Cost estimation practices: a comparative analysis of traditional 5D BIM and IFC methods

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Abstract
Nowadays in the Architecture, Engineering, and Construction (AEC) Industry, the cost is quantified using 5D BIM software that facilitates and accelerates the cost estimation. However, the cost estimation process is still heavily reliant on subjective evaluations that are influenced by the judgment of each estimator. This activity can be time-consuming and prone to errors.
The research aims to compare the 5D BIM cost estimation method, and a proposed method carried out through a code in IfcOpenShell. This new method uses structured cost items in IFC and defines the relationship between cost and geometric IFC entities.
The results show that the new approach is more agile and effective than the 5D BIM approach based on cost assignment via attributes. The new method ensures the possibility of querying the cost item based on the information contained in the geometric entities and verifying the plausibility of the link between them and the cost estimate.

Keywords: Cost estimation, 5D BIM, Industry Foundation Classes, Cost Item

1 Introduction

Accurate cost estimation remains a crucial challenge in the field of architecture, engineering, construction, and facility management (AEC/FM). Initially reliant on manually correlating costs with physical quantities extracted from graphical tables, the industry's transition towards cost integration through the 5D BIM methods offers new opportunities (Jia et al., 2024, Elghaish et al., 2020). Despite efforts, problems remain due to inconsistencies and uncertainty in cost estimates, such as the absence of procedures to validate the accuracy of cost data associations (Farouk & Rahman, 2023). The research aims to compare 5D BIM methods with a new cost estimation method developed through the IfcOpenShell code and library and proposed by the research team to explore the differences and possibilities offered by the development of a BIM model that contains both cost geometric entities.

The AEC/FM industry faces challenges in estimating costs due to the fragmentation of information, stored and managed in different documents (Biancardo et al., 2023). For this reason, due to the absence of an integrated system for both activities, experts estimate construction costs separately (Liu et al., 2014). The lack of standardized integration of cost data causes problems in financial planning, leading to incorrect information (Parsamehr et al., 2023). These issues emphasize the need to enhance the management and validation methodologies of cost data.

The objective of this research is to compare the 5D BIM methodology used for cost estimation with a new proposed method developed by the research group. Through this, current challenges can be identified, and the potential of the innovative approach can be highlighted. This method improves the accuracy, consistency, and reliability of cost estimation. This study emphasizes the need for a BIM model in an IFC open format to report and manage geometric and cost data through informative entities. This model will help generate a dynamic cost estimation, divided into "n" views, that are queryable, verifiable, and viewable**.**

Two separate cost estimations were developed from the same architectural model using different methods. The current 5D BIM approach defines a final static document, total and not related to the geometric model. On the other hand, the new method enabled the inclusion of all cost items (*IfcCostItem*) within the BIM model and the definition of different cost schedules to group them (*IfcCostSchedule*).

The following document is structured as follows. First, it presents an analysis of the existing literature on cost estimation through 5D BIM methods and then through IFC, studying the use of IFC classes, with particular attention to the entities *IfcCostItem* and *IfcCostSchedule* (attributes and relationships). Subsequently, the operational phase of the estimation was carried out within Primus IFC and through code developed by the research group through the IfcOpenShell library. Finally, the processes and outputs have been validated and compared to highlight the criticality and potential of the proposed methods and future developments.

2 Background

BIM aims to digitize the design, construction, and operation processes, acting as a reliable basis for decision-making (Khosakitchalert et al., 2020). Through a digital model, it is possible to accurately describe the geometric and semantic details of a physical building. Its use reduces time, repetitive tasks, errors, and expenses. This also includes the use of BIM for cost estimation (Elghaish et al., 2020).

2.1 5D BIM Potential and Challenges in Cost Estimation

The use of BIM in cost estimation has been studied in previous research suggesting the integration of cost and time data to create a link with 3D objects (Baldrich Aragó et al., 2021). This method is known as 5D BIM (Khosakitchalert et al., 2020). This approach reduces repetitive tasks and ensures greater data accuracy (Baldrich Aragó et al., 2021, Yang et al., 2022), compared to conventional estimation methods (Kim et al., 2019). In addition, BIM offers a superior approach to quantity take-off of quantities for each element, allowing direct extraction of quantities from identifiable objects in the model (Sacks et al., 2018, Fazeli et al., 2021).

