Jayasena, H. S., 2024. O2E2: A framework for evolving cost estimation in BIM workflow. In: Sandanayake, Y.G., Waidyasekara, K.G.A.S., Ranadewa, K.A.T.O. and Chandanie, H. (eds). *Proceedings of the 12th World Construction Symposium*, 9-10 August 2024, Sri Lanka. pp. 802-814. DOI: https://doi.org/10.31705/WCS.2024.64. Available from: https://ciobwcs.com/papers/

O_2E_2: A FRAMEWORK FOR EVOLVING COST ESTIMATION IN BIM WORKFLOW

Himal Suranga Jayasena[1]

ABSTRACT

This study proposes a novel framework and workflow, termed Object-Oriented Evolutionary Estimating (O_2E_2), for integrating cost estimation with Building Information Modelling (BIM). An inductive approach to theory, informed by a systematic literature review, was adopted to synthesise the knowledge necessary to develop the proposed framework. The developed O_2E_2 framework facilitates data exchange using Industry Foundation Classes (IFC) and enables the generation of evolving cost estimates through the design and construction process as BIM information evolves through different Levels of Detail (LOD). The framework separates elemental and construction operations cost estimation for improved accuracy and integrates cost estimates with project schedules via Object-to-Schedule Maps to facilitate comprehensive cost views within the BIM workflow. It relies on a single Model View Definition (MVD) within IFC for data exchange between cost-estimating software and other BIM tools. The framework adopts an agile approach, treating cost estimation at each LOD as a sprint within the overall workflow. Building on existing knowledge, this study presents a promising approach for BIM-based cost estimation, enabling more informed decision-making through the design and construction phases. Future research should focus on validating the framework through practical applications and evaluating its key components in individual studies.

Keywords: *Building Information Modelling (BIM) Workflows; Cost Estimation; Industry Foundation Classes (IFC); Levels of Detail (LOD); Object-Oriented Data.*

1. INTRODUCTION

Since the introduction of Building Information Modelling (BIM) nearly three decades ago, cost-estimating practices have also advanced in parallel. BIM is already being established as a standard information practice in construction and is also recognised as an effective approach for high cost-estimating accuracy (Babatunde et al., 2019). The need to develop tools, techniques, technologies, and work practices is emphasised to streamline cost estimation with BIM practices to maximise the quality of cost services with improved reliability (Stanley & Thurnell, 2014). The general approach is to link cost estimation standards to work and material quantity take-offs from BIM models (Fazeli et al., 2020). The ability of BIM technology to automate the cost estimation process, especially the time-consuming quantity take-off process within it, which can enhance accuracy and efficiency compared to manual cost estimation methods, is now well understood (Hasan & Rasheed, 2019). Despite this advancement, cost estimation has yet to achieve its best potential in a BIM environment. One of the key barriers is the limitations of current BIM

[1] Senior Lecturer, Dept. of Building Economics, University of Moratuwa, Sri Lanka, suranga@uom.lk

cost-estimating practices, which prevent full integration of cost estimation with the BIM workflow. While the need for aligning the cost practices for effective information sharing in BIM-based project delivery has long been recognised (Silva & Jayasena, 2013), the focus of developments has been on using BIM to automate conventional cost-estimating methods (Babatunde et al., 2019; Cerezo-Narváez et al., 2020; Hussain et al., 2024). Consequently, the focus on aligning cost estimation with BIM workflow has been largely neglected.

Addressing the above gap, this study proposes an alternative approach: O_2E_2, a cost-estimating practice to align it with the BIM workflow. The aim of this study is to identify a framework that integrates cost estimation with the BIM workflow of the delivery phase of a construction project. The framework addresses two key objectives i.e.:

i. identify the alignment needs of cost estimating with the BIM information schema, and
ii. identify the alignment needs of cost-estimating process with the BIM workflow

The first objective is to understand how the data structure within a BIM model can be best utilised for cost estimation and cost information sharing purposes. The second objective focuses on exploring how the evolving information through BIM workflow can be effectively integrated into the cost-estimating process.

2. LITERATURE SYNTHESIS

The existing knowledge addressing these two objectives was first synthesised from the extant literature. The literature synthesis is presented in three sections. The first section identifies the IFC schema as the appropriate information structure to review when developing the framework for sharing cost estimate information. The second section reviews ISO 19650 parts 1 and 2 to identify the requirements for aligning the cost-estimating process with the BIM workflow. The third section synthesises the specific research questions of the study.

2.1 BIM INFORMATION STRUCTURE

To ensure seamless collaboration across various software programs, the Architecture Engineering and Construction (AEC) industry has adopted Industry Foundation Classes (IFC) as the international standard for building information exchange. The International Alliance for Interoperability (IAI) initiated the IFC in 1994 (Laakso & Kiviniemi, 2012). IFC acts as a common language, allowing interoperability across different BIM applications. It defines building components with properties and connections, encompassing both physical elements (walls, windows, etc.) and non-physical ones (rooms, floors, etc.) (Silva & Jayasena, 2013). This ensures smooth data sharing across platforms, supporting collaboration, and efficiency in construction projects. Additionally, IFC data have built-in intelligence, enabling the automated computer analysis of building information (Tang et al., 2020).

