EXPERT VERIFICATION OF INFORMATION REQUIREMENTS FOR INTEGRATING BUILDING INFORMATION MODELLING WITH OPERATION AND MAINTENANCE

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Despite the successful project delivery for BIM in facilities management, limited investigations have focused on BIM and Operation and Maintenance (O&M) integration. Although this phase accounts for approximately 60% of total life cycle costs, making it crucial for realising good return on investment (ROI). It was found that one of the main reasons for slow adoption of BIM in O&M is the absence of clear information requirements, making it challenging to create asset registers. Therefore, the purpose of this work is to identify the information requirements for integrating BIM with O&M. This research deploys a combination of a systematic literature review (SLR) and expert verification (via questionnaire) to identify the information requirements. The combination of the information extracted from the SLR with their validation by 21 experts resulted in identifying 21 information requirements (IRs) grouped into five categories: general IRs, strategic IRs, operational IRs, commercial IRs and continuous improvement IRs. These IRs provide a fundamental framework for O&M practitioners and researchers to promote the implementation of BIM in O&M.

Keywords: BIM; operations; maintenance; integration; reliability

INTRODUCTION

Building information modelling (BIM) has provided designers and builders with opportunities for successful project delivery, at a higher quality and a lower cost (Suprun *et al.,* 2022). While the design-to-construction phases typically account for 2-5 years, the operations and maintenance (O&M) phase usually takes up to 20 years and even beyond, which makes it crucial to the realisation of a good return on investment (ROI). This implies that there is a possibility for huge cost savings with BIM in O&M. One crucial pillar to this integration, is information management (Chan *et al.,* 2016; Ma *et al.,* 2020). The application of clearly defined asset information needs is therefore a vital element to the success of BIM and O&M integration (Chan *et al.,* 2016; Ma *et al.,* 2020). However, BIM adoption and

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utilisation during the O&M phase remains slow, owing to several justifications. Firstly, the absence of clear information needs that support the use of BIM in the O&M phase makes it difficult to support the integration. Secondly, the compatibility between BIM and the different systems used during the building life cycle (e.g., CMMS, CAFM and BAS) is complex. Thirdly, since assessing the performance of the integration is critical to its success, the absence of key metrics can further hinder the process. For these reasons, BIM integrations within the O&M phase remain slow and their applications are limited. This necessitated a state-of-the-art review to capture and identify what information requirements are crucial to facilitate the adoption for BIM in O&M. Therefore, the purpose of this work is to identify the information requirements for integrating BIM with O&M.

METHOD

The first phase of this research was the systematic literature review SLR. The second phase was a quantitative method approach (survey) to show the extent of alignment between theory and practice. Therefore, a combination of both approaches was used to answer the following research questions: RQ1.What is the current state of art of BIM integration with O&M and what are the research gaps? RQ2. What are the key information requirements that are needed to support the integration of BIM in O&M in construction sector?

The key research questions and the research phenomenon under investigation is influenced by the type of philosophical worldview (Creswell, 2017). To address the research questions, particularly RQ2, the information requirement for BIM-O&M integration was viewed as a single reality (in other words, there are specific, precise set of information requirements) that needed to be identified. In this of view, the study adopted the positivist world view which considers reality to be single, existing independently of the researcher and thus being able to be objectively assessed.