On the other hand, there are still several doubts about the actual improvement given by the application of the 5D BIM methodology (Wahab & Wang, 2022, Moses et al., 2020). The difficulties that emerged in the implementation of 5D BIM are, for instance, software securing, investment in training, less efficiency of time, up to software accessibility standards (Mesároš et al., 2019). Another limitation is the level of development (LOD) by which information/objects are extracted from the information model because directly affects the accuracy of BIM-based quantity take-off and cost estimation (Peansupap & Thuanthongdee, 2016).

However, when evaluating 5D BIM as more than just a quantity take-off practice, new opportunities in BIM deployment can emerge. Cost estimation can be conducted by linking the 3D model to cost items. Then, the integration of 5D BIM in construction offers significant benefits but faces obstacles like software usability and industry resistance (Hosamo et al., 2024; Abanda et al., 2017). Nowadays some leading software in the field are Navisworks, CostX, Innovaya, iTWO, Vico, and so on.

2.2 IFC in Construction Project and Cost Estimation

The AEC/FM industry commonly uses IFC as a neutral data format for describing, exchanging, and sharing information. The IFC model includes geometric objects such as slabs, floors, walls, columns, doors, windows, and ceilings, as well as abstract concepts such as costs, activities, schedules, documents, and spaces. All these data are described using entities (*IfcWall*, *IfcSlab*, *IfcCostItem*, *IfcTask*), their attributes (Name, Description, PredefinedType), and relationships with other entities or properties (*IfcMaterial*, *IfcPropertySet*, *IfcQuantitySet*). The first version of the IFC was released in 1997, and many revisions and extensions have followed, ending with the latest version IFC 4.3 ADD2 - 4.3.2.0 released in April 2024 and approved by ISO standard. Until IFC4, the focus of the IFC standard was mainly on buildings, but with growing global demand, substantial efforts are being made to expand its reachness (Borrmann et al., 2018).

Nowadays, in the AEC sector, the exchange and management of information takes place through BIM and non-BIM data. Non-BIM data comes from several sectors such as energy efficiency design, fire safety, cost estimation, environmental engineering, time management, etc. (Scherer & Katranuschkov, 2019).

Several studies have explored the applicability of IFC in project planning and cost estimation. Fu et al. utilized IFC to develop an nD model for planning and cost-related information (Fu et al., 2006). Ma et al. created a BIM-based methodology for estimating construction cost (CCE) using Chinese standards. (Ma et al., 2010). Zhiliang et al. investigated the use of the IFC standard to estimate construction costs in China, discovering the necessity for extensions in the form of proxy elements and property sets. (Zhiliang et al., 2011). Ma et al. discussed key issues for semi-automatic Tendering of Building Projects (TBP) cost estimation using IFC data (Ma et al., 2013).

3 Methodology

The research follows a structured methodology to highlight the differences in the definition of cost estimation from a geometric BIM model in IFC format. The primary objective is to compare the 5D BIM method, which involves specific software, with a proposed method based on a code developed with the IfcOpenShell library. This code helps define relationships between geometric and cost entities in the BIM model. The methodology includes the following steps (Figure 1):