The adoption of proprietary BIM systems has increased over time owing to factors such as functionality, market shares of software vendors, success stories, and technological advancements within the industry (Epasinghe et al., 2018; Won et al., 2013). Adopters often choose BIM software based on their features, the reputation of software vendors, and observations of successful implementation. Therefore, the market mechanism has been promoting proprietary BIM systems in BIM infant industries and relatively mature industries (Jayasena et al., 2023). These systems also use object-oriented information schemas compatible with IFC. They can write to and read from the IFC schema using translators with varying levels of compatibility (Lee et al., 2021). It is important to note that the underlying information structure of all systems remains compatible with the IFC. This compatibility is what enables interoperability among different BIM systems and among BIM software from different vendors (Jiang et al., 2019). Consequently, for effective and efficient cost information sharing, the IFC information structure becomes the target information schema for conceptualising cost information within the BIM workflow.

2.2 EVOLUTION OF INFORMATION THROUGH THE BIM PROCESS

The international standard addressing BIM workflow is BS EN ISO 19650-2:2018 (British Standards Institution, 2019b). It focuses on the broader workflow of information management in the delivery phase of a building and includes steps such as assessment of need, invitation to tender, tender response, and appointment. The workflow was designed to ensure efficient information management using BIM. This document emphasises the need to manage the evolving BIM information by defining the minimum information requirement for each participant at each stage of the project. Section 5 specifies the approach to achieve this by establishing the project's information requirements, information delivery milestones, and information standards, as well as the information production methods and procedures.

By establishing the appointing parties' (i.e., the clients) information requirements, the ISO specifies to "establish the level of information need required to meet each information requirement" (British Standards Institution, 2019b, p. 7) to ensure that each appointed party (i.e. project team members) will fulfil the information production and delivery at specific information levels to maintain efficient and effective BIM workflow. "A responsibility matrix should be generated as part of the information delivery planning process in one or more levels of detail" (British Standards Institution, 2019a, p. 22). A high-level responsibility matrix is first prepared as part of appointing the parties' information requirements, which is used by the appointed party in preparing their BIM execution plan. The high-level responsibility matrix is later refined into a detailed one identifying (British Standards Institution, 2019b, pp. 13-14):

- what information is to be produced,
- when the information is to be exchanged and with whom, and
- which task team is responsible for its production.

The level of information needed to meet each information requirement is established next. The details of such information are identified in each team member's Task Information Delivery Plan (TIDP) and the aggregated Master Information Delivery Plan (MIDP) of the overall delivery team.

ISO 19650 part 4 "*specifies the detailed process and criteria for decision-makings when executing an information exchange and details the implementation of the concepts in ISO 19650-1 and is applicable to any information exchange within the delivery stages covered by ISO 19650-2*" (British Standards Institution, 2022, p. 1). It emphasises how an information reviewer should take steps to ensure communication efficiency, content continuity, conformance, consistency, and completeness of information exchange. It is not prescriptive of data formats but supports IFC, among others.

ISO 19650 Part 2 specifies that team members "*shall not generate information that exceeds the required level of information need*" (British Standards Institution, 2019b, p. 18). This is further elaborated in ISO 19650 Part 1: Concepts and Principles, where the level of information needed is discussed in detail. It highlights that the purpose of the concept is to establish a framework for defining the extent and granularity of information required and that it aims to prevent the delivery of excessive information.

The practical approach taken to establish the level of information needed is by defining them using the Level of Development (LOD). The LOD framework defines the level of information and development of building elements within a BIM model. LOD allows appointed parties to depict building elements at various levels of development, ranging from basic approximations to highly detailed representations (Alshorafa & Ergen, 2019). This framework shall be used to identify the level of information needed and available for cost estimation and to define the level of cost information to be shared at a given point in the project timeline.

2.3 SPECIFIC RESEARCH QUESTIONS

Specific research questions are essential for a research study as they help to focus the research to ensure that the study remains on track and addresses the intended objectives. These questions play an important role in addressing the main purpose of the study (Barroga & Matanguihan, 2022; Creswell & Creswell, 2018).

From the extant knowledge outlined in Section 2.1, the specific research question to address the first objective, that is, identifying the alignment needs of cost estimation with the BIM information schema, can be synthesised as to how the IFC schema can be best utilised for cost estimation and cost information sharing. To address the second objective: identify the alignment needs of the cost estimating process with the BIM workflow, Section 2.2 presents knowledge that can be interpreted to define its specific research question as how the evolving levels of reliable details within a BIM LODs can effectively be integrated into the cost estimating process. However, it is observed that the first question is intertwined with the second question, presenting a challenge to address it with rigour. Consequently, the specific research questions were redefined as follows:

- RQ1: What is the appropriate methodology for writing back cost information to the IFC or other parametric BIM models?
- RQ2: How can an evolving cost estimate be produced along with BIM LOD evolution or other increasing levels of information development, as defined in the BIM workflow?