Review of Related Literature

The literature review methodology deployed for this study was based on preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) (Petrosino and Lavenberg, 2007). A comprehensive protocol from (Okoli, 2015; Iheukwumere-Esotu and Yunusa-Kaltungo, 2020; Qiao, Yunusa-Kaltungo and Edwards, 2021) was adapted. The three databases were Scopus, Web of Science and Engineering Village. The selection of these databases was due to their efficient, easy, and advanced searching options, as well as their reliable and comprehensive academic information in the specified area of this research. The methodology consists of 5 main stages, namely, scoping, identification, screening, eligibility, and final records. In the second stage, the advanced keywords searching option was used with the following phrases ((“Building information model *” OR “building model *” OR “BIM”) AND (“operation and maintenance” OR “asset management” OR “facility * management” OR “maintenance information management” OR “maintenance management *” OR “computeri * maintenance management *”)). The total number of returned results were 669 articles which was further refined based on the inclusion criteria which were: (1) All available articles on BIM integration within the O&M phase of construction and infrastructure domains; (2) All available articles that address drivers and barriers to BIM-O&M integration; (3) only journal papers were included ; (4) The SLR was not constrained by a time frame so as to ensure a more encompassing approach to information tracking and data capturing; (5) Articles written in English. In the third stage, the unrelated articles were excluded through title and abstract assessments. The penultimate stage entailed establishing the eligibility of the remaining articles based on full-text availability. Finally, 196 articles were included in the review. Full details of the SLR can be found at (Abideen *et al.,* 2021, 2022).

Many efforts have been devoted towards the definition of information requirements that can better drive the integration of BIM into O&M FM. For instance, A 7-step handover framework based on owner requirements for educational institutions was developed by Thabet and Lucas (2017). However, further grouping of the proposed data would improve the quality of the integration. Sadeghi *et al. (*2019) proposed a taxonomy of information requirements under: location, specifications, warranty, maintenance instructions, and construction specifications.

However, the proposed model is considered inflexible and requires further customization. (William East, Nisbet and Liebich, 2013) grouped information requirements into either geometric related or asset related. Mayo and Issa (2016) addressed the non-geometric information needs using Delphi method. The study did not provide sufficient details regarding which O&M systems relate to the identified information needs. Most of these studies lacked demonstration of actual benefits in maintenance tasks and had little focus on O&M. Even though each organization is different and has diversion in their business nature, there is a research gap in generalising the requirements and information needs with respect to the asset's operational performance.

Experts' Verification Process

Though the literature review addressed some information requirements for BIM, it has also revealed that these information requirements do not capture clear information needs in the operation and maintenance phase of the building/construction project. In addition, it was found that these information requirements are not clearly outlined with respect to O&M. For that reason, experts' verification of the potential information requirement for BIM in O&M was necessitated. The verification process was conducted to (1) verify the appropriateness and comprehensiveness of identified categories of information requirements for inclusion into the BIM-O&M framework, and to (2) identify additional key requirements that might have been missed or not reported by the literature.

The philosophical worldview adopted in this study further informed the research strategy and research method to be a quantitative research method (Creswell, 2017). Therefore, the verification process was done through a quantitative method (survey) to gather objective evidence of the relevance of the information requirements to the BIM and O&M integration. The survey was remotely deployed and was not constrained by geographical location. Hence, participants were drawn from several countries e.g., United Kingdom, Saudi Arabia, etc. Several studies have proposed frameworks or examined information needs through the application of quantitative approaches like questionnaires /surveys in and around BIM and O&M. Lin et al., (2016) used questionnaires to develop a BIM framework with seven core elements. Tucker and Masuri (2018) developed a framework with three main areas: the drivers, the barriers, and RIBA plan of work. Nguyen et al., (2017) identified the needed information for FM staff from the hand-over data for high rise buildings. Liu and Issa (2016) used surveys to understand the requirements of facility managers and the type of maintainability problems.

To achieve an effective verification process, a panel of experts was constituted. The selection guidelines were adapted from the guidance of (Hallowell and Gambatese,

2009) in selecting experts for expert group techniques. At least three of the following requirements should be met; (1) Minimum of five years of professional experience in BIM or O&M or other related domains like facilities management in the construction industry ;(2) Minimum educational qualification of a bachelor's degree in relevant fields; (3) At least one professional qualification relevant to BIM, O&M or FM; (4) An academic who has carried out research in areas of BIM applications in the O&M phase.

Verification of Information Requirements

The systematic literature review revealed 21 information requirements that are crucial to the support of BIM in O&M. These 21 information requirements were used to design a simple questionnaire. The main task put before the experts was to determine the suitability of the initially identified information requirements from the literature. Therefore, the questionnaire requested the experts to review and indicate the relevance of the 21 information requirements to the support of BIM and O&M integration for building projects. The experts were asked to select from the list of the information requirements the ones they consider to be relevant. The questionnaire also asked experts to identify other suitable information requirements that may have been missed.