- **Input**: The first step involves the development of a BIM model that contains the geometric information, essential for the cost estimation. The model is exported in IFC format to ensure data interoperability between the several software available.
- **Experimental Phase**: After defining the BIM model, the next step is associating each geometric model object with a cost item. This process is crucial for accurate cost estimation. The operational phase involved two activities:
    - **5D BIM Method**: Through Primus IFC, a 5D BIM software developed by ACCA, the geometric model in IFC format has been imported and linked to the cost items from the price list loaded in XML format. Subsequently, the useful rules for the definition of the quantity for the cost estimation are inserted manually.
    - **Proposed method**: Through a code, developed with Python and IfcOpenShell, the cost entities (*IfcCostItem*) are created and related to geometric objects (*IfcElement*). The cost entity has been developed through a new architecture more detailed than a simple description in natural language. This is stored in an external database containing only the entries useful for experimentation. Each cost item contains the quantification rules and does not need to be defined manually by the user. Due to the scope of the article, the structure is not presented here but rather refers to another study by the same research group (Cassandro et al., 2023).
- **Output**: This step aims to create a cost estimation. The final output is different depending on the method used. The 5D BIM method defined Excel or PDF documents, without an effective relationship with the geometric model. Instead, the proposed method defined a new BIM model characterized by geometric (*IfcElement*) and cost entities (*IfcCostItem*); the latter can also be grouped within other entities (*IfcCostSchedule*) to create "n" separate views, the total cost for the realization of all plastering or insulation layers, or an overall view of the cost estimation of the project.
- **Comparison**: The final step compares the 5D BIM Method and the Proposed Method for cost estimation. The advantages and limitations of the two methods are discussed and presented.

The scope of this research is defined by the capabilities of IFC technologies to manage structured cost data. The results are useful for understanding the differences and potential of the proposed method by comparing it with the BIM 5D method.

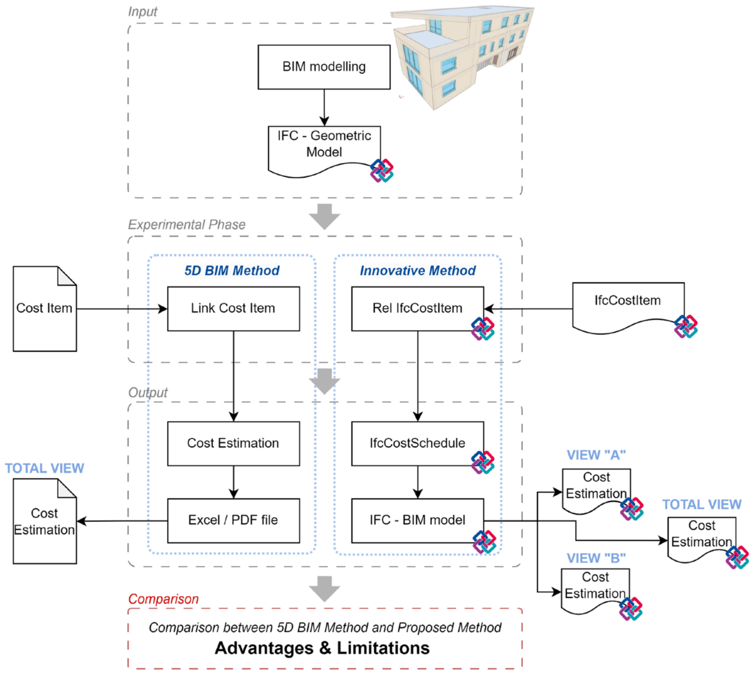

Figure 1. Proposed methodology

4 Cost Data Structure

Starting from natural language and unstructured cost items [1], the cost items have been broken down into a new standardized structure hypothesized by the research team for the ongoing project with the Lombardy Region [2]. Subsequently, a new structure of cost items has been defined based on IFC entities and the relationships that can be activated [3] (Figure 2).

IFC is an open and interoperable standard and the most widely used exchange format in the AEC/FM sector. In the IFC schema, entities for cost scheduling data are categorized into:

- **Cost schedule information**: *IfcCostSchedule* is used to estimate construction costs, either independently or in conjunction with other work orders.
- **Cost item information**: *IfcCostItem* specifies the assignment of cost or financial value to items or products relevant to a cost schedule. For example, costs associated with formwork, concrete, or steel can be detailed.
- **Quantity information**: *IfcElementQuantity* within the IFC schema provides derived measurements of exact quantities for elements. *IfcQuantitySet*, an abstract supertype, encompasses all quantity sets associated with objects. Quantities are classified based on measure type, such as length, area, volume, and time.
- **Price information**: Pricing information, representing rates or costs from bills of quantities or cost schedules, is captured by *IfcCostValue* entity in the IFC schema.
- **Resource information**: *IfcResource* represents details necessary for assessing costs, schedules, and other impacts related to the use of resources, products, equipment, and labor during project execution.
- **Product information**: *IfcProduct* contains abstract information about objects, including their geometric or spatial context. This category encompasses details about non-physical elements such as grids, annotations, and structural actions.