RQ1 addresses how IFC schema can be utilised for cost information sharing, while RQ2 addresses how information schema can be utilised for cost estimation with a specific focus on understanding how this could be done with evolving levels of reliable details, as may be defined by LOD or similar methods. Other parametric BIM models are accounted for in RQ1 because the review in Section 2.1 identified that they also have a similar structure; thus, the knowledge can contribute to the first objective.

3. RESEARCH METHODOLOGY

Since the answers to the specific research questions were to be explored, the theoretical approach to the study was inductive. While various research methods were viable, when the recent rise in BIM cost estimating research is considered, a knowledge-based approach emerged as the most strategic choice. This approach allowed drawing upon existing knowledge to synthesise answers to the specific RQs of the study.

3.1 RESEARCH APPROACH

A search for a technological solution in industry practices that addresses the objectives of this study was not found. Consequently, reliable data representing the experiences of a practical solution were unavailable. A preliminary search of the literature revealed a relatively high amount of research that had been carried out on BIM cost estimating. However, none of them had specifically addressed the RQs of this research, while a few had useful insights that helped address those questions. To capture the knowledge in current research that can contribute to this study, a Systematic Literature Review (SLR) was identified as the appropriate approach to this research.

SLRs are recognised for their rigorous and structured approach to collecting, analysing, and synthesising existing research (Page et al., 2021). Initially widespread in the medical sciences, SLRs have gradually gained recognition and adoption in diverse fields, such as social sciences, management, psychology, and computer science (Brewster et al., 2021). SLR has become a preferred approach for synthesising existing knowledge (Page et al., 2021), as required in this study.

A large majority of research on BIM cost estimation has focused on the automation of quantity take-offs. This focus is also aligned with the current technology and practice within the industry. They would not contribute much to this study, except when at a later stage LOD, an estimate based on accurate quantities is expected by stakeholders. These studies were excluded from the review because these approaches are now common knowledge. However, any other approach to cost estimation would have potential usefulness. To bring that knowledge in, another research question was defined.

- RQ3: How to produce an early design stage cost estimate that does not rely on detailed quantities extracted from BIM models (such as parametric estimates)?

The three research questions were addressed through the SLR guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement (Page et al., 2021). While this study itself is not a full-fledged SLR, utilising the PRISMA principles is intended to enhance the transparency and clarity of the review process. The documents selected through the process were thematically analysed for three RQs. The findings were synthesised to develop the proposed framework.

3.2 SEARCH STRATEGY AND SELECTION CRITERIA

3.2.1 Search Strategy

To identify potentially relevant literature, a comprehensive search was conducted in April 2024 in the Scopus database using the following search string:

TITLE-ABS-KEY (bim AND cost AND estimat*) AND PUBYEAR > 2018 AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cp"))

This search string aimed to identify studies published from 2019 to the day of the search that focused on Building Information Modelling (BIM) and cost estimation. The search was limited to articles (ar) and conference papers (cp) to ensure the inclusion of relevant research.

Scopus is a leading curated database known for its rigorous selection processes and extensive coverage in the science and technology field (Baas et al., 2020). Many authors have chosen the Scopus search for BIM-related research (Mongeon & Paul-Hus, 2016; Radzi et al., 2023; Yin et al., 2019). Its focus on rigour and comprehensiveness permits the identification of relevant and reliable studies for this BIM cost-estimating research.

3.2.2 Selection Process

Clear reporting of the literature selection process of this study brings validity and reliability to the review findings through several means. At first, it offers transparency on how the different documents were identified and selected. It then allows other researchers to replicate and verify the results. It should also help in identifying potential selection biases, increasing the trustworthiness of the review.

The selection process followed a three-stage approach:

(i) Title Review: Titles were screened to identify studies potentially related to BIM-based cost estimating or cost information-sharing approaches. Irrelevant studies were excluded. This initial screening resulted in 261 documents being rejected, and 106 documents being moved on to the next stage.

(ii)Abstract Review: Abstracts of the remaining studies were reviewed to determine if the research explored methodologies to write cost information to IFC or other parametric BIM models, or if they link cost estimates to different levels of information in BIM at different stages of a project. Three specific RQs previously defined guided this review.

The test question was, "does this paper likely identify, explain, propose, or prompt an answer for any of the three RQs?" Studies that did not address any of these three questions were excluded. This stage resulted in the rejection of 95 documents, leaving eleven for a full-text review.

(iii) Full-text review: The full text of the remaining documents was to be reviewed for the detailed analysis. However, limited access to two studies necessitated contacting the authors for full-text access. Only one author replied along with the requested document. Consequently, altogether ten documents were retrieved and reviewed for selection.