The level of agreement and acceptability of each information requirement was determined using percentages. The results are presented in Figure 1 A total of 21 out of the 32 experts responded to the questionnaire: thereby, reflecting around 67% response rate.

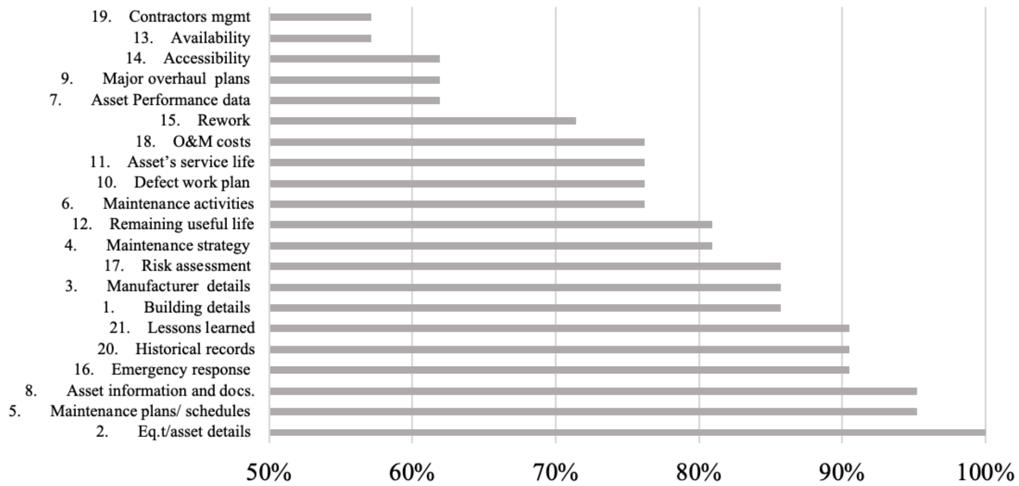

Figure 1: Results on expert survey

For each of the information requirements over half of the experts (i.e., a simple majority- 50%) agreed that it is relevant to the integration of BIM and O&M in building projects. Also, the experts did not suggest any new information requirements. In the end, the 21 information requirements were verified to include in the BIM and O&M integration framework. Based on these 21 information requirements and the PDCA management cycle, an integrated BIM and O&M framework was established. It involves planning, implementation, checking, and reviewing phases which consist of processes and procedures that help in the continuous improvement of BIM and O&M.

Detailed descriptions of the thematic categories namely, general IRs which capture the general information for the building, asset and manufacturer details. Strategic IRs which capture high level strategic plans and information that an organisation requires to maintain their assets effectively. Operational IRs which capture technical information that an organisation requires to evaluate design, operational and maintenance performance limits of their assets. Commercial IRs which capture commercial information that supports the monitoring and validation of key financial and contracting performance management, and continuous improvement which capture the historical maintenance related information to facilitate the concepts of learning from successes and failures, as well as developing feedback loops for an improved and sustainable maintenance regime. The various information requirements within and their corresponding PDCA phase are presented in the Table1.

Table 1: Verified categories and sub-categories of information requirements (IR) to facilitate BIM and O&M integration

Category	Proposed information requirements	Description
General	1. Building details	General building information
	2. Equipment/asset details	General equipment information
	3. Manufacturer and warranty details	General manufacturer information and warranty details
Strategic (PLAN)	4. Maintenance strategy	Existence of a clear maintenance strategy that identifies the vision, mission, constrains and required resources
	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
	6. Maintenance activities/task	Each asset/component has a clear description of the required maintenance activity
	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
	8. Asset information and documentation	Clear O&M documentation (that is updated regularly with all the required information), data retrieval, and recovery.
	9. Major overhaul plans	Major overhaul plans (if needed) that are required during plant/ asset's shutdown/disassembly to carry out maintenance
	10. Defect work plan	Clear rectifying measures to handle components defects
Operational (DO and CHECK)	11. Asset's service life	The service life of the component
	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 warranting replacements
	13. Availability	The duration of time a particular asset can perform its intended task
	14. Accessibility	Means to access the component for maintenance works
	15. Rework	Repair work done on previously maintained equipment
	16. Emergency response	Emergency response protocols for urgent / late maintenance works
	17. Risk assessment	Efforts to identify and analyse potential hazards
Commercial (DO and CHECK)	18. Operational and Maintenance costs	Records and means to calculate potential associated costs
	19. Contractors management	Strategy of outsourced O&M activities and contractors selection criteria
Continuous improvement (ACT)	20. Historical maintenance records	Maintenance history and status of components
	21. Lessons learned/ feedback loops	Documented lessons learned of previous maintenance interventions and plans of feedback loops

DISCUSSION

The analysis identified five main thematic categories that are relevant to the integration of BIM with O&M. Regarding the ranking of each information requirements, all the participants agreed that equipment/asset details are the topmost important set of information needed to facilitate the support of BIM in O&M with 100% agreement level. Ultimately, 86% of experts believe other general asset's information requirements should be available from the very first stage to facilitate the integration.

BIM and O&M Integration Framework

Plan

In the first phase (Plan), the grouped list of strategic IRs helps in setting the strategic maintenance objectives as well as the means and methods of reaching these targets. To ensure an effective planning of the integration between BIM and O&M, establishing a clear maintenance strategy that identifies the vision, mission, constrains and required resources for the maintenance organisation as well as clear rectifying measures to handle components defects is a main pillar in optimizing maintenance and crucial to the preparedness and readiness of the integration (Liu and Gao, 2017b; Heaton, Parlikad and Schooling, 2019). 81% of experts emphasised this fact. Also, it is unsurprising that 95% of participants agreed on the relevance of maintenance plans and schedules that show start-up and shutdown information to the success of this integration. This will decrease the total maintenance costs through saving human labour and time (Liu and Gao, 2017a; Lu *et al.,* 2018).

Ultimately, 76% of experts approve that defining a clear description of the required maintenance activity/task for each asset, will help in maximizing equipment operating time and reducing asset's failures (Cavka, Staub-French and Poirier, 2017; Liu and Gao, 2017a; Farghaly *et al.,* 2018; Lu *et al.,* 2018; Heaton, Parlikad and Schooling, 2019). On the other hand, 95% of experts agree that identifying the means to document asset information from the planning phase helps in better tracking of maintenance history at later phases, thus allowing for continuous improvement by learning from failures (Cavka, Staub-French and Poirier, 2017, 2018; Liu and Gao, 2017a; Lu *et al.,* 2018). Also, defining major overhaul plans (if needed) that are required during plant/ asset's shutdown/disassembly to carry out maintenance saves breakdown costs and can be more profitable in the long term than immanent repair (Shou *et al.,* 2020).

Do and Check

In the second and third phase (Do and Check), the operational and commercial IRs presented, work as a guide by presenting the operational data needed, tools to collect and analyse these data and performance indicators. In the operating phase of the PDCA cycle, measuring asset's operational performance through key performance indicators can give an indication regarding equipment's health and understanding its patterns. Therefore, it is unsurprising that asset's remaining useful life became of equal performance to maintenance strategy followed by asset's service life.

Moreover, 71% of experts agree that rework rate and 62% and 57% of experts agree that asset's accessibility and availability allow breakdowns to decrease, resulting in higher asset's reliability (Shou *et al.,* 2020). The importance of such information requirement was reported in literature in various building types like Institutional, Infrastructure, healthcare, industrial and residential buildings as well as HVAC systems as seen in (Cavka, Staub-French and Poirier, 2017; Liu and Gao, 2017a; Lu *et al.,* 2018; Heaton, Parlikad and Schooling, 2019; Dias and Ergan, 2020). Also, very few studies considered accessibility.