As the article's objective is not to analyze the single cost item inside the standard IFC and its relation to the geometric entity, it will not be explained in detail. However, the structure and relations of the cost item have already been defined (Cassandro et al., 2023). Figure 2 provides a simplified example of the possible architecture behind the cost item related to the laying of the insulation layer.

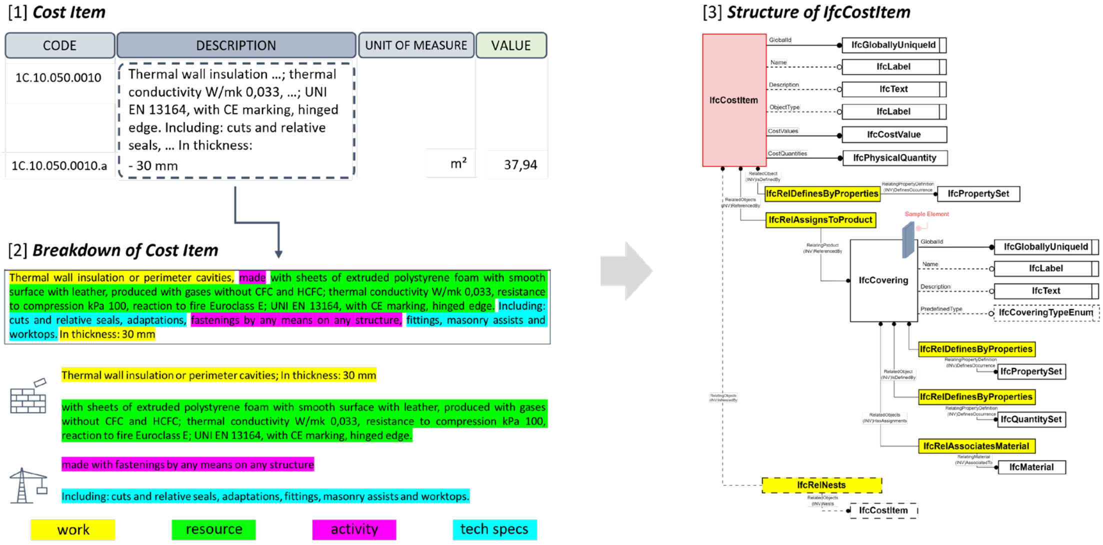

Figure 2. A simplified approach to establishing the structure of a cost item in IFC

5 Results and Experimentation: Cost Estimation of IFC Architectural Model

To validate the proposed methodology, the research emphasizes the execution of a cost estimation for an architectural model in IFC format (Figure 3). The cost estimation is determined using both the 5D BIM method (utilizing the Primus IFC software) and the proposed method, which was implemented through code developed using the IfcOpenShell library.

The IFC model is characterized by several entities visible in Figure 3.

Figure 3. IFC architectural model, entities and number of instances

In Italy, the cost estimation for public procurement varies by region. Each region uses a specific price list, which includes cost items that serve as the basis for economic bids in public contracts. Through the analysis of the IFC model and the use of the Price List of Regione Lombardia, it was possible to identify the cost items necessary for determining the cost estimation for the realization of the analyzed geometric model. The price list of Regione Lombardia was used because a research project is currently ongoing with this public administration.

The identification of the cost items subsequently allowed for the continuation of the methodology validation through the second phase, termed the "operational phase," eventually leading to the output phase.

5.1 5D BIM Method

This method enabled the determination of cost estimates using 5D BIM tools. Their usage is increasingly widespread because they allow for the reduction of time required to generate cost estimates through advanced querying and analysis tools of the BIM model. The work is based on four steps: (1) loading the IFC model and the Price List, (2) selecting the geometric objects and cost items, (3) defining the measurement rules for each cost item, and (4) extracting the cost estimate document.