The same three RQs were used to assess whether the research was directly linked to BIM information schema and/or evolving levels of information in BIM. The test questions this time required an answer with higher certainty: "does this paper identify, explain, propose, or prompt an answer for any of the three RQs?" Studies that did not address any of these questions were excluded.

A research paper by Abdel-Hamid and Abdelhaleem (2023) on developing a conceptual framework for 5D-BIM in cost control and management did not identify sharing cost information in IFC nor estimating practices with evolving levels of information in BIM, and hence rejected. Consequently, nine full-text papers were identified for the final review.

4. FINDINGS OF THE SYSTEMATIC LITERATURE REVIEW

A summary of the SLR is presented in Table 1. It presents key findings from the selected articles in reverse chronological order. It concisely identifies what each study is about and how each can contribute to the objectives of this study. However, this does not account for the full contribution of each study. Their contributions are elaborated further in the discussion in this section.

Table 1: Summary of literature findings

Source	Summary of Study	Contribution to Current Study
Hussain et al., 2024	A conceptual governance framework for integrating 5D BIM to enhance cost management and control.	Classifies cost estimates based on the maturity level of the project, aiding in budget approval during different project milestones. Also emphasises the importance of LODs in it.
Hussain et al., 2023	A conceptual framework for 5D-BIM in cost control and management.	Classifies cost estimation aligning the estimating process with the development of project scope and financial decision-making processes.
Alzraiee, 2022	A BIM cost estimating system using Structured Query Language (SQL).	Uses dynamic mapping to link the relevant work items, created by the estimator, to the corresponding BIM elements in a parametric environment. Involves creating a relational database of work items by the estimator.
Rouhanizadeh et al., 2021	An automated tool for cost estimation in transportation projects.	Utilises BIM and IFC to estimate costs at different stages of the project. An estimation mechanism that operates in a continuous spectrum from the study phase to the construction phase.
Ren & Zhang, 2021	A new framework for addressing BIM interoperability.	Improves the information transfer and coordination between architectural and structural IFC. Suggests extending to other fields including cost estimation
Fazeli et al., 2020	Semi-automated BIM-based cost estimation system	Links object-oriented data in BIM to activity-based cost estimation standard through MasterFormat.
D'Amico et al., 2020	Implementing BIM for infrastructure, focusing on optimising the design process through 4D and 5D BIM.	Estimating model that dynamically updates the bill of quantities (BoQ) and the project timeline. Divide BoQ into two. Bills of Supplies linked to model quantities, Bills of Resources linked to time schedule. Updates with each change.
Cerezo-Narváez et al., 2020	Integrating Cost Breakdown Structures (CBS) and Work Breakdown Structures (WBS)	Use of standardized cost classification systems such as ISO 12006-2, ISO 81346-12 and OmniClass. Utilise CBS to generate project WBS.
Mamaeva et al., 2019	A regulatory framework for cost calculation within BIM systems	Proposes a structure for developing construction costs that align with LOD and information content of BIM models.

Not all the selected studies focused on BIM cost estimation, yet they all addressed it from different points of view. Blending the SLR findings with the extant knowledge, an Integrated BIM Cost Estimating Framework was synthesised. A graphical representation of the estimating process in this framework is shown in Figure 1.

