IFC-BASED COST ESTIMATION: APPLICATION TO A STRUCTURAL MODEL

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Abstract

Accurate cost estimation is an essential factor in the success of any construction project. Based on previous work, this study aims to use the IFC data model to support cost estimation processes and reduce human error. Through a code, developed in IfcOpenShell, a cost estimation has been made in IFC associating the new *IfcCostItems* with the IFC 3D model objects. The study was validated by applying the methodology to a real case of a structural model and defining a cost schedule for the structural project. Ultimately, this study seeks to support, verify, and improve public tenders quality of cost estimates.

Introduction

Accurate cost estimation is a crucial factor for any construction project's success. In the Architecture, Engineering, and Construction (AEC) industry, this task demands a high degree of accuracy and attention to detail. Without proper cost estimation, projects can easily exceed the budget, leading to delays, reduced profit margins, and ultimately project failure.

The construction process is characterized by its dynamic, complex, and time-consuming nature. Within the AEC industry, effective collaboration among all stakeholders is essential for sharing diverse information generated throughout the construction phase. This information includes quantities of physical building components, schedule plans, resource consumption, costs, site layout, safety management, and quality evaluation (Adeli et al., 2001). Cost estimation is a key task involving calculating quantities, and project costs, and classifying essential products within a construction project. Cost estimation is commonly defined as the process of predicting project costs at the operational level, based on detailed design drawings/documents and specific construction methods/specifications. Construction cost estimation is typically carried out separately by construction professionals due to the lack of a well-developed integrated system for both activities (Liu et al., 2014). Despite the existence of advanced technologies for quantitative take-off (QTO), scheduling, and costing, a significant gap remains in seamlessly integrating these activities into a cohesive system. The potential solution lies in a system founded on modeling technologies associated with scheduling and economic management, promising automatic and effective integration (Lu et al., 2016).

In the AEC industry, the standard format for information exchange is the Industry Foundation Classes (IFC), an open international standard developed by BuildingSMART.

Therefore, to support, verify, and improve the quality of cost estimates, in public tendering, and reduce human error-prone, this paper studies how to develop a cost estimation based on IFC.

IFC provides some entities to represent information in building management, including *IfcCostSchedule* (cost planning), *IfcCostItem* (unit cost estimation item), and *IfcCostValue* (value).

A cost estimation (*IfcCostSchedule*) for a structural project has been created including all cost classes (*IfcCostItem*) needed to define a correct estimate of costs. The *IfcCostItems* are linked to the 3D model's geometric objects to determine the quantity of individual works. They are also associated with unitary items in the public works price list (in this specific case of the Lombardy Region's Price List), to establish the unit cost values. The price list items are characterized by a new architecture based on IFC that contains a set of attributes in which information can be instantiated and created. This new architecture of cost items was validated in a previous study by the same research team (Cassandro, et al., 2023). Furthermore, the study carried out seeks to analyse, evaluate, and use the IFC data model to support the economic analysis processes of the projects.

The paper is structured as follows. Firstly, it presents an analysis of the existing literature on cost estimation, including the use of IFC classes, and the IFC standard with a specific focus on the *IfcCostItem* and *IfcCostSchedule* entities (attributes and relations). Currently, no BIM authoring software can write this entity, so it was decided to use the IfcOpenShell library to create the entity and the cost estimation through code. The final step included the validation of the data model generated through IFC viewer/reader, the analysis of the results, the limitations of the study, and future developments.

Literature Review

Cost Estimation Process in Construction

The process of cost estimation involves using available information to estimate the total cost of construction work activities of the project (Ji et al., 2019). Estimating the cost of the project plays a key role in the success of a construction project (Ji et al., 2019), (Jrade & Alkass, 2007). This involves assessing and predicting total costs over a specified period, incorporating all available project information and resources (A. Kwakye, 1994). Initial estimates, with an accuracy of -30% to +50%, are refined at the budget and conceptual level (-15% to +30%) and ultimately at the definitive level (-5% to +15%) (Rast & Peterson, 1999). Cost estimation serves the purpose of providing decision-making information (Carr, 1989).