The first step involves loading the IFC model and the price list into the Primus IFC program. Figure 4 shows the main screen of the Primus IFC program, where the toolbar, the IFC model object list, the graphical representation of the IFC model, and the price list section can be seen.

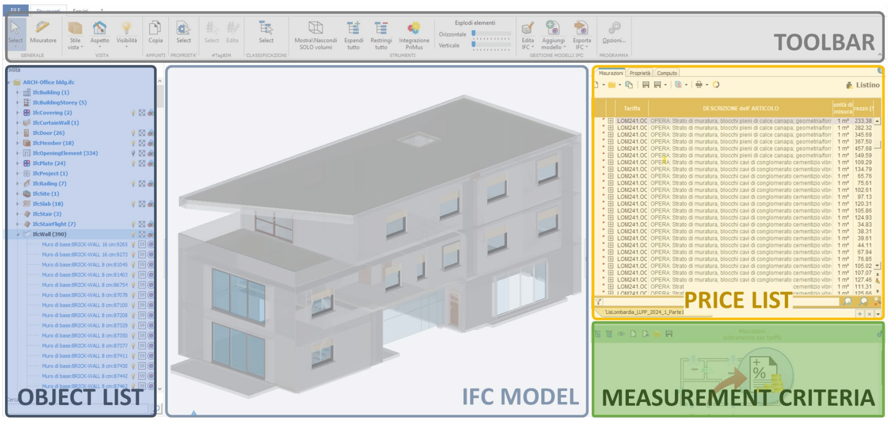

Figure 4. Main screen of the Primus IFC program

At this point, the process continues with the second step: selecting the geometric objects and the corresponding cost items from the "Price List". If the cost items are not present, it will be necessary to create new cost items.

In both cases, the selection is done manually. For geometric objects, it is possible to select a single entity or, from there, a set of entities with similar characteristics. Meanwhile, for cost items, manual selection or the use of a text search filter is possible.

Once the groups of objects and their corresponding cost items are defined, it is possible to proceed with the third step. This involves defining the measurement rules with which the fundamental quantities for cost estimation will be extracted.

In this phase, four different methods of defining quantities for cost estimation have emerged:

- Quantities correspond exactly to the physical quantities of the geometric objects (limited cases);
- Quantities do not correspond exactly to the physical quantities of the geometric objects but have to be obtained through specific rules (common cases). For example, concrete casting does not involve the use of the physical quantity "net volume" but rather the quantity increased by a wastage factor;
- Quantities do not directly correspond to the physical quantities of geometric objects and must be defined based on them through specific measurement rules (common cases). For example, the wet surface area of a masonry wall required for formwork installation does not directly correlate with a physical quantity in the IFC model objects but needs to be obtained through a formula like "base perimeter" * "height";
- Quantities are not present in the geometric model, thus making it impossible to define the quantities necessary for cost estimation within the 5D BIM software (limited cases).

At the end of this phase, it is possible to view the complete list of construction work with their respective quantities and unit prices. The system will then calculate the final amount.

Finally, the last phase involves exporting the cost estimation document. This document can be exported in PDF and Excel formats with the total cost estimation.

5.2 Proposed Method

The proposed method was implemented using the IFC4_ADD2_TC1 - 4.0.2.1 version, IfcOpenShell v0.7.0, and Python 3.10. The developed code can be divided into 4 phases (Figure 5): (1) importing the IFC model and its analysis to identify groups of entities according to ObjectType, (2) choosing the quantity to extract for cost estimation (Volume, Wet Area, etc.), (3) selecting cost entities and creating the relationship with geometric objects, (4) saving the new BIM model in IFC format and extracting the cost estimation views.

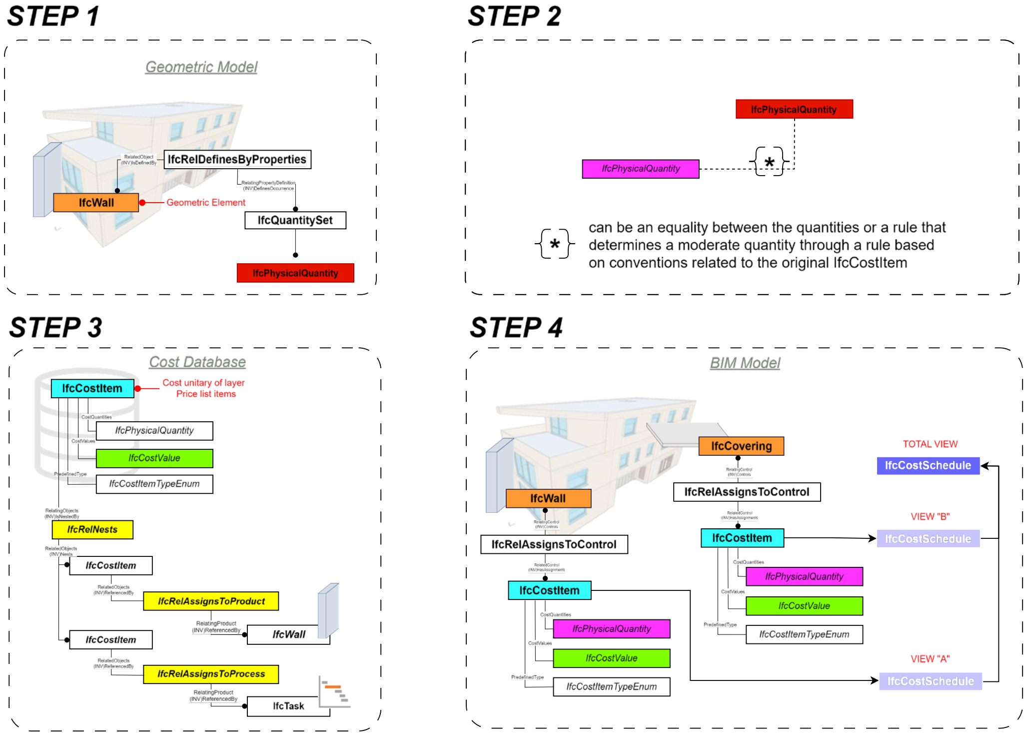

Figure 5. Step of Proposed Method

The first step involves opening and analyzing the IFC model. Specifically, the IFC version of the model is analyzed, and a list of all entities contained within it is created, categorized by class (*IfcWall*, *IfcWindow*, etc.) and subsequently by ObjectType. The number of instances contained within these groups is then indicated.

The second step involves analyzing each instance within the created groups to define the quantities necessary for cost estimation. The analysis performed by the code considers only the basic quantities (*IfcElementQuantity*) defined in the IFC standard.

However, the defined quantities do not always precisely correspond to those present in the analyzed instance (physical quantities), but they must be adjusted according to specific measurement rules for accurate cost estimation (such as adding wastage, quantities derived from specific formulas, etc.). These rules are not input by the user but are already defined within the type of quantity to be extracted. Therefore, the group of instances to be analyzed and the type of quantity for cost estimation (predefined list) are selected, resulting in the new adjusted quantity to be used in the subsequent step.

At this point, the third step involves querying an external database containing unit cost items (currently containing only items relevant to this cost estimation but can be expanded in the future). Querying the database allows for the selection of the cost item structured in IFC according to the new architecture defined by the research group (Cassandro et al., 2023) and relating it to the geometric instance. This is done through manual input, allowing the creation of a new *IfcCostItem* entity in the model. The new cost item includes attributes such as Name, Description, ObjectType, Identification, PredefinedType, and CostValues, which inherit information from the unit cost entity contained in the cost database. In the CostQuantities attribute, the list of quantities created in step (2) is stored. The code allows for iteration of operations within the same group of instances to further relate additional cost items or move on to subsequent groups.

Finally, step (4) involves aggregating the newly defined cost entities into cost schedules (*IfcCostSchedule*). These schedules can be partial, gathering all similar construction works (for example, all costs related to window installation), or total, defining the cost estimation for the entire project. At this point, it is possible to save the new BIM model in IFC format containing both geometric and cost information.