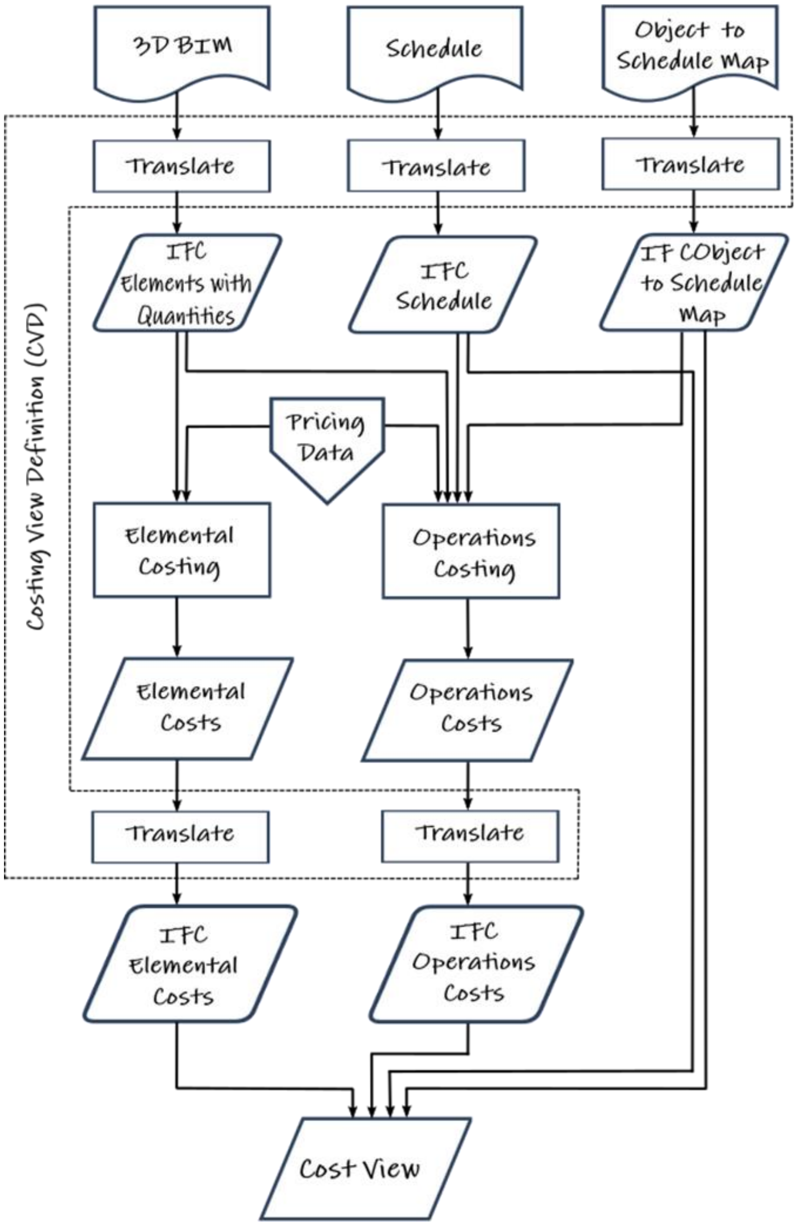

Figure 1: Integrated BIM cost estimating process framework

The cost estimation process is divided into two distinct but interlinked processes, i.e. (i) Elemental Costing, and (ii) Operations Costing. An Elemental Cost covers the cost of all the supplies that become part of a building element, while an Operations Cost covers the cost of all the resources required to build that building element. This is an efficient approach proposed by D'Amico et al. (2020) to improve the accuracy of estimates and allow complete dynamism to evolve the levels of information in BIM models.

The overall estimation process begins with information documents developed outside the estimation process. These are 3D-BIM models developed by other team members, construction schedules, and object-to-schedule maps. The object-to-schedule map procedure is followed to link BIM model objects to the Work Breakdown Structure (WBS) used in the construction schedule. Technically, the object to the schedule map is related to project time information, commonly referred to as 4D-BIM, to be established by planning engineers.

Fazeli et al. (2020) also presented a study that integrates the standards of MasterFormat and UniFormat with items of Iran's cost estimation standard: FehrestBaha. The structure of FehrestBaha is identified to be similar to MasterFormat, primarily because both are organised based on construction activities and materials. Further, similar to traditional estimating methods, FehrestBaha uses an activity-based approach to cost, instead of an object-based approach.

In Fazeli et al. (2020)'s workflow, UniFormat code is added to the building element Type Properties (as Assembly Code), while MasterFormat code is added to the material identity (as Keynote). There is a separate database to link FehrestBaha to MasterFormat and another to link UniFormat with MasterFormat. In this way, relevant UniFormat items are linked to FehrestBaha, enabling automation.

Taking a similar approach, Alzraiee Hani (2022) used Structured Query Language (SQL) to create a dynamic mapping to link the relevant work items, created by the Quantity Surveyor, to the corresponding BIM elements in a parametric environment. This method can be applied to link BIM objects to WBS items. Their method involves the creation of a relational database of work items by the estimator. Once created, they can be reused and appended when and where necessary. Dynamic mapping facilitates evolving cost estimates along with the evolving LOD of BIM data.

Cerezo-Narváez et al. (2020) analyse "whether the integration of a Cost Breakdown Structure (CBS) can lead to the generation of more robust WBSs in construction projects" (p.1). They primarily consider ISO 12006-2, ISO 81346-12, OmniClass, CoClass, CCS, and UniClass to affect the required integration. These studies will assist in developing a robust approach to integrating building elements with the work breakdown structures used in project schedules.

In the early stages of a project, construction schedules are generally not prepared. Consequently, it may become necessary for the Quantity Surveyors themselves to prepare both the schedules and object-to-schedule maps.

All three types of documents are required to begin the cost estimation process. To enable interoperability between different types of documents and cost-estimating software, data in those documents must be translated to IFC. To ensure that all relevant data are translated, and that no unnecessary data are translated, a specific Model View Definition (MVD) should be defined. For consistency, a single Costing View Definition (CVD) is recommended. As shown in Figure 1, it governs the translation of all BIM information relevant to cost estimation.

A similar approach was proposed by Ren and Zhang (2021) in their work, where they added extended material properties to the architectural model and used this material information and geometric information while generating the structural model. By doing this, they improve the information transfer and coordination between architectural and structural IFC. They suggest that this should be extended to other fields, including cost estimation. Their study highlights that, instead of a separate repository, key coordination information or data needed for coordination shall be included in the model itself. Translating the construction schedule and object-to-schedule map to IFC is therefore further justified.