However, despite the availability of advanced technologies, construction contractors still rely on conventional methods, leading to potential inaccuracies due to factors such as insufficient time and poor tender documentation (Famiyeh et al., 2017).

A cost estimation document contains all work items with a short description, estimated quantities, the unit cost of the repair work, the total cost of each item, and then summing all the items, the total project cost. However, other methods are also developed for estimating construction costs. These include expert systems, artificial neural networks, case-based reasoning, fuzzy logic systems, simulations, statistical regression approaches, decision trees, radial basis function neural networks, and particle swarm optimization (Tayefeh Hashemi et al., 2020).

Cost Estimation Process through IFC

Several studies have explored the applicability of IFC in project planning and cost estimation. Froese T et al. suggested that IFC can effectively represent information related to costs, construction processes, resources, products, and project documents (Froese T et al., 1999). Ma et al. established a BIM-based Construction Cost Estimating (CCE) software framework based on Chinese standards (Ma et al., 2010). Zhiliang et al. investigated the use of IFC standard for construction cost estimating in China, noting the need for extensions in the form of proxy elements and property sets (Zhiliang et al., 2011).

Additionally, Ma et al. discussed key issues for semi-automatic Tendering of Building Projects (TBP) cost estimation using IFC data (Ma et al., 2013). Liao et al. proposed a method to develop a collaborative construction prototype model on BIM software to enhance information-sharing efficiency (Liao et al., 2014). Xu et al. introduced a philosophic position for model-based cost estimation using IFC, emphasizing contextual information and pricing extension (Xu et al., 2013). Xu et al. innovatively used BIM data linked to a project to create items for a bill of quantity for cost estimation (Xu et al., 2016).

Other researchers, including Wu et al., Sacks et al., and Elghaish et al. explored the potential of BIM to enhance cost estimation (Wu et al., 2014), (Sacks et al., 2018), (Elghaish et al., 2020). Staub-French et al. and Lee et al. investigated the use of semantic web technology in BIM-based cost estimation (Staub-French et al., 2003), (Lee et al., 2013) Fürstenberg, et al. delved into how semantic web technology can support automated cost estimation linked to IFC property sets (Fürstenberg et al., 2021).

In the context of cost estimation, current practices often involve connecting codes in digital objects to matching keys with various price items. This process requires different codes for each element generating distinct articles (Pavan et al., 2017).

IFC & Construction Management

Developed by BuildingSMART, the IFC is an open and interoperable standard with a mission to facilitate interoperability across different domains in civil engineering projects. Its objective is to enable the sharing and exchange of project information among various computer applications used by different project participants. Initially released in 1997, the official version, IFC4 ADD2 TC1, became an ISO standard in 2018 (ISO 16739-1:2018). At the beginning of 2024, the new IFC version 4.3 ADD2 - 4.3.2.0 was finally approved by ISO and was published in April 2024 becoming the basis for IFC software certification.

Structured in EXPRESS data specification language or XML, the IFC standard describes actors, processes, controls, resources, and products within the construction domain. The IFC data model is organized hierarchically into four conceptual layers: Resource layer, Core layer, Interoperability layer, and Domain layer. Entities within this model can be related to each other and characterized by a set of attributes, facilitated by the *IfcRelationship* entity. This allows related information to reside either inside or outside the project data.

The IFC standard plays a crucial role in information exchange throughout the project lifecycle in construction or building management projects, serving as a prominent vendor-neutral data schema in the AEC industry. IFC enables the exchange of both geometric and semantic information among different stakeholders and software (Fürstenberg et al., 2021).

In the field of construction management, IFC provides entities like *IfcWorkPlan* (schedule planning), *IfcTask* (construction tasks), *IfcScheduleTimeControl* (task time information), *IfcCostSchedule* (cost planning), *IfcCostItