

Table 2
Overview of previous BIM maturity assessment models.

Ref.	Name of maturity model	Abbreviation	Aim	Number of maturity levels	Descriptors	Def. of description.	Strengths	Weakness	Items of framework/factors/ attributes
Olawumi and Chan (2019a)	Benchmarking model	BM	To evaluate BIM innovation of implementation using the BIM benchmarking model in a construction project	6	Very poor, Poor, Average, Good, Very Good, and Outstanding	NA	The model used quantitative methods to establish scoring indicators	Did not define descriptors with respect to model elements	BIM processes, BIM products, measures of good practice
Mahamadu et al. (2020)	BIM Capability Assessment of Post-Selection Performance	BCAPSP	To compare predicted BIM capability and post-selection performance by utilising fuzzy sets theory	6	Very poor, Poor, Average, Good, Very Good and Outstanding	Yes	The study focuses on collaborative information maturity	Lacks flexibility when comparing predictive performance versus actual performance. Further ethnographic studies are needed.	Competence, capacity and resources, culture and attitude, cost
Prabhakaran et al. (2021)	Macro BIM maturity assessment		To identify the influence of selected maturity characteristics on BIM application	5	Low maturity, Medium-low maturity Medium maturity, Medium–high maturity and High maturity	NA	The study adopts qualitative and quantitative approach to address BIM maturity assessment for Qatar and the UK	Model descriptors were not clearly defined	Objective, Stages and Milestones, Champions and Drivers, Regulatory framework, noteworthy publication, Learning and Education, Measurement and Benchmark, Standardised parts and Deliverables, Technology Infrastructure
Siebelink et al. (2018)	BIM Maturity Tool	BMT	To enable the evaluation of the digital and institutional aspects of BIM within the Dutch construction industry	5	Non-Existent, Initial, Managed, Defined, Measured, and Optimising	Yes	The study considers and defines inner and outer characteristics for BIM maturity	Further applications in other sectoral analyses to check model applicability especially in O&M	Strategy, Organizational structure, People and culture, Processes and procedures, IT Infrastructure, Data (structure)
Haji et al. (2021)	BIM Maturity Level on the 4D Simulation Performance	BMM4D	to evaluate 4D BIM and define the corresponding Level of Development (LOD)	5	Initial/adhoc, Managed, Defined, Measured, and Optimised	Yes	Explored benefits of 4D BIM simulation in relation to BIM maturity	limited to 4D BIM	BIM implementation process, Software selection, Economic purposes of BIM implementation, Systematic documentation
Yilmaz et al. (2019)	A reference model for assessing BIM capability	BIM-CAREM	To measure BIM capability assessments through a scoring scale	4	Incomplete BIM, Performed BIM, Integrated BIM, and Optimised BIM	Yes	Proposed a comparison of eight BIM CMMs	Requires a deeper understanding of the issues within AEC	Process, technical, organisational, human aspect, BIM standards
Lu W et al. (2021)	Multifunctional BIM maturity model (MBMM)	MBMM	To evaluate BIM maturity at project, organisation and industry level	4	Level 0, Level 1, Level 2, and Level 3	NA	Achieved a holistic view of BIM implementation through the three-level evaluation	the valuation approach is subjective	Technology Process Protocol
Rashidian et al. (2023)	Capability assessment model		To effectively assess productivity improvements in organisations	NA	NA	NA	Lean focused	Unclear model descriptors with no definitions	Customer focus, Culture and people, Workplace standardization, Waste minimization, Continuous improvement
Sun et al. (2022)	Two-Dimensional Maturity	BATM	To utilise evaluation indexes to develop an innovative BIM MM	6	PBM Maturity (6): Level 0, Level 1, Level 2, and Level 3, level 4, level 5 and PBA Maturity (5) level 1-5	Yes	Investigated the 2D maturity with the maturity of PBA and PBM Across actual vs. predicted performance, with performance criteria	Little focus was given to organisational BIM capability	Stakeholder, Team, Development approach and life cycle, Planning, Project work, Delivery, Measurement, Uncertainty

(*continued on next page*)

Table 2 (*continued*)

Ref.	Name of maturity model	Abbreviation	Aim	Number of maturity levels	Descriptors	Def. of description.	Strengths	Weakness	Items of framework/factors/ attributes
							driven from the 7th edition of PMBOK		
Edirisinghe et al. (2021)	Life cycle BIM maturity model	LCBMM	To assess BIM maturity within the hole life cycle of the asset	4	Emerging BIM, Developed BIM, Converged BIM, Durable BIM	Yes	Model elements are considered flexible and practical	Needs further validation	Leadership for BIM, Goal setting for BIM, Specificity of BIM requirements, Resource integration, Formalisation of processes
Phang et al. (2020)	Precast- concrete BIM	PCBIM Hexagon	To identify critical success factors (CSFs) impacting BIM implementation	4	Computer-aided-design CAD, lonely BIM, proprietary BIM, integrated BIM	Yes	Addressed lesson from earlier BIM adopters'	Factors are more organisational and less focused on the information needed for O&M; less focus is given to asset life cycle concepts	The government, ecosystem, company, team, process, and BIM software tool
Chen et al. (2023)	National BIM Standard NBIMS and BIM Maturity Matrix (BIM MM) BIM maturity assessment	NBIMS CMM,	To provide a refined assessment system for the of BIM maturity assessment during design and construction phases	10 for NBIMS CMM, 5 BIM MM	[0–1) Not present, [1–2) Initial, [2–3) Experiential, [3–4) Adjusted, [4–5) Managed, [5–6) Defined, [6–7) Standard, [7–8) Quantitatively managed, [8–9) Optimised, [9–10) Full-fledged	Yes	Provided an updated and integrated indicator system and a new level division, and combines efficiently with (large-scale group decision making) LSGDM	The permanent invariance of the model cannot be guaranteed due to time and geographic application	Equipment, Organization, Policy
Yun et al. (2021)	Project management maturity evaluation index system		To adequately assess BIM maturity	5	Preliminary, Development, Improvement, Maturity and Optimisation stages	Yes	The establishment of a maturity assessment index based on five factors: progress, cost, quality, safety and risk	More focused on project management, less on asset management	Progress, quality, cost, safety and risk

knowledge gaps from the conducted SLR. Results from the SLR were analysed to expose common themes and applications of BIM MMs in construction, then a deeper analysis covered those models/frameworks related to the O&M phase along with their limitations, thereby highlighting knowledge trends and critical gaps in the literature.

2.2. Scope and applications of BIM maturity models

The successful applications of MMs in the manufacturing and technology sectors had inspired the construction industry to push efforts towards contextualising MMs, like CMM and CMMI, to address their needs. Therefore, many studies explored CMM in the construction domain. Additionally, these studies extended beyond traditional aspects aimed at conceptual evaluations to multifaceted tools addressing organisational, project, and lifecycle dimensions.

- ***Conceptual assessment frameworks***

Olawumi & Chan (Olawumi and Chan, 2019b) proposed a three level BIM concept assessment model through the application of qualitative and quantitative techniques. The aim of the model was to evaluate BIM performance and improvements for organisations in developing countries. Although, the model has six maturity levels, the study did not provide clear cell descriptors with respect to model elements to aid sufficient assessment of BIM capability. This further undermines the model's utility for in-depth assessments. Mahamadu et al. (2020) also presented a BIM capability model with six maturity levels to assess the performance of organisations. The study utilises fuzzy sets technique to compare actual versus predicted BIM performance, emphasising the criticality of BIM experience and information maturity to capability assessments. While the study focuses on collaborative information management, it lacks flexibility, as it requires complex computations, which reduces its practical applicability.

- ***Multi-factorial and comparative frameworks***

Prabhakaran et al. (2021) conducted a comparative analysis of Qatar and UK to investigate and explore how major holistic maturity factors impact BIM applications. This comparative analysis highlights contextual disparities but lacks actionable guidance to aid model application in real life scenarios. Siebelink et al. (2018) developed a BIM maturity tool (BMT) to evaluate the technical and structural dimension of BIM. A unique contribution of the study is its provision of internal and external definitions of descriptors thereby enhancing the clarity of supply chain aspects by differentiating between in-house and outsourced operations. However, the tool does not consider the organisational aspects and their relation to broader adaptation which may affect the model's generalisability.

- ***Lifecycle assessment frameworks***

Recent studies have also addressed the increasing awareness of BIM's potential to facilitate the concept of through-life asset management. Dadashi Haji et al. (2021) proposed a maturity model and evaluated the correlation between 4D BIM applications and their level of maturity. Additionally, the suggested framework highlighted the necessary Level of Development (LOD) with BIM to ensure alignment of such strategy with high end objectives. Nevertheless, the 5-level maturity assessment model is limited to 4D BIM applications and does not cover advanced features or capabilities of BIM, such as maintenance planning. Edirisinghe et al. (2021) proposed the life cycle BIM maturity model (LCBMM) which was constructed based on an actor-network approach to comprehensively address the entire asset life cycle, particularly during the operations phase. However, subsequent efforts could include additional evaluation and refinement of the model under different scenarios. For instance, assessments of other smaller institutions might reveal alternative phases for the model. Additionally, insights from early adopters in the field could contribute to refining the model.

- ***Sector-specific frameworks***

The application of BIM CMMs extends to address specific sectoral needs. Rashidian et al. (2023), suggested a framework to address lean construction methodologies, with the aim of bridging the gap between BIM and lean principles. Lu et al. (Lu W et al., 2021) presented a multifunctional BIM maturity model (MBMM) to evaluate BIM capability across project, institutional, and sectoral domains. Although the comprehensive scope of the model enhances its versatility, the evaluation technique adopted utilises subjective rubrics that makes repeatability challenging and increases complexity, thereby requiring more customised applications.

- ***Methodological innovations***

Several studies looked at how emerging approaches could be integrated to further enhance BIM maturity assessments, including those investigating performance metrics, success factors, and decision-making optimisation. Thomas et al. (Phang et al., 2020) developed a model to ascertain the critical success factors (CSFs) impacting BIM adoption. Their model comprises six domains: authorities, environment, organisation, workforce, workflow, and BIM tools and has four maturity levels. Yet, the factors were less focused on the IRs in the context of the whole asset life cycle. Yun et al. (2021) proposed a model with five key factors: progression, excellence, finances, security and uncertainty as inputs to determine a maturity index scoring scheme. Their five levels maturity model is however more focused on project management aspects and less focused on asset management. Sun et al. (2022) proposed a two-dimensional maturity (BATM) model, incorporating project BIM application (PBA) and business management (PBM) concepts and maturity levels across both expected and actual performance. Their model was informed by eight thematic categories and 37 corresponding results which are highlighted by the 7th edition of PMBOK. The dual scope presented in the model focusing on operational and strategic elements offers great enhancements but demands extensive data to be operationalised.

2.3. BIM maturity models in O&M

To date, very few frameworks have been developed to explore O&M IRs with BIM in construction. Heaton et al. (2019) proposed a BIM strategy for harmonising organisational objectives with asset needs and classifies IRs into three categories, namely, financial, managerial and technical with an approach for determining the IRs, which may in turn facilitate strategic alignment between BIM and asset management, but lacks a structured and systemised maturity model for BIM in O&M.

There is also the BIM-CAREM reference model for BIM capability assessments by Yilmaz et al. (2019). Although the model classifies FM attributes into process, technical, organisational, human aspect and BIM standards, these attributes do not capture specific O&M needs to enhance asset/building performance. While the model provides the foundational basis for assessing BIM capabilities, it lacks specificity and sufficient level of detail in terms of operational processes, asset tracking, key performance indicators and building lifecycle management. In addition, the investigation process of examining the related practices and attributes in the study could be enhanced by further detailed assessment to effectively review and evaluate different practices within AEC/FM processes.

Moreover, Edirisinghe et al. (2021) proposed the life cycle BIM maturity model (LCBMM). The model places emphasis on the asset life cycle, considering the operations phase. Further clarification and categorisation of these needs and their relation to BIM and asset management could enhance the proposed model. Edirisinghe et al.'s LCBMM is a robust framework directly addressing O&M needs, but its complexity may limit practical implementation over time.

Apart from the three models discussed in this section, namely, Heaton's, the BIM-CAREM and the LCBMM which addressed the context of IRs in construction, the literature surrounding alternative maturity models that sufficiently and systematically address detailed IRs for integrated BIM and O&M maturity is limited. Additionally, given the underwhelming prospects of O&M IRs in construction, the BIM and O&M MM proposed in this study aims to empower asset owners and managers with a deeper understanding of their maintenance performance and processes.

2.4. Knowledge gaps in BIM maturity models for O&M

- ***Insufficient focus on O&M***: one major gap in existing studies is the lack of clear IRs to reflect BIM and O&M maturity, specifically addressing the dynamic nature of O&M processes and the need for real-time responsiveness. Many of the cell descriptors in current models lack sufficient level of detail to reflect real operational needs. Few models, such as LCBMM (Haji et al., 2021), explicitly address the operational phase, foregoing a significant room for improvement in lifecycle-oriented maturity assessments. This work fulfils this gap by providing a comprehensive BIM and O&M maturity assessment tool that examines maturity against 21 detailed IRs. This in turn motivated the first research objective of developing a BIM maturity model that is tailored for O&M.
- ***Prioritisation of O&M needs***: many of the existing studies do not assign levels of importance to individual O&M needs and their impact to the O&M phase of the building life cycle. Instead of assigning equal importance to these criteria, a more comprehensive and flexible model that reflects real-life dynamics should incorporate how different priorities of IRs contribute to the enhancements of BIM and O&M maturity over time. This gap is addressed in this study by assigning global weights to the 21 IRs used for the maturity assessment, which satisfies this study's second objective of aligning the BIM maturity assessment process with O&M IRs prioritisation.
- ***Complexity and practicality***: Many models suffer from computational or structural complexities, limiting their adoption in the O&M environment. Additionally, some models lack the practical adaptability needed for various building needs and contexts. The tool developed in this study aims to bridge this gap through its user-friendliness and the incorporation of simplified, yet practical computations that enable fast and objective assessments of the maturity of buildings, which aligns with the study's third objective of ensuring practicality and usability of the proposed BIM and O&M MM for real-world applications.

2.5. Capability maturity models

The achievement of business excellence and performance improvements relies on the implementation and effectiveness of process improvement techniques. However, while maturity models (MMs) provide a systematic approach to assess processes, other procedural improvement techniques like The Six Sigma, Lean management and The Total Quality Management (TQM) often lack this systematic evaluation and fail to deliver clear demonstrations of capability enhancements. However, MMs, on the other hand, show a sequential progress of processes that enable the organisation to identify practical and realistic room of improvements to achieve required outcomes.

The *Carnegie Mellon* Software Engineering Institute initially proposed the first CMM model as an application of the software industry aimed at inspecting the maturity of technology suppliers. The concept behind CMM was that all the procedures utilised in developing software are identified, documented and traced in a systematic manner. These processes align with maturity levels, ranging from the least to the most effective practice, which are driven by the degree to which processes are outlined, managed, and recognised (CMMI Product Team, 2010). While CMMs and ISO 9001 share their similarities, ISO 9001 outlines the lowest acceptable quality threshold to be accomplished, whereas the CMM provides a comprehensive scheme to drive performance improvement. Therefore, CMM provides a coherent systematic method to aid continuous process improvement. Main contributions for CMMs are threefold. Initially, they function as assessment tools that measure organisational capability in product or service delivery. Additionally, they offer detailed explanations and descriptions of activities to be undertaken for practical improvements. Finally, CMMs facilitate a systematic approach to guide performance improvements.

The CMM comprises unique characteristics along with their maturity levels which inform the evaluation of organisational competencies on standardised scale (CMMI Product Team, 2010). It can be depicted in either a staged or continuous formats and usually encompass five/six levels of assessment: the first level being initial; the second level being repeatable; the third level being refined; the fourth level being managed; and the fifth level being optimised. Due to the flexibility and generic nature of CMMs, they are becoming very popular across different application areas (CMMI Product Team, 2010). Some examples of previous CMMs include the capability maturity model integration (CMMI) version and CMMs developed for Software evaluation or Systems Design (CMMI Product Team, 2010). Additionally, the European Commission (EC) proposed an advanced model (Bootstrap), incorporating concepts from CMM and ISO for technological process improvements (Kuvaja, 2012). CMMs are now seen in construction, risk management, software engineering and more (CMMI Product Team, 2010).

The CMM Integration (CMMI), is an evolved version of the traditional CMM which represents a singular, yet holistic and progressive framework tailored to suit organisations of varying structures. Its primary focus lies in driving continuous improvement. The CMMI presents the maturity levels systematically, integrating both, the staged and continuous formats (CMMI Product Team, 2010). In the staged format, just like CMM, the evaluation procedure yields a single maturity score. Whereby in the continuous format, the competencies corresponding to each process is assessed individually. Thereby, establishing a unique maturity rating for each assessed area. This approach integrates the multiple domains being evaluated (i.e. by utilising both formats), thus effectively reflect their integrated capabilities (CMMI Product Team, 2010). This approach aligns with ISO/IEC 15504, defined as SPiCE (**S**oftware **P**rocess **I**mprovement and **C**apability d**e**termination).

Owing to its flexibility, user-friendliness and practicality, CMMI is widely acknowledged within the academia and industry as a standard reference for constructing MMs. Examples of CMMI in the field of construction are seen in (Mahamadu et al., 2020)– (Haji et al., 2021), (Lu W et al., 2021)– (Phang et al., 2020), (Yun et al., 2021), (Olawumi and Chan, 2019b). Respectively, this study adopts the continuous format for CMMI in a maturity grid layout to develop the BIM and O&M MM. The maturity levels will be assigned to IRs, informing the creation of a sequence of blocks. Each block will include a concise text explanation (i.e., descriptor) for each corresponding level of maturity. Further details can be seen in section 3.

3. Materials and methods

The methodology outlined by Maier et al. (2012) for constructing maturity models for organisational capability evaluations was followed. The methodology comprises four phases: (1) Planning stage which involves identifying target audience, defining the aim and scope, and determining rooms of improvements; (2) Development stage which involves determining the process areas of the model, maturity levels, the cell characteristics and administrative approaches; (3) Evaluation stage which involves verifying, refining and validating the proposed model.; and (4) Maintenance stage which focus on documentation and communication of results. The fundamental design decisions are the determination of (1) primary processes (the integrated BIM and O&M

IRs) and (2) the main levels reflecting maturity. Fig. 2 below depicts a detailed methodology plan for this work.

3.1. The development of BIM and O&M maturity assessment tool: identification of design decisions

The proposed model follows a grid format incorporating two key aspects: the integrated BIM and O&M IRs and their corresponding levels of maturity. The established maturity levels are assigned to their perspective IRs, thereby informing a series of blocks. Each block presents a concise explanation or descriptors for each key information requirement at their corresponding level of maturity. The steps undertaken to construct the BIM and O&M maturity assessment tool are explained below.

In maturity model literature, there is little focus on the theoretical framework or holistic methodologies and traceability of what constitutes a maturity model (MM) (Pöppelbuß and Röglinger, 2011)– (Mettler et al., 2010). There is little demonstration on the procedural development process for CMMs in literature (Becker et al., 2009), (de Bruin et al., 2005). Nonetheless, previous studies have presented structured approaches and design methodologies that build upon previously proposed CMMs, offering valuable insights into their developmental processes and various applications. For instance, De Bruin et al. (de Bruin et al., 2005) introduced a CMM framework that integrates both explanatory and regulatory aspects, thereby facilitating a foundational

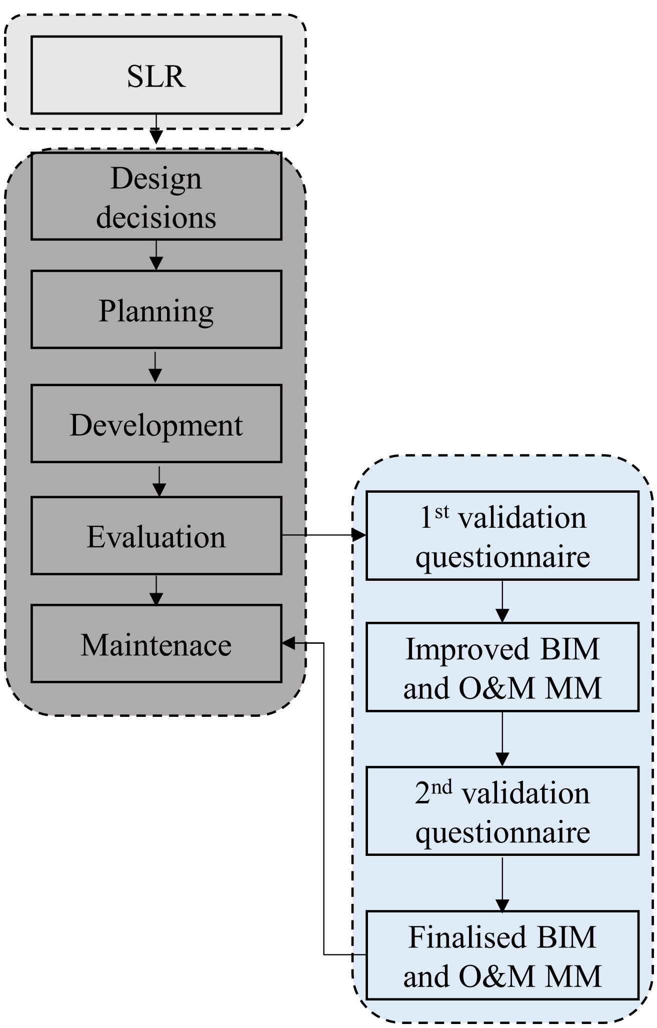

Fig. 2. Methodology for developing the integrated BIM and O&M assessment tool.

understanding of MMs in terms of theory and practicality. This further stresses on the dual need for descriptive clarity and actionable guidance when developing CMMs.

Drawing on the work of De Bruin et al., Maier et al. (2012) introduced a rigorous methodology for constructing CMM grids. Their approach enhances the development procedure by proposing four maturity levels informed by 13 critical design aspects, ensuring the model's alignment with strategic needs and high-level objectives. Adopting this systematic approach ensures the practical usability and applicability of CMMs in different contexts.

Building upon the design theory, Becker et al. (2009) further expanded the design theory of CMMs and applied the principles of design introduced by Hevner et al. (2008), constructing an eight-level requirements model that integrates theoretical rigor with practical implementation. Their proposed model provides a structured approach to progressive advancement through distinct maturity stages.

To enhance the adaptability of these previously developed models, Mettler (Mettler et al., 2010) critically analysed the work of Becker et al. and proposed a framework that facilitates seamless integration among various domains. Mettler's approach is based on a four-stage maturity levels. The enhancement offered in their model make it more responsive to real life scenarios and easily adopted in dynamic environments.

Collectively, these studies demonstrate the evolution of CMMs design and development, ranging from foundational basis to more sophisticated, practical, and context-specific methodologies. Building on the foundational principles adopted in these studies and their methodologies, this work further emphasises on the importance of the iterative refinement of maturity models and its role in improving the relevance and effectiveness of the developed CMMs as depicted in the research design adopted for this study.

This study adopts the main design science principles and CMMs procedures introduced by Maier et al. (2012) due to its rigorous, flexible, systematic and consistent approach. Furthermore, the design science principles share commonalties in their model developmental procedure with the proposed models/frameworks. The four stages for developing maturity models are (1) planning, (2) development, (3) evaluation, and (4) maintenance stages which are presented and discussed in detail in the next section.

The integrated BIM and O&M maturity assessment tool developed in this study, is constructed based on the CMMI format, based on the following justifications. To begin with, the continuous format offers a comprehensive and detailed assessment of the maturity level for each IR related to the proposed BIM and O&M integration assessment tool. Moreover, it allows flexible approaches, since built asset owners and managers can target critical IRs that meet the strategic maintenance policy and goals of assets. Also, it provides opportunities to explore the strengths and deficiencies in the maturity of each IR, thereby facilitating continuous improvement. Construing the proposed maturity model in this study in the CMMI format would provide asset owners and managers with a comprehensive view of the building's BIM and O&M maturity. This would enable decision makers to prioritise investments and allocate resources effectively and efficiently.

3.1.1. Stage 1: planning

Step 1: Specify the audience. The integrated BIM and O&M maturity assessment tool is designed to aid construction firms, asset owners and managers to improve their maintenance and reliability management for their buildings. Therefore, the targeted end users of the proposed model are construction companies, asset owners and managers.

Step 2: Define the aim of the developed model. The main purpose of the proposed tool is to enable the assessment of built assets with particular emphasis on BIM and O&M integration maturity of buildings.

Table 3
Verified information requirements (IR) and their respective categories (Abideen et al., 2023).

Category	Proposed information requirements	Description	Example of information requirements
General	1. Building details	General building information	name, capacity, owner, address,
	2. Equipment/asset details	General equipment information	Material, date of purchase, location
	3. Manufacturer and warranty details	General manufacturer information and warranty details	Bar code, point of contact, warranty period, production year
Strategic (PLAN)	4. Maintenance strategy	Existence of a clear maintenance strategy that identifies the vision, mission, constrains and required resources	Maintenance scope
	5. Maintenance plans and schedules	Existence of clear maintenance plans that show how maintenance will be conducted, including schedules that show start-up and shutdown information for each activity as well as their sequence	Date, time and location for maintenance works
	6. Maintenance activities/ task	Each asset/component has a clear description of the required maintenance activity	Proactive, inspection, redesign, replacement, fabrication, corrective/reactive, condition monitoring or preventive, change control procedures for assets/component.
	7. Asset Performance data collection/data handling	The means for data collection and sampling for O&M activities used to assess the performance of the asset	Sensors, software e.g. maintenance management system (MMS)
	8. Asset information and documentation	Clear O&M documentation (that is updated regularly with all the required information), data retrieval, and recovery.	Manuals for standard operating procedures (SOP's) for O&M tasks i.e. repair manuals, progress/condition photos of assets during construction/commissioning, repair etc., asset tagging and identification, as-built drawings
	9. Major overhaul plans	Major overhaul plans (if needed) that are required during plant/asset's shutdown/disassembly to carry out maintenance.	Plans for engine overhaul
	10. Defect work plan	Clear rectification measures to handle components defects	Updated manuals for faults correction
Operational (DO & CHECK)	11. Asset's service life	The service life of the component	Component age
	12. Asset's remaining useful life	The approximate number of years that an asset or system is estimated to be able to function as planned prior to replacements	Expected remaining processing time
	13. Availability	The ratio of asset uptime to total available time	Mean time between failure (MTBF), Mean time to repair (MTTR)
	14. Accessibility	Means to access the component for maintenance works	Components accessibility procedure
	15. Rework	Repair work done on previously maintained equipment or component	Rework rate
	16. Emergency response	Emergency response protocols for urgent/late maintenance works	Backup and spare parts inventory
	17. Risk assessment	Efforts to identify and analyse potential hazards	Safety hazards
Commercial (DO & CHECK)	18. Operational & Maintenance costs	Records and means to calculate potential associated costs	operational costs, total maintenance costs, proactive and reactive maintenance costs, life cycle cost, spare parts cost (lead time, holding & procurement)
	19. Contractors' management	Strategy of outsourced O&M activities and contractors selection criteria	Contractors' management plan (price list, point of contact)
Continuous improvement (ACT)	20. Historical maintenance records	Maintenance history and status of components	Assets failure history, previous actions to rectify the faults
	21. Lessons learned/ feedback loops	Documented lessons learned from previous maintenance interventions and feedback loop plans	Case Based Reasoning modules, root cause failure analysis

Step 3: Clarify the scope. Assessment models are tailored to improve either broad or selective applications. The BIM and O&M maturity assessment tool is developed to assess a particular scope, which is the integration of BIM and O&M for buildings.
Step 4: Define the success guidelines. The motivation of developing the integrated BIM and O&M maturity assessment tool lies behind the potential cost savings and positive return on investment (ROI) resulting from improved maintenance performance through BIM. Therefore, the model's success is dependent on the following aspects: (1) **Usefulness for end users**, this is identified by the suitability and relevance of the IRs. The tool could enhance BIM applications in building's O&M by extending building life span and improving building's operational performance thus, decreasing maintenance costs; (2) **Usability** outlined by the precision and quality of the assessment tool; and (3) **comprehensiveness of key BIM and O&M IRs** determined by the effectiveness of the assessment tool in demonstrating essential IRs crucial to BIM and O&M integration.

3.1.2. Stage 2: development

Step 5: Selection of performance areas. A fundamental characteristic in developing an assessment tool is the determination of the assessed capabilities (Maier et al., 2012), (de Bruin et al., 2005). According to Maier et al. (2012), there are two methods of identifying key capabilities in an assessment matrix (1) the experience of the developer in addition to the available surrounding knowledge for a specified area; and (2) a pool of experts in the selected field, this is mostly useful when literature is limited.

The process of developing the BIM and O&M MM comprised three phases: (1) a SLR to determine the integrated BIM and O&M IRs followed by an initial verification by experts to determine the relevance and comprehensiveness of the identified IRs; and (2) a two-round Delphi process combined with (3) voting analytical hierarchy process (VAHP) to determine the relative priorities/weights of the IRs. Further details of the approach is explained thoroughly in (Abideen et al., 2024). Consequently, 21 IRs were identified as listed in Table 3. These 21 IRs were then grouped under five main thematic categories, namely general, strategic, operational, commercial, and continuous improvement IRs. The five thematic groups were further aligned to the Plan-Do-Check-Act (PDCA) cycle to reflect the principle of continuous improvement espoused by maturity models. Thus, these IRs along with their categories constituted the performance areas for the developed assessment tool.

Step 6: Formulation of maturity levels and blocks descriptors. Different CMMs address different assessment levels and ranges (i.e.

Table 4
Maturity level definitions.

Maturity level	Definition of maturity
Level 1	The approaches, methodologies and guidelines are not established. Performance outcomes are poor.
Level 2	Few approaches, methodologies and guidelines may be available but are traditionally corrective and unplanned. There is no proper identification of systematic approaches, methodologies and guidelines. Performance outcomes are reasonable and fair.
Level 3	Some systematic approaches, methodologies and guidelines are formally identified and planned. Systematic approaches, methodologies and guidelines are reactive. Performance outcomes are adequate.
Level 4	Most of the approaches, methodologies and guidelines are systematically planned, well-identified and proactive. Performance outcomes are satisfactory.
Level 5	All systematic approaches, methodologies and guidelines are reviewed, updated and standardised and seamlessly harmonised with strategic objectives for continuous improvement, utilising advanced and innovative techniques. Performance outcomes are outstanding and equivalent to industry's best practice.

ranging from three to six assessment levels). Literature show (Maier et al., 2012), most common frameworks comprises five levels of maturity as suggested by Paulk et al. (Paulk, 1994). Ultimately, the proposed tool adopted five evaluation levels (i.e, 1–5). The definitions of maturity levels and their corresponding characteristics were driven from the SLR. Following the principles outlined in the work of Maier et al. (2012), the maturity levels with Level 1 denoting the lowest maturity and Level 5 indicating progression towards the highest maturity and their explanations, were tailored according to the fundamental concept of maturity and what determines its significance in the information requirement. The developed tool utilises lower maturity levels to inform the higher maturity levels. To illustrate, for a certain building to achieve ideal maturation (level 5) in a particular information requirement, the requirements explained through lower levels must be met. Thus, understanding the practical meanings of these evaluation levels are crucial to model's application as Table 4 demonstrates.

Step 7: Formulation of blocks explanations and descriptors of each level of maturity. This step outlines the intersection between performance areas, hence the IRs and their corresponding levels of maturity. Therefore, it is necessary to provide detailed descriptions and explanations of each information requirement against each level of maturity (Maier et al., 2012). Maier et al. (2012) highlights three aspects of formulating block descriptors to ensure their accuracy, adequacy, and sufficiency, which are: 1) employing a hierarchical or granular evaluation methods; 2) the quality of the content and; 3) structuring strategy. The hierarchical method entails formulating definitions prior to developing maturity measures to align with these outlined definitions, whereas the granular method involves establishing maturity measures before drafting definitions to accommodate these measures (Maier et al., 2012). Since integrated BIM and O&M maturity is a relatively emerging field in construction, there is limited evidence available regarding what signifies the maturity of IRs. Ultimately, this study adopts the top-down approach in generating block explanations, where the definitions of what performance/maturity means are identified prior to establishing measurement methods (Maier et al., 2012). This approach is justified by the scarcity of empirical evidence on assessing the IRs of the integrated BIM and O&M maturity. The fundamental concept of maturity assessment in this study, was derived through a review of existing literature surrounding BIM and O&M IRs, existing maturity assessment models and best practice guides in the areas of BIM and O&M. For example, current CMMs such as the BIM-CAREM by Yilmaz et al. (2019) and the LCBMM proposed by Edirisinghe et al. (2021) were critically examined to define what maturity means for each IR. Eventually, the blocks' explanations were structured based on 1) the significance of the maturity to the IR: and 2) the determination of descriptions of the highest and lowest performances (for the first level and the fifth level). Thus, these descriptions informed the formulation and generation of the other performance features/characteristics for the remaining blocks (i.e., Levels 2–4). For the sake of brevity, an excerpt of the BIM and O&M CMM is presented as a grid in Table A.1 of Appendix A.

Step 8: Define administration Mechanisms. The BIM and O&M maturity assessment tool is constructed as in independent model and designed to be implemented for buildings assessments. To aid the deployment of the grid for use during practical assessment, the grid was further developed into a web-based platform. Details of this development are given in Section 3.2.

3.1.3. Stage 3: evaluation

Step 9: Model's validation. The evaluation of the proposed tool was done through an assessment questionnaire. Once the BIM and O&M assessment tool was built, it was then evaluated by BIM and O&M professionals, and professionals within other related areas such as facilities management, reliability management, asset management, maintenance management, etc., to ascertain its practicality and robustness.

3.1.4. Stage 4: maintenance

Step 10: Documentation and communication of the proposed model. The aim of this stage is to ensure the final model is reviewed, updated and standardised.

3.2. Architecture of the proposed BIM and O&M maturity assessment tool

The proposed web-based platform "BIM and O&M maturity assessment tool" comprises three sections: (1) the BIM and O&M MM home page shown in Fig. 3; (2) the information page which highlights the purpose of the tool as well as instructions on how to use it (Fig. 4); and (3) the BIM and O&M assessment tool page shown in Fig. 5. The tool's elements are easily accessible via an interactive and user-friendly web-based interface. The suitability of digitised platforms and user-friendly interfaces in this study was justified by its considerable cost savings and flexibility for end users (El Ammari and Hammad, 2019)–(Iheukwumere-Esotu and Yunusa-Kaltungo, 2022).

3.3. Assessment of BIM and O&M maturity

Generating the maturity level score via the proposed integrated BIM and O&M tool involves five computational steps. The integration between BIM and O&M for any selected building is considered "Poor" if the maturity score ranges up to 1.24; "Fair" if the score falls with 1.25–2.24, "Average" if the score falls within 2.25–3.74, "Good" if the score falls within 3.75–4.74 and "Excellent" if the score falls within 4.75–5.0. Figs. 5 and 6 respectively shows a sample assessment, while Fig. 7 demonstrates the primary steps to calculate the level of maturity as described below.

Step one: To assess the BIM and O&M integration maturity level for a building, the assessor initially rates the current and target performance levels out of five, thereby reflecting the building's performance corresponding to each IR as demonstrated in Fig. 6.

Step two: After entering the scores for each IR, each score is divided by 5 and the result is then multiplied by its corresponding global weight as depicted in Equations (1)–(6). Further details on global wights estimations can be found in (Abideen et al., 2024).

$$C_{vi} = \frac{C_{pi}}{5} \cdot W_i \tag{1}$$

$$T_{vi} = \frac{T_{pi}}{5} \cdot W_i \tag{2}$$

where:

- C_{vi} and T_{vi} are the current and target resultant values for the ith item.
- C_{pi} and T_{pi} are the current and target performance values chosen by the assessor for the ith item.
- W_i is the global weight value for the ith item.

Step three: This step sums all the resulting scores for each IR at both current and target performance levels.

Step four: Calculate the category maturity score by dividing each total from the previous step by the sum of the corresponding global weights. Then, multiply each result by 5 to obtain the maturity score for that category, on a scale of 1–5. This can be done by applying Equations (3) and (4).

$$S_{Cn} = \frac{C_{v1} + C_{v2} + \dots}{GW_n} \cdot 5 \tag{3}$$

$$S_{Tn} = \frac{T_{v1} + T_{v2} + \dots}{GW_n} \cdot 5 \tag{4}$$

where:

- S_{Cn} and S_{Tn} denote the current and target maturity level score for each nth category.
- GW_n denotes the sum of corresponding global weights (W_i) for the IRs under each nth category.

Step five: Sum up all the corresponding maturity level scores for each current category, then calculate the weighted average to determine the overall BIM and O&M maturity for the building being assessed. Repeat the same process for the scores corresponding to target level. Fig. 7 shows the flowchart for the computational process.

$$\textit{Current overall score} = S_{C1} \cdot GW_1 + S_{C2} \cdot GW_2 + \dots \tag{5}$$

$$\textit{Target overall score} = S_{T1} \cdot GW_1 + S_{T2} \cdot GW_2 + \dots \tag{6}$$

4. Results and discussion

This section discusses the main results of the study under two subsections. The first part discusses the findings of the conducted SLR and the developed BIM and O&M maturity model. Additionally, it provides a comparison of the similarities and differences shared with previously

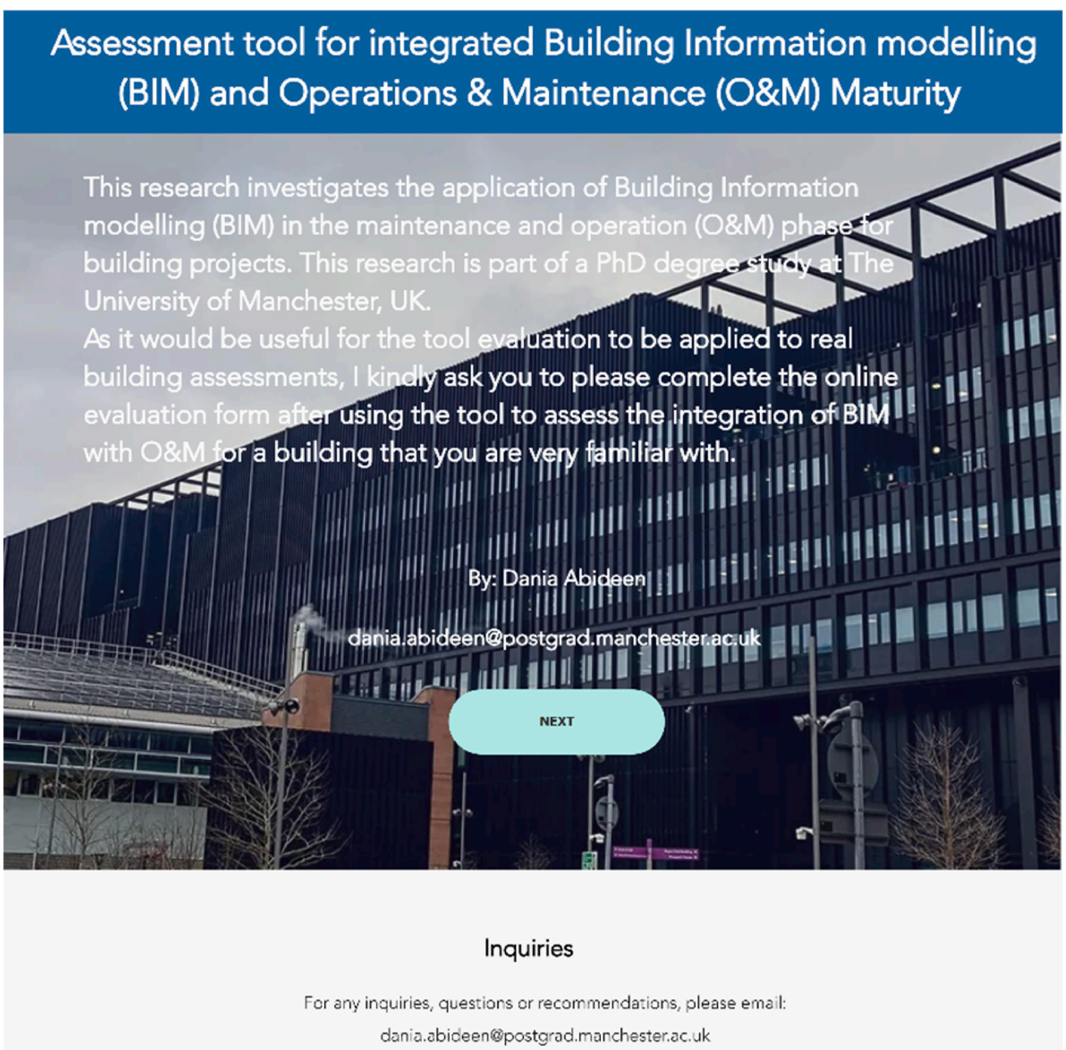

Fig. 3. The Homepage for BIM and O&M maturity assessment tool.

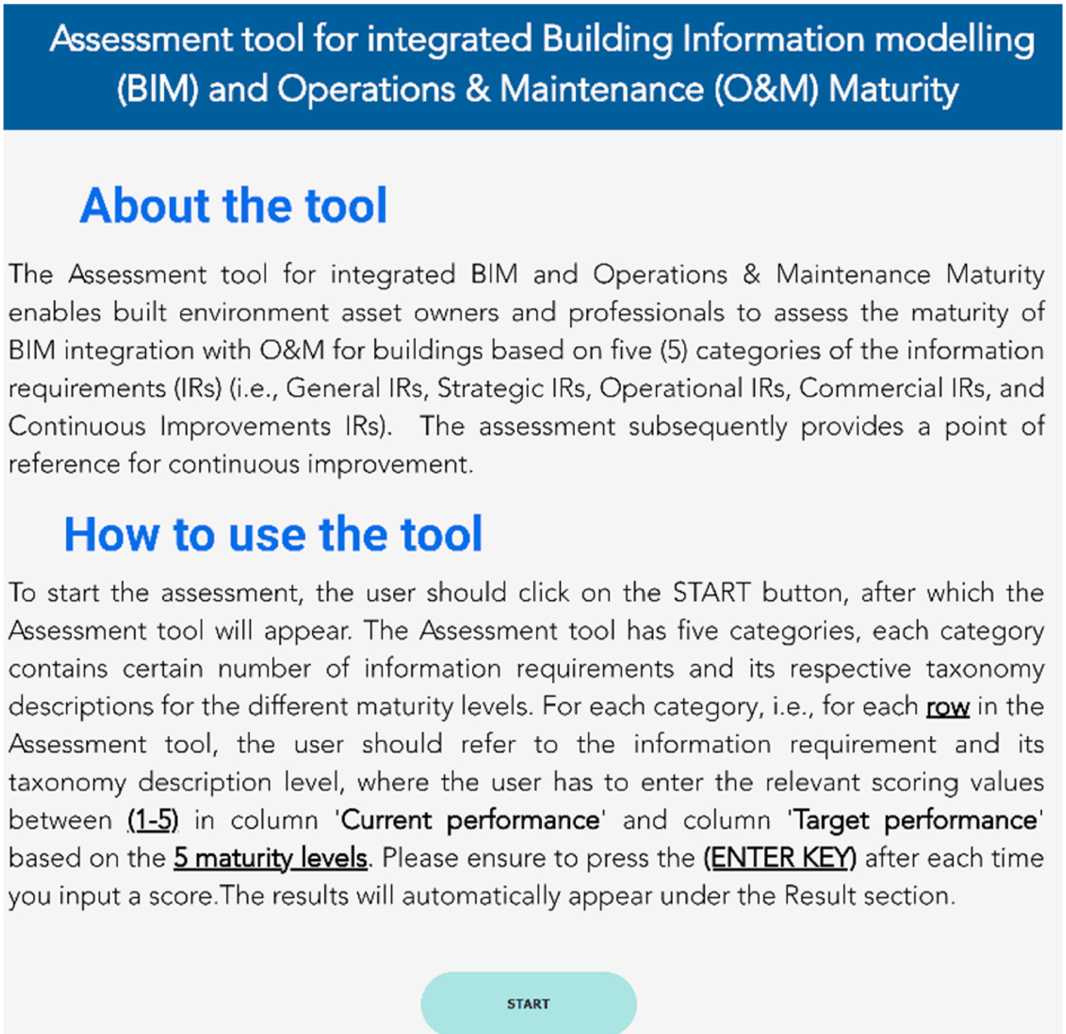

Fig. 4. Information page of the BIM and O&M maturity assessment tool.

proposed BIM models in construction. The second part presents the findings of the evaluation stage of the model, and illustrates the evaluation questionnaires along with detailed discussions on the evaluation process and steps undertaken to evaluate the proposed BIM and O&M MM.

4.1. The BIM and O&M maturity model

From the systematic literature review, twenty-one (21) potential IRs were determined. After verifying the IRs and the two Delphi iterations, 21 integrated BIM and O&M IRs were identified and categorised, according to their relevance and the PDCA cycle, into five thematic areas. The five thematic categories are general IR, strategic IR, operational IR, commercial IR and continuous improvement IR. The categorisation of the IRs aligns with the primary concepts of organisational CMMs in terms of applicability of maturity levels, specific key process areas, practicality in driving improvements evaluation and structured approaches to adopt best practices. Table 2 above demonstrates comprehensive descriptions and explanations of the main categories and their corresponding IRs. A critical review of earlier CMMs, especially those in (Mahamadu et al., 2020), (Siebelink et al., 2018), (Edirisinghe et al., 2021), (Lu W et al., 2021)– (Sun et al., 2022), (Asah-Kissiedu et al., 2021) provided essential insights on the commonalities between IRs identified in the BIM and O&M MM proposed here and their categorisation. The resemblance of these elements/attributes will be discussed with respect to the five main categories of IR.

4.1.1. General IRs

Several CMMs underscore the significance of data accuracy and interoperability for effective data management in BIM. For example, Rashidian et al. (2023) stresses on the need for rigour data validation mechanisms which directly aligns with the perspective reflected by the general IRs in the model presented in this study. This alignment indicates a shared understanding of the fundamental role of effective data management in enhancing BIM performance. Without a robust foundation of data, creating asset registers would be challenging and thus the integration of BIM and O&M would be significantly compromised.

4.1.2. Strategic IRs

The strategic alignment of BIM is often discussed in literature. Researchers such Sun et al. (2022), Siebelink et al. (2018), Heaton et al. (2019) and Edirisinghe et al. (2021) emphasise the significance of leadership, competency, stakeholder engagement and strategic alignment with long term goals. Such concepts are mirrored by the strategic IRs in the proposed BIM and O&M MM. Both perspectives underline the need for effective stakeholder engagement to achieve higher end goals and strategic foresight for BIM implementation.

4.1.3. Operational IRs

Many authors have discussed the importance of identifying clear day

General Information Requirements								
Information requirement (IR)	Description of IR	Capability levels					Current performance (enter 1-5)	Target performance (enter 1-5)
		Level 1	Level 2	Level 3	Level 4	Level 5		
Equipment/asset details	General building information.	• Lack of equipment/asset details to enable the operation and maintenance (O&M) personnel to conduct their daily operational tasks.	•Very few equipment/asset details to enable O&M personnel to conduct their daily operational tasks are available and identified independently of BIM.	• Some equipment/asset details to enable O&M personnel to conduct their daily operational tasks are available but stored in basic non-unified 3D BIM models.	• Most equipment/asset details to enable O&M personnel to conduct their daily operational tasks are available, and established in unified BIM models.	• All equipment/asset details to enable O&M personnel to conduct their daily operational tasks are available, and fully integrated with BIM through utilising advanced technologies like visualisation software or real time monitoring with Enterprise Asset Management system (EAM) and Computerised Maintenance Management System (CMMs). All the equipment/asset details are continuously reviewed, updated, and standardised.	1	5
Building details	General equipment information.	• Lack of building details to enable the O&M personnel to conduct their daily operational tasks.	• Very few building details to enable O&M personnel to conduct their daily operational tasks are available and identified independently of BIM.	• Some building details to enable O&M personnel to conduct their daily operational tasks are available but stored in basic non-unified 3D BIM models.	• Most building details to enable O&M personnel to conduct their daily operational tasks are available, and established in unified BIM models.	• All building details to enable O&M personnel to conduct their daily operational tasks are available, and fully integrated with BIM through utilising advanced technologies like visualisation software or real time monitoring with Enterprise Asset Management system (EAM) and Computerised Maintenance Management System (CMMs). All building details are continuously reviewed, updated, and standardise.	1	5
Manufacturer and warranty details	General manufacturer information and warranty details.	• Lack of manufacturer and warranty details to enable the O&M personnel to conduct their daily operational tasks.	• Very few manufacturer and warranty details to enable O&M personnel to conduct their daily operational tasks are available and identified independently of BIM.	• Some manufacturer and warranty details to enable O&M personnel to conduct their daily operational tasks are available but stored in basic non-unified 3D BIM models.	• Most manufacturer and warranty details to enable O&M personnel to conduct their daily operational tasks are available, and established in unified BIM models.	• All manufacturer and warranty details to enable O&M personnel to conduct their daily operational tasks are available, and fully integrated with BIM through utilising advanced technologies like visualisation software or real time monitoring with Enterprise Asset Management system (EAM) and Computerised Maintenance Management System (CMMs). All the manufacturer and warranty details are continuously reviewed, updated, and standardised.	1	5

Fig. 5. Example of inputting the current and target scores in the BIM and O&M maturity assessment tool.

Result

General information requirements

Category	Current overall perfromance	Target overall perfromance
General information requirements	1.00	5.00

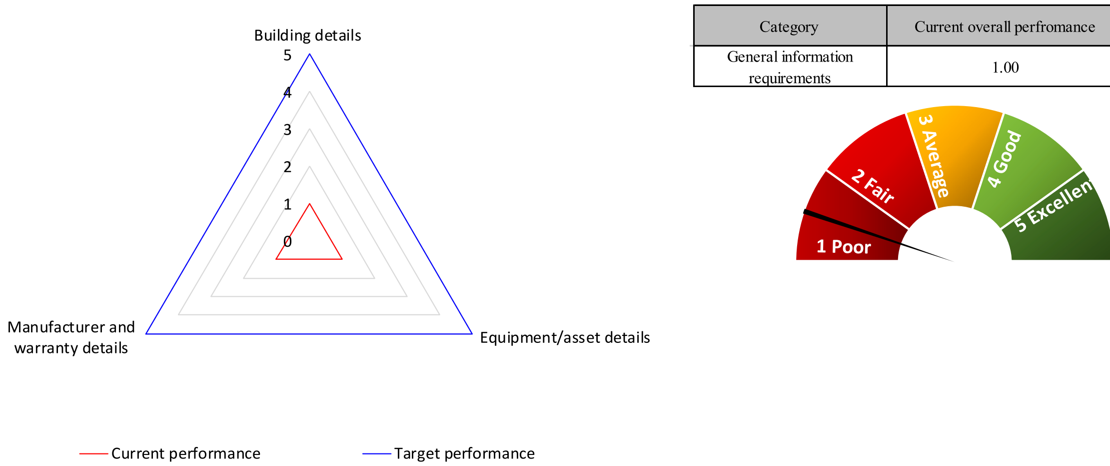

Fig. 6. Example of summary output for the integrated BIM and O&M maturity for general IRs.

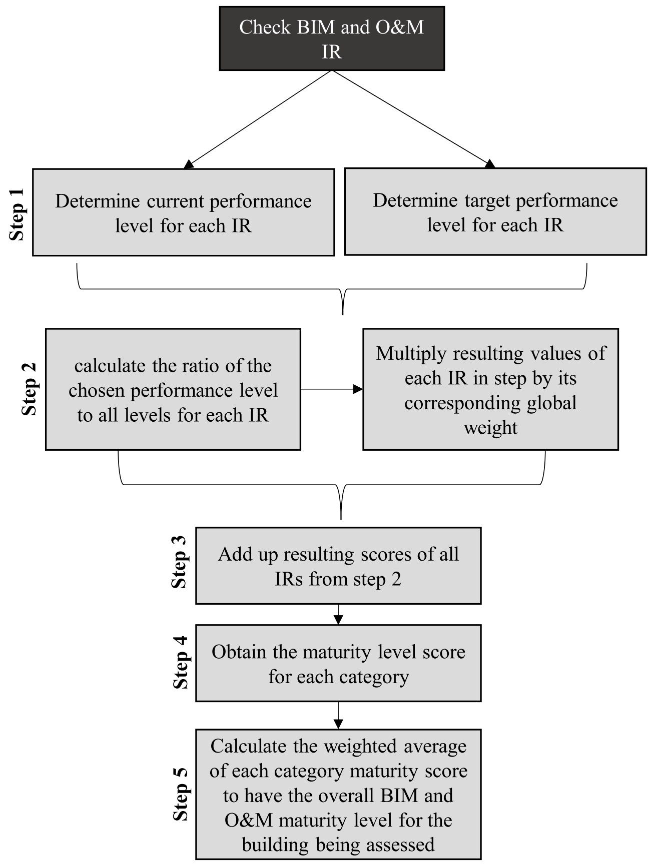

Fig. 7. Flowchart of computational process for assessing integrated BIM and O&M maturity.

to day processes in their CMMs. For instance, Lu et al. (Lu W et al., 2021) and Yilmaz et al. (2019) highlighted the importance of well-defined processes for BIM. Similarly, Mahamadu et al. (2020) highlight how structured workflows can streamline BIM performance. The alignment is indicated in the operational IRs by the common emphasis on the establishment of clear operational guidelines and key performance indicators, to monitor and maximise BIM performance. These perspectives advocate for data sharing and effective communication among relevant stakeholders for effective operational efficiency.

4.1.4. Commercial IRs

Previous CMMs investigated the financial aspects of BIM. Mahamadu et al. (2020) and Edirisinghe et al. (2021) underscore the importance of cost management with BIM. This resonates with the commercial IRs in the BIM and O&M MM. These studies share resemblance with the proposed tool in underscoring the need for effective cost management and budgeting as well as understanding the commercial viability for BIM initiatives.

4.1.5. Continuous improvement IRs

Continuous improvement is a fundamental principle in many CMM frameworks. Several studies have highlighted the need to implement feedback loops (Sun et al., 2022), analysing failures and knowledge sharing (Asah-Kissiedu et al., 2021). This directly resonate with the continuous improvement IRs presented in the BIM and O&M MM. The commonalities are demonstrated by the necessity of adopting a culture of ongoing improvements through effective documentations and learning from failures which are vital to the success of BIM implementation and continuous improvements.

While the previously developed CMMs by Lu et al. (Lu W et al., 2021), Rashidian et al. (2023), and others, provide valuable insights and structured frameworks for BIM implementation, they often fall short to effectively evaluate the actual maturity for O&M practices with BIM due to several limitations. Initially, most of these models lack sufficient detail regarding the contextual factors essential for O&M. Furthermore, they mostly focus on high level processes without exploring specific operational practices, maintenance protocols and real-time data. Moreover, these models often overlook the dynamic nature of O&M environments, thereby forgoing essential adaptability and preparedness for actual operational challenges. In contrast, the BIM and O&M MM proposed in this study demonstrate a comprehensive and systematic approach to overcome these limitations, by ensuring BIM sufficiently supports proactive maintenance and long-term asset management. This is accomplished through the realisation of both technical capabilities and specific needs of end users.

4.2. Evaluation of the BIM and O&M maturity assessment tool

The evaluation process was conducted once the deployment of the maturity model as a web-based platform was finalised. The evaluation process involved experts' evaluation of BIM and O&M maturity assessment tool. Generally, evaluation primarily verifies the adequacy and usability of the model as a whole. At the beginning, the evaluation instrument was designed to collect feedback from participants on the comprehensiveness of the contents of the proposed tool (i.e. the coverage, relevance and suitability of maturity levels and the IRs) as well as the tool's usability (i.e. understanding, convenience and practicality). After that, the exercise itself was conducted. Subsequently, analysis of feedback was conducted to determine if experts regard the tool as suitable, relevant, comprehensive, easy to use, useful and practical for assessing BIM and O&M integration maturity.

4.2.1. Selection of experts

To ensure a thorough evaluation process, experts in the domain of BIM and O&M in construction, as well as other related areas like facilities management, reliability management and construction professionals were invited to take part in the evaluation process. Participants were chosen according to the guidance for expert group techniques provided in (Hallowell and Gambatese). The participants were deemed suitable if the majority of the following minimum criteria were met: (1) have at least 5 years expertise in the field of BIM, O&M, or other related fields such as FM, reliability or construction, (2) Hold a minimum of bachelor's degree in the specified field. (3) Hold at least one professional qualification related to the field, and (4) academic experience in conducting research in the related fields.

4.2.2. Evaluation questionnaire

An evaluation questionnaire was developed to evaluate the tool. This approach is in line with literature as the utilisation of questionnaire for frameworks or model assessments through experts opinion is widely used (Lucko and Rojas, 2010)– (Salah et al., 2014).The questionnaire consisted of two sections. The first section of the questionnaire was used for extracting the background details of the participants. In the second section, participants were asked to assess the tool according to six assessment criteria (i.e. relatedness of IR, comprehensive coverage, suitability, and distinctiveness of maturity levels, convenience, and industrial practicality). To assess the aforementioned criteria in the proposed tool, a five-point Likert scale was utilised, where Strongly Agree, Agree, Neither Agree nor Disagree, Disagree, and Strongly Disagree corresponds to 5, 4, 3, 2, 1 respectively. Table A.2 in Appendix Ademonstrates the evaluation questionnaire.

4.2.3. Evaluation results

22 experts participated in the evaluation process. Table 5 shows the result of the evaluation.

The evaluation results prove that the tool is holistic and adequate for assessing the IRs related to BIM integration with O&M for buildings. The level of agreement and satisfaction of the assessment criteria were assessed using percentages. Percentages and quantitative analysis have also been utilised to investigate BIM integration with O&M by other researchers as in (Abideen et al., 2023), (Asah-Kissiedu et al., 2020). Over half of the experts (i.e. a simple majority of 50% or more) agreed or strongly agreed on most aspects of the assessment criteria indicating an adequate acceptance level of the tool. Regarding the relatedness of the IRs to the integration of BIM with O&M, results show the mean of the responses is higher than 3.5, thus indicating a minimum of moderate agreement leaning toward higher levels of agreement. Further analysis emphasises their relevance to BIM integration with O&M as 90.9% of experts collectively agree on the relevance of the IRs. Similarly, for the comprehensiveness and coverage of the categories and their respective IRs as well as their correct assignment, the mean responses reflect adequate agreement (i.e. more than 3.5). Moreover, 63.6% agreed and 13.6% strongly agreed on the comprehensiveness of the IRs. Also, the majority of experts with 81.8% agree or strongly agree on the adequate allocation of the IRs to their corresponding maturity levels. This assessment criteria scored a median of 4.0. Results confirm that the experts expressed their agreement on the comprehensiveness of the information requirement along with their corresponding maturity levels in the proposed tool. Also, 68.1% of experts expressed their agreement with a mean score of 3.73, regarding the distinctiveness of the IRs. Likewise, a considerable number of experts (i.e. 72.8%) agreed or strongly agreed that maturity levels exhibit sufficient and adequate representation of each progression stage in the maturity of IRs.

Regarding the ease of understanding, the majority of the experts (i.e. 86.3%) were of the opinion that the maturity levels and their IRs are understandable. Moreover, most of the experts viewed the supporting documents and tool's output as easy to understand. 86.3% of experts agreed or strongly agreed that the definitions of maturity levels and the evaluation instructions were clear. 72.7 % of the experts regarded the tool as understandable.

Furthermore, results show that the proposed BIM and O&M maturity assessment tool is useful and practical to use in the construction industry. Over 85% of experts agreed or strongly agreed that the BIM and O&M maturity assessment tool was easy to use; particularly the ease of using the user-friendly web-based tool for inputting scores of maturity levels. Also, the majority of the experts (i.e., 81.8%) regard the tool as practical for industrial applications. Primary results, prove that the developed BIM and O&M integration maturity assessment tool was generally well-received and accepted by the experts. However, the feedback from the initial evaluation revealed where improvements are needed. It is worth noting that, 40.9% of experts agreed or strongly agreed that there is no overlap between the maturity level descriptors, and 22.7% neither agreed nor disagreed that the descriptors of the maturity levels were distinguishable. In that regard, this aspect was revisited (i.e. the overlap detected between the maturity levels), and consequently, the tool was further enhanced to address the overlap and provide more distinctive maturity level descriptions. An excerpt of the improved tool is available in Table A.3 of Appendix A.

The modifications/refinements were informed by the feedback from the experts and outputs of the statistical analysis. The procedures followed for the modifications to address the overlap are as follow:

1 Obtained consistency among the five maturity levels in all the IRs.
2 Added more descriptions and explanations of maturity levels to make them more comprehensible and distinct. This was accomplished by:
   a Clarifying the specific BIM maturity from level 1 to 5
   b Provision of examples/elements to demonstrate how maturity can be reached
3 Deleted similarities or repeated characteristics. This was done by:
   a Deleting any detected repetitions in horizontal overlap
   b Deleting any detected repetition in vertical overlap
   c Maintaining consistency in the level descriptors

Table 5
Evaluation results.

Evaluation criteria	Percentage of agreement (%) (N = 22)						
	Strongly agree 5	Agree 4	Neither agree nor disagree 3	disagree 2	Strongly disagree 1	Total	Mean/Median/Standard Deviation
Categories and Information requirements (IR) used in the building information modelling-operations & maintenance (BIM-O&M) integration tool							
Q1.IR are relevant to BIM-O&M integration	**50**	**40.9**	9.1	0	0	100	4.41/4/0.67
Q2. Categories and IR cover all aspects of BIM and O&M integration	**13.6**	**63.6**	18.2	4.5	0	100	3.86/4/0.71
Q3.IR are correctly assigned to their respective categories.	**13.6**	**68.2**	18.2	0	0	100	3.95/4/0.58
Q4.IR are clearly distinct.	**13.6**	**54.5**	22.7	9.1	0	100	3.73/4/0.83
Maturity levels							
Q5. The maturity levels adequately represent progression for each IR.	**27.3**	**45.5**	27.3	0	0	100	4/4/0.76
Q6. There is no overlap detected between descriptions of maturity levels.	**9.1**	**31.8**	22.7	36.4	0	100	3.14/3/1.04
Ease of Understanding							
Q7. The maturity levels are understandable	**22.7**	**63.6**	13.6	0	0	100	4.09/4/0.61
Q8. The documentations (i.e., assessment instructions) are easily understood	**13.6**	**72.7**	13.6	0	0	100	4/4/0.53
Q9. The results are understandable	**18.2**	**54.5**	18.2	9.1	0	100	3.82/4/0.85
Ease of Use							
Q10. Scoring scheme (i.e., inputting maturity levels 1 to 5) is easy to use	**31.8**	**63.6**	4.5	0	0	100	4.27/4/0.55
Q11. The BIM and O&M integration assessment tool is easy to use	**31.8**	**50**	18.2	0	0	100	4.14/4/0.71
Usefulness and Practicality							
Q12. The tool is useful for assessing the maturity of BIM-O&M integration of buildings	**31.8**	**54.5**	13.6	0	0	100	4.18/4/0.66
Q13. The tool is practical for use in the construction industry	**22.7**	**59.1**	18.2	0	0	100	4.05/4/0.65

To assess the adequacy of the modifications, a second evaluation questionnaire specifically for evaluating the overlap criteria was sent to the same experts who participated in the previous tool evaluation. Maintaining the anonymity of the participants and ensuring the same pool of experts help in eliminating bias. The questionnaire was designed to obtain their feedback on the distinctiveness and clarity of the maturity levels in the improved tool. Additionally, the experts were asked to provide any other comments that they think might be useful to the tool. According to the findings from 11 experts out of 22 experts (i.e., 50% response rate) who participated in the evaluation of the improved tool, it is evident that the distinctiveness of the maturity level clearly improved. 63.64% of experts agree or strongly agree on the distinctiveness and clarity of the descriptions of maturity levels. Also, it is worth noting that the mean of the responses was 3.54. It is evident from the results shown in Table 6 that the BIM and O&M MM has been improved. The total agreement or strong agreement increased from 40.9% to 63.64%, representing a 22.74% rise in agreement. Additionally, the mean, median and mode increased from 3.13, 3 and 2 in the previous evaluation to 3.54, 4 and 4, respectively in the final evaluation.

According to the findings, there is clearly higher agreement on the distinctiveness and distinguishability of the maturity levels in the improved BIM and O&M MM. Based on the results and feedback form the evaluation questionnaires, the developed BIM and O&M integration maturity assessment tool was generally well-received and accepted by the experts emphasising on the comprehensiveness and relevance, distinctiveness, ease of use, ease of understanding as well as usefulness and practicality of the tool. Additionally, experts were able to use the BIM and O&M maturity assessment tool to assess different types of buildings like commercial, educational, religious, industrial and healthcare buildings. This indicates the flexibility of the tool for assessing BIM and O&M integration for different building functions/types.

5. Conclusions

Recent studies have demonstrated that the integration of BIM into the O&M stage of the life cycle of buildings is gaining attention. This is driven by the significant cost-saving opportunities associated with optimised maintenance processes. The effective enhancement of maintenance performance requires built assets to achieve an adequate level of maturity in their integration of BIM and O&M practices. Therefore, a comprehensive understanding of the definition of BIM and O&M maturity is essential for advancing these objectives. This study utilised the concept of capability maturity modelling to develop an integrated BIM and O&M maturity assessment tool for buildings. The developed assessment tool comprises five distinct maturation levels for 21 IRs that are extracted from literature and further verified by experts. The study goes further to evaluate the developed tool and findings highlight the applicability and suitability of the developed tool to assess BIM and O&M integration maturity of buildings. The main contributions of this study are:

- Comprehensive framework: This study developed a BIM and O&M maturity assessment tool that identifies 21 detailed IRs crucial for effective integration of BIM and O&M practices.
- Stakeholder alignment: The developed BIM and O&M MM ensures alignment among key stakeholders in facility management and BIM implementation. Additionally, it tackles real world challenges in O&M and addresses industrial needs.
- Enhanced data consistency: The BIM and O&M MM emphasises on the need for standardised data structures and effective information management practices. This consistency ensures smooth interoperability and seamless integration between BIM models and O&M systems.
- Optimised long-term asset management: The model identifies IRs that facilitate proactive maintenance strategies and real-time monitoring of buildings, thereby improving overall building reliability and performance.
- Strengthened data-driven decision making: The BIM and O&M MM provides a road map towards a data-centric approach to decision making. Facility managers can leverage accurate and in-time data to make more informed, timely, and reliable asset management decisions, thereby improving operational efficiency and strategic planning.
- Framework for future research: The model serves as a foundation for further research into BIM and O&M maturity, encouraging the development and integration with more advanced technology.

5.1. Research implications

The development of the BIM and O&M maturity assessment tool for buildings holds significant research implications across several areas. Mainly, the BIM and O&M maturity assessment tool would enhance facility management practices and increase efficiency through the systematic identification of weaknesses and opportunities for improvements. Additionally, the tool can aid building owners and facility managers to make informed decisions regarding building renovations, maintenance shutdowns and other operational strategies. The quantification of a typical building's BIM and O&M maturity would enhance the decision-making process. Also, the developed tool will promote the standardisation of BIM and O&M maturity by serving as a benchmarking mechanism for different building types and thus driving continuous improvements. Furthermore, the tool can aid effective risk mitigations and operational sustainability. This can be accomplished by highlighting operational risks, such as outdated maintenance schedules, incorrect maintenance plans or under-explored BIM capabilities. The assessment of BIM and O&M maturity can provide useful insights for proactive risk mitigation and thereby reducing asset's failures and downtime. The broader impact of BIM and O&M maturity assessment can optimise building operations through enhanced efficiency, higher reliability and sustainability and effective risk management.

5.2. Research limitations and future work

Since this study gathers insights from professionals and experts specifically in BIM and O&M, the findings are likely tailored to the specific features and applicability of these systems within the construction industry. Future research could focus on developing similar models for different industries to broaden its impact and relevance. Another limitation could relate to the sample size utilised in the

Table 6
Evaluation results of the improved tool.

Evaluation criteria	Percentage of agreement (%) (N = 11)						
	Strongly agree 5	Agree 4	Neither agree nor disagree 3	disagree 2	Strongly disagree 1	Total	Mean/Median/Standard Deviation
Q6. There is no overlap detected between descriptions of maturity levels.	**9.1**	**54.5**	18.2	18.2	0.0	100	3.545/4/4

evaluation process. The guidance provided for evaluating CMM through an expert involvement (Salah et al., 2014) lacks specification regarding the minimum number of experts. Nevertheless, the literature report a common range of 8–15 experts to be sufficient for expert based methods such as the Delphi Technique (Adler and Ziglio, 1996), (Mitchell and Mcgoldrick). Such techniques focus on the depth of expertise and quality of responses rather than quantity and the extent of engagement, thereby, emphasising the adequacy of the chosen sample size in this study. Nonetheless, future research could consider a larger sample size to ascertain whether fresh empirical realities could emerge.

CRediT authorship contribution statement

Dania K. Abideen: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation. **Akilu Yunusa-Kaltungo:** Writing – review & editing, Visualization, Validation, Supervision, Software, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Clara Cheung:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Patrick Manu:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

Table A.1
The BIM and O&M maturity assessment tool.

General Information Requirements							
Information requirement	Capability levels					Current performance (enter 1–5)	Target performance (enter 1–5)
	Level 1	Level 2	Level 3	Level 4	Level 5		
Equipment/ asset details	•The absence of equipment/asset details hinders the O&M personnel to conduct their daily operational tasks.	•Equipment/asset details that empower O&M personnel to conduct their daily operational tasks are unplanned and not properly identified	•Some equipment/ asset details that empower O&M personnel to conduct their daily operational tasks are planned	•All equipment/asset details that empower O&M personnel to conduct their daily operational tasks are systematically planned and well identified	•Equipment/asset details are reviewed, updated, standardised, and fully integrated with O&M systems.		
Building details	•The absence of building details hinders the O&M personnel to conduct their daily operational tasks.	•Building details that empower O&M personnel to conduct their daily operational tasks are unplanned and not properly identified.	•Some building details that empower O&M personnel to conduct their daily operational tasks are planned.	•All building details that empower O&M personnel to conduct their daily operational tasks are systematically planned and well identified.	•Building details are reviewed, updated, standardised and fully integrated with other O&M systems.		
Manufacturer and warranty details	•The absence of manufacturer and warranty details hinders the O&M personnel to conduct their daily operational tasks.	•Manufacturer and warranty details that empower O&M personnel to conduct their daily operational tasks are unplanned and not properly identified.	•Some manufacturer and warranty details that empower O&M personnel to conduct their daily operational tasks are planned.	•All manufacturer and warranty details that empower O&M personnel to conduct their daily operational tasks are systematically planned and well identified	•Manufacturer and warranty details are reviewed, updated, standardised and fully integrated with other O&M systems.		

Table A.2
Evaluation questionnaire.

Assessment criteria	Level of agreement				
	Strongly agree 5	Agree 4	Neither agree nor disagree 3	disagree 2	Strongly disagree 1
Categories and Information requirements (IR) used in the building information modelling-operations & maintenance (BIM-O&M) integration tool					
Q1.IR are relevant to BIM-O&M integration	☐	☐	☐	☐	☐
Q2. Categories and IR cover all aspects of BIM-O&M integration	☐	☐	☐	☐	☐
Q3.IR are correctly assigned to their respective categories.	☐	☐	☐	☐	☐
Q4.IR are clearly distinct.	☐	☐	☐	☐	☐
Maturity levels					

(continued on next page)

Table A.2 (*continued*)

Assessment criteria	Level of agreement				
	Strongly agree 5	Agree 4	Neither agree nor disagree 3	disagree 2	Strongly disagree 1
Q5. The maturity levels sufficiently represent progression in the IR.	☐	☐	☐	☐	☐
Q6. There is no overlap detected between descriptions of maturity levels.	☐	☐	☐	☐	☐
Ease of Understanding					
Q7. The maturity levels are understandable	☐	☐	☐	☐	☐
Q8. The documentations (i.e., assessment instructions) are easy to understand	☐	☐	☐	☐	☐
Q9. The results are understandable	☐	☐	☐	☐	☐
Ease of Use					
Q10. Scoring scheme (i.e., inputting maturity levels 1 to 5) is easy to use	☐	☐	☐	☐	☐
Q11. The BIM-O&M integration assessment tool is easy to use	☐	☐	☐	☐	☐
Usefulness and Practicality					
Q12. The tool is useful for assessing the maturity of BIM-O&M integration of buildings	☐	☐	☐	☐	☐
Q13. The tool is practical for use in the construction industry	☐	☐	☐	☐	☐
Further comments					
Please provide any further comments you may have:					

Table A.3
The improved BIM and O&M MM.

	General Information Requirements							
Information requirement (IR)	Description of IR	Capability levels					Current performance (enter 1–5)	Target performance (enter 1–5)
		Level 1	Level 2	Level 3	Level 4	Level 5		
Equipment/asset details	General building information.	• Lack of equipment/ asset details to enable the operation and maintenance (O&M) personnel to conduct their daily operational tasks.	• Very few equipment/ asset details to enable O&M personnel to conduct their daily operational tasks are available and identified independently of BIM.	• Some equipment/ asset details to enable O&M personnel to conduct their daily operational tasks are available but stored in basic non-unified 3D BIM models.	• Most equipment/ asset details to enable O&M personnel to conduct their daily operational tasks are available and established in unified BIM models.	• All equipment/ asset details to enable O&M personnel to conduct their daily operational tasks are available, and fully integrated with BIM through utilising advanced technologies like visualisation software or real time monitoring with Enterprise Asset Management system (EAM) and Computerised Maintenance Management System (CMMs). All the equipment/asset details are continuously reviewed, updated, and standardised.		
Building details	General equipment information.	• Lack of building details to enable the O&M personnel to conduct their daily operational tasks.	• Very few building details to enable O&M personnel to conduct their daily operational tasks are available and identified	• Some building details to enable O&M personnel to conduct their daily operational tasks are available but stored in basic non-unified	• Most building details to enable O&M personnel to conduct their daily operational tasks are available and established in	• All building details to enable O&M personnel to conduct their daily operational tasks are available, and fully integrated		

(*continued on next page*)

Table A.3 (*continued*)

Information requirement (IR)	General Information Requirements							
	Description of IR	Capability levels					Current performance (enter 1–5)	Target performance (enter 1–5)
		Level 1	Level 2	Level 3	Level 4	Level 5		
			independently of BIM.	3D BIM models.	unified BIM models.	with BIM through utilising advanced technologies like visualisation software or real time monitoring with Enterprise Asset Management system (EAM) and Computerised Maintenance Management System (CMMs). All building details are continuously reviewed, updated, and standardise.		
Manufacturer and warranty details	General manufacturer information and warranty details.	• Lack of manufacturer and warranty details to enable the O&M personnel to conduct their daily operational tasks.	• Very few manufacturer and warranty details to enable O&M personnel to conduct their daily operational tasks are available and identified independently of BIM.	• Some manufacturer and warranty details to enable O&M personnel to conduct their daily operational tasks are available but stored in basic non-unified 3D BIM models.	• Most manufacturer and warranty details to enable O&M personnel to conduct their daily operational tasks are available and established in unified BIM models.	• All manufacturer and warranty details to enable O&M personnel to conduct their daily operational tasks are available, and fully integrated with BIM through utilising advanced technologies like visualisation software or real time monitoring with Enterprise Asset Management system (EAM) and Computerised Maintenance Management System (CMMs). All the manufacturer and warranty details are continuously reviewed, updated, and standardised.		

Data availability

Data will be made available on request.

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