The next step in the process is to perform cost estimation. As previously mentioned, this step is informed by the method used by D'Amico et al. (2020). Their method improves the estimation accuracy by separately estimating the material and resource costs. "4D BIM simulations can turn into 5D BIM simulations by incorporating information about the resource consumption. This can provide a better understanding of the utilisation of resources over time" (D'Amico et al., 2020, p. 2). This shows that their interpretation of 5D is different from common use. This, however, is more meaningful because as per this approach the 5th dimension of BIM (i.e. the cost) comes only after 3D and 4D BIM.

The material cost is proportional to the quantity of building elements. Therefore, the quantities were obtained from the element quantities of the IFC file. Prices may vary for bulk purchasing, and such adjustments can be made by the Quantity Surveyor. The resource cost (such as labour, machinery, and tools) depends on both the quantity of work and time allocated for them. Therefore, resource cost estimation requires the federation of three IFC files i.e. (i) elements with quantities, (ii) construction schedule, and (iii) object-to-schema map. Alternatively, if software can federate them in native formats and export them as one IFC, it would increase the accuracy and efficiency, as demonstrated by Ren and Zhang (2021), when they linked architectural and structural models.

Presenting their approach of two separate estimates, D'Amico et al. (2020) state that "a dynamic model is proposed that can integrate time and cost variables in a bi-directional model able to simultaneously update: (i) the parameters of the proper design model, (ii) the quantity surveying, and (iii) the timeline at any given modifications" (p. 3).

To perform the estimation, proprietary software is utilised. A price database comprising market prices of materials, building element costs, and resource costs should be a part of or linked to the proprietary software. Once the cost estimates are completed, they are exported to IFC as two separate files. The same view definition, CVD, is used to perform this translation to maintain consistency.

The exported IFC Elemental Costs and IFC Operations Costs will then be federated with IFC Schedule and IFC Object to Schedule Map in different software to generate cost views for the project stakeholder. The data richness of these documents and the full integration of data in them enables highly sophisticated views compared to conventional cost information, including yet not limited to, (i) Traditional Cost Plan view, (ii) Traditional BoQ-based view, (iii) Material costs and resource costs in project timeline view, (iv) Summary views costs and cashflows, and (v) Cost views as heatmaps in 3D models and 2D drawings.

The framework shown in Figure 1 depicts the cost estimation process in a waterfall manner. However, for the cost estimate to evolve with developing levels of information in the BIM workflow, an agile approach is required. Therefore, in evolutionary estimation, the estimation process presented in Figure 1 is only a single sprint in an agile workflow. Other papers identified in SLR contribute to identifying approaches to handle evolving levels of information in this workflow.

BIM LOD frameworks are used to define the progression or evolution of details in BIM models (Hussain et al., 2024). Rouhanizadeh et al. (2021) claim that their cost estimation mechanism *"operates in a continuous spectrum from the study phase to the construction phase" (p.1)* to cover cost estimation from LOD 100 through LOD 400. They achieve this by first mapping data between LOD, Uniformat, MasterFormat, and IFC to ensure that all necessary information is captured and accurately represented, and then developing an algorithm to find related cost items at each LOD level and extract the required information from the IFC format. Cost estimation is performed based on a cost database established on MasterFormat. Different estimation methods are implemented at different LOD. *"There are different cost items for a specific element in each LOD, and the framework must be consistent with LOD specifications. Therefore, the framework uses various cost estimation methods and implements different cost items based on the selected LODs"* (Rouhanizadeh et al., 2021, p. 6). Therefore, their cost estimation may not literally "operate in a continuous spectrum" (Rouhanizadeh et al., 2021, p. 1), yet operates at a specific evolving LOD, viz. LOD 100, LOD 200, LOD 300, LOD 350, and LOD 400.

Mamaeva et al. (2019) have developed an evolving cost estimate in parallel with the evolving LOD in BIM systems. In their approach, from the BIM model of a capital construction object, the types and scopes of works are formed for both the entire construction object and its structural elements. These data are then translated into cost estimates. The estimation is carried out using consolidated cost indices. The paper does not identify the specifics of the translation. However, the use of consolidated cost indices indicates that BIM models at generic (LOD 100) and approximate (LOD 200) levels are supported by this approach. This point is further confirmed by their statement "*LOD 400) it is required to make the minimum use of indices of the enlarged format and to make the maximum use of elemental indices with price information*" (Mamaeva et al., 2019, p. 5).

Hussain et al. (2023, 2024) proposed a conceptual governance framework to integrate BIM cost estimation with project governance. The framework assists in aligning the cost estimation process with the strategic objectives of the project and facilitates transparency and accountability. The developed framework was guided by ISO 19650. The AACE International Cost-Estimate Classification System was utilised to align the cost estimation with the evolving levels of information in BIM. This study presents an initial guidance for aligning the proposed cost-estimating workflow for societal acceptance.

5. CONCLUSIONS

Synthesising the extent of knowledge on various aspects of cost estimation with BIM, this study proposes an Object-Oriented Evolutionary Estimating (O_2E_2) framework and workflow that facilitates IFC-based data exchange and evolving estimates through the design and construction processes as BIM information evolves through different LOD. The estimation framework separates the estimation of elemental costs and construction operations costs for improved accuracy (refer to Figure 1). The integration of cost estimates with project schedules and Object-to-Schedule Maps offers comprehensive cost views through the BIM workflow. This framework relies on data exchange between cost-estimating software and other BIM tools by using IFC with a single MVD, agile workflow for cost estimation where cost estimation at a given LOD is one of its sprints. Logically developed from extant knowledge, the proposed framework and workflow provide a promising vision for integrating cost estimation with BIM workflow, enabling more informed decision-making through the design and construction process.

The study's findings point to several areas for future research. Importantly, this study is inductive, and the proposed framework needs to be tested in future research. Because the framework covers several facades, it is recommended that each of (a) object-to-schedule map, (b) concept of single Costing View Definition, (c) IFC data integration for operations costing, (d) different costing views, and (e) cost estimation at different LOD be studied individually. These may require many more exploratory studies to refine the proposed framework and workflow.

6. REFERENCES

Abdel-Hamid, M., & Abdelhaleem, H. M. (2023). Project cost control using five dimensions building information modelling. *International Journal of Construction Management, 23*(3), 405–409. doi:10.1080/15623599.2021.1880313

Alshorafa, R., & Ergen, E. (2019). Determining the level of development for BIM implementation in large-scale projects: A multi-case study. *Engineering, Construction and Architectural Management, 28*(1), 397–423. doi:10.1108/ECAM-08-2018-0352

Alzraiee, H. (2022). Cost estimate system using structured query language in BIM. *International Journal of Construction Management, 22*(14), 2731–2743. doi:10.1080/15623599.2020.1823061

Baas, J., Schotten, M., Plume, A., Côté, G., & Karimi, R. (2020). Scopus as a curated, high-quality bibliometric data source for academic research in quantitative science studies. *Quantitative Science Studies, 1*(1), 377–386. doi:10.1162/qss_a_00019

Babatunde, S. O., Perera, S., Ekundayo, D., & Adeleye, T. E. (2019). An investigation into BIM-based detailed cost estimating and drivers to the adoption of BIM in quantity surveying practices. *Journal of Financial Management of Property and Construction, 25*(1), 61–81. doi:10.1108/JFMPC-05-2019-0042

Barroga, E., & Matanguihan, G. J. (2022). A Practical Guide to Writing Quantitative and Qualitative Research Questions and Hypotheses in Scholarly Articles. *Journal of Korean Medical Science, 37*(16), 1-9. doi:10.3346/jkms.2022.37.e121

Brewster, C., Suutari, V., & Waxin, M.-F. (2021). Two decades of research into SIEs and what do we know? A systematic review of the most influential literature and a proposed research agenda. *Journal of Global Mobility, 9*(3), 311–337. doi:10.1108/JGM-05-2021-0054

British Standards Institution. (2019a). *Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM)—Information management using building information modelling—Part 1: Concepts and principle* (BE EN ISO 19650–1; Version 2018). BSI Standards Limited.

British Standards Institution. (2019b). *Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM)—Information management using building information modelling—Part 2: Delivery phase of the assets* (BS EN ISO 19650–2; Version 2018). BSI Standards Limited.

British Standards Institution. (2022). *Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM)—Information management using building information modelling—Part 4: Information Exchange* (BS EN ISO 19650–4; Version 2022). BSI Standards Limited.

Cerezo-Narváez, A., Pastor-Fernández, A., Otero-Mateo, M., & Ballesteros-Pérez, P. (2020). Integration of cost and work breakdown structures in the management of construction projects. *Applied Sciences, 10*(4), 1386. doi:10.3390/app10041386

Creswell, J. W., & Creswell, J. D. (2018). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (5th ed.). SAGE Publications, Inc.

D'Amico, F., D'Ascanio, L., De Falco, M. C., Ferrante, C., Presta, D., & Tosti, F. (2020). BIM for infrastructure: An efficient process to achieve 4D and 5D digital dimensions. *European Transport/Trasporti Europei, 77*, 10. doi:10.48295/ET.2020.77.10

Epasinghe, E. A. K., Jayasena, H. S., Kolugala, L. M. B. N., & Wijewickrama, M. K. C. S. (2018). Open BIM Adoption in Sri Lankan Construction Industry. *Proceedings of FOSS4G Asia 2018* (pp. 1-13). https://www.foss4g-asia.org/2018/wp-content/uploads/2018/12/Full-paper_ID_44.pdf