One study did consider equipment accessibility but did not explain the later relation to O&M and the maintainability design requirements (Cavka, Staub-French and Poirier, 2018). Similarly, the higher the time between the failure, the more reliable the asset. On the other hand, Mean time to repair (MTTR) is considered an important metric that gives indications about asset's efficiency. Examples are seen in healthcare, industrial, and residential buildings as well as HVAC systems as in (Cavka, Staub-French and Poirier, 2017; Dias and Ergan, 2020).

Establishing an emergency response which covers the response protocols for urgent / late maintenance works reduces asset's interruption chances and enhances compliance with health and safety regulations (Shou *et al.,* 2020). 86% of experts believe that proper risk management and effective safeguarding protocols are vital to protect the workforce from injuries (Lu *et al.,* 2018). To improve monitoring and constant checking of the BIM and O&M integration 76% of experts agree that tracking asset's costs history allows to optimise budgeting.

While (Cavka, Staub-French and Poirier, 2017; Heaton, Parlikad and Schooling, 2019) was among the very few studies who focused on maintenance costs, this study details the associate costs with respect to O&M systems in by giving insights of different cost categories that tailored to specific O&M requirements. Moreover, 57% of expert agree that contractor's management plan (price list, point of contact) helps in mitigating risks and avoiding loss in time and money due to pre-defined collaboration strategies (Dias and Ergan, 2020).

Act

In the final phase (Act), efforts and adjustments to sustain and standardise the integration process are established. 90% of experts chose the historical maintenance records and Lessons learned/ feedback loops as necessary information requirements. Capturing such information to facilitate the concepts of learning from successes and failures, as well as developing feedback loops allows tracking of equipment's performance and demonstrating its compliance, helps in better budget planning. Thus, the amount of redundant maintenance works is decreased. These information requirements are in line of what was reported in previous efforts of integrating BIM in O&M as seen in (Cavka, Staub-French and Poirier, 2017; Liu and Gao, 2017a; Lu *et al.,* 2018; Heaton, Parlikad and Schooling, 2019)

CONCLUSION

It can be concluded that although BIM asset delivery is now well developed to globally recognised and accepted standards, some drawbacks hinder the adoption of BIM in O&M. We aim to address these deficiencies through the proposed framework. The current study proposes an integration framework for BIM and O&M and contributes to the existing body of knowledge by identifying clear information requirements from the perspective of a reliability information management to support BIM integration with O&M phase. It provides a means to categorise, and priorities the required information needs based on their importance and relevance to the integration of BIM in O&M and standardising the integration process between BIM and O&M through the adoption of the PDCA cycle.

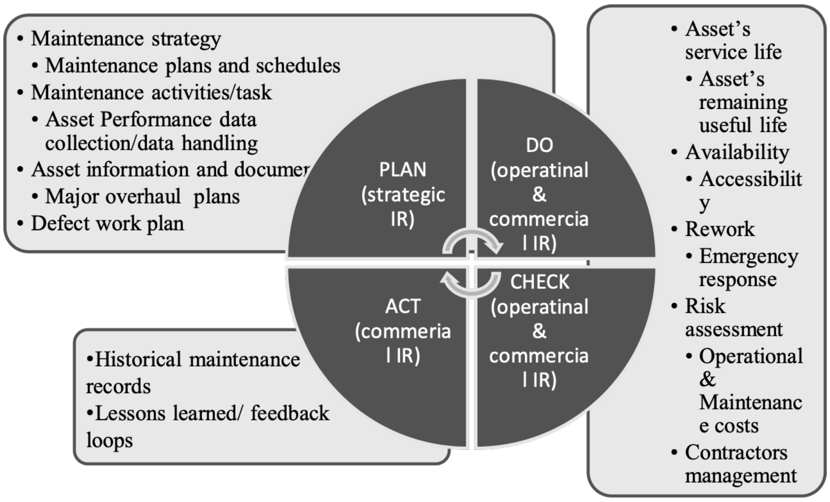

Figure 2 Integration framework between BIM and O&M based on the PDCA cycle

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