6 Discussion

This study, based on previous research and a larger project with Lombardy Region, compares the proposed method and 5D BIM method for cost estimation. The comparison highlights the need to introduce semi-automatic validation processes and reduced manual input to minimize errors, thereby improving cost estimation accuracy and reliability in the AEC sector. Table 1 shows the advantages and limitations of the two methods.

Table 1. A comparison between 5D BIM Method and Proposed Method

	5D BIM Method	Proposed Method
Advantages	Automated Quantity Extraction	Automatic Quantity Extraction
	Automatic Quantity Updates	Automatic Quantity Updates
	IFC Model Import and Reading	IFC Model Import and Reading
	Graphical Interface for Object Visualization and Selection	Structured Relationships between IFC Entities
	Multiple Object Selection	Data Consistency Validation
		Semi-Automatic Cost Entity Suggestions
		IFC Model Update
		IFC Model Querying and Data Analysis
		Exporting Multiple Cost Estimate Views
Limitations	Reliance on Unstructured Data	Use only Through Programming Language
	Lack of Validation	Lack of a Graphic Viewer
	Manual Cost Item Selection	Need to Validate the Input Model
	Need to Validate the Input Model	
	Limited Interoperability	
	Association via Alphanumeric Codes	
	Multiple Codes in Single Object Attribute	
	Human Error in Cost Item Selection	
	Manual Measurement Rule Entry	
	Manual Group Selection	
	Lack of Automatic Validation	
	Static Cost Estimate Documents (PDF-xls)	

While the 5D BIM method offers improvements such as error reduction, time savings, and automated quantity extraction, it relies on unstructured data for cost item selection and estimation. This increases the risk of human errors and prevents the validation of associations between cost items and geometric objects. An analysis of cost estimation using 5D BIM revealed errors in item selection, accounting for 10% of the total estimate (3 out of 30 items), primarily due to trivial selection and "drag and drop" errors within the application. Despite its advantages, the method still has a high risk of human error due to the necessary manual operations.

In contrast, the proposed method, based on structured entity relationships, enables advanced data analysis, validation, and cost estimation directly within the BIM model, ensuring greater interoperability across different domains and integrating cost information within the model. This method relates structured entities (cost items and geometric objects), facilitating data querying and validation procedures not possible with the 5D BIM method. This method also speeds up the estimation process and ensures its automated control and updating. Furthermore, the proposed method significantly enhances the efficiency of the estimation process by reducing execution times. Automating the filtering of cost items based on geometric data, and eliminating the need to extract quantities with external tools and define quantification rules, accelerates cost item selection and relation phases for cost estimation. This not only expedites the process but also improves its precision and reliability. However, the proposed method has limitations, including its reliance on programming for implementation and the lack of a user-friendly graphical interface.

7 Conclusion

In the AEC sector, cost estimation is a key aspect of construction project realization. Hence, the ability to establish an accurate cost estimate is of paramount importance.

The research compared the method for cost estimation using Primus IFC, one of the 5D BIM software solutions available on the market, with a method proposed by the research group developed using the IfcOpenShell library. This method is based on relationships between structured entities in openBIM format (IFC).

The comparison between the 5D BIM method and the proposed method for cost estimation underscores the need for advancements in the field of BIM to enhance accuracy and reliability in construction project cost estimation. While the 5D BIM method offers automation and intuitive visualization features, its reliance on unstructured data and manual processes poses challenges in validating cost-object associations and ensuring data consistency. On the other hand, the proposed method introduces structured relationships between IFC entities, enabling data validation and semi-automatic cost entity suggestions. However, its reliance on programming languages and the absence of a graphical viewer present accessibility and visualization limitations. Despite these challenges, both methods contribute valuable insights into cost estimation methodologies within the AEC sector.

For future work, which has already partially begun, it is necessary to validate this methodology across different and more extensive case studies, expanding the analysis and comparison of existing cost estimation methods and tools. Furthermore, validating the relationships established between geometric entities and cost entities will be essential.

Data availability

The data presented in this study are openly available on GitHub at https://github.com/Cassa97/IFC-ARC-cost-estimation.git under a Creative Commons Attribution 4.0 International License.

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