Fazeli, A., Dashti, M. S., Jalaei, F., & Khanzadi, M. (2020). An integrated BIM-based approach for cost estimation in construction projects. Engineering, *Construction and Architectural Management, 28*(9), 2828–2854. doi:10.1108/ECAM-01-2020-0027

Hasan, A. N., & Rasheed, S. M. (2019). The Benefits of and Challenges to Implement 5D BIM in Construction Industry. *Civil Engineering Journal, 5*(2), 412–421. doi:10.28991/cej-2019-03091255

Hussain, O. A. I., Moehler, R. C., & Walsh, S. D. C. (2023). A conceptual framework for 5d-bim cost control and management: A state-of-the-art review of mega rail projects in Victoria. *Computing* *in civil engineering 2023: visualization, information modelling, and simulation* (pp.613–621). ACSE. doi:10.1061/9780784485231.073

Hussain, O. A. I., Moehler, R. C., Walsh, S. D. C., & Ahiaga-Dagbui, D. D. (2024). Minimizing cost overrun in rail projects through 5d-bim: A conceptual governance framework. *Buildings, 14*(2), Article 478. doi:10.3390/buildings14020478

Jayasena, H. S., Thurairajah, N., Perera, B. A. K. S., & Siriwardena, M. (2023). Affordance-led framework of understanding of BIM adoption. *International Journal of Architectural Research, ahead-of-print*. doi:10.1108/ARCH-02-2023-0028

Jiang, S., Jiang, L., Han, Y., Wu, Z., & Wang, N. (2019). OpenBIM: An enabling solution for information interoperability. *Applied Sciences, 9*(24), 5358. doi:10.3390/app9245358

Laakso, M., & Kiviniemi, A. (2012). The IFC standard: A review of history, development, and standardization. *Journal of Information Technology in Construction (ITcon), 17*(9), 134–161. Retrieved from https://www.itcon.org/paper/2012/9

Lee, Y.-C., Eastman, C. M., & Solihin, W. (2021). Rules and validation processes for interoperable BIM data exchange. *Journal of Computational Design and Engineering, 8*(1), 97–114. doi:10.1093/jcde/qwaa064

Mamaeva, O. A., Burakov, S. M., & Savenkov, A. N. (2019). Establishing relevant regulatory framework for construction cost calculation in BIM-systems. *IOP Conference Series: Materials Science and Engineering* (775, pp. 1–7). IOP Science. doi:10.1088/1757-899X/775/1/012050

Mongeon, P., & Paul-Hus, A. (2016). The journal coverage of web of science and Scopus: A comparative analysis. *Scientometrics, 106*(1), 213–228. doi:10.1007/s11192-015-1765-5

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, *372*, 71. doi:10.1136/bmj.n71

Radzi, A. R., Azmi, N. F., Kamaruzzaman, S. N., Rahman, R. A., & Papadonikolaki, E. (2023). Relationship between digital twin and building information modelling: A systematic review and future directions. *Construction Innovation, 24*(3), 811–829. doi:10.1108/CI-07-2022-0183

Ren, R., & Zhang, J. (2021). A new framework to address BIM interoperability in the AEC domain from technical and process dimensions. *Advances in Civil Engineering, 2021*, 8824613. doi:10.1155/2021/8824613

Rouhanizadeh, B., Kermanshachi, S., Ramaji, I. J., & Shakerian, S. (2021). Development of an Automated Tool for Cost Estimation of Transportation Projects. *International conference on transportation and development 2021: Transportation planning and development* (pp.178–190). ACSE. doi:10.1061/9780784483541.017

Silva, R. D., & Jayasena, H. S. (2013). The need for an integrated cost modelling framework for building information modelling. In Y.G. Sandanayake & N.G Fernando (Eds.). *World construction symposium 2013: Socio-economic sustainability in construction: practice, policy and research* (pp. 427–434). CIOB. https://ciobwcs.com/downloads/WCS2013-Proceedings.pdf

Stanley, R., & Thurnell, D. P. (2014). The benefits of, and barriers to, implementation of 5D BIM for quantity surveying in New Zealand. *Construction Economics and Building, 14*(1), 105-117. doi:10.5130/AJCEB.v14i1.3786

Tang, S., Shelden, D. R., Eastman, C. M., Pishdad-Bozorgi, P., & Gao, X. (2020). BIM assisted building automation system information exchange using BACnet and IFC. *Automation in Construction, 110*, 103049. doi:10.1016/j.autcon.2019.103049

Won, J., Lee, G., Dossick, C., & Messner, J. (2013). Where to focus for successful adoption of building information modelling within organization. *Journal of Construction Engineering and Management, 139*(11), 04013014. doi:10.1061/(ASCE)CO.1943-7862.0000731

Yin, X., Liu, H., Chen, Y., & Al-Hussein, M. (2019). Building information modelling for off-site construction: Review and future directions. *Automation in Construction, 101*, 72-91. doi:10.1016/j.autcon.2019.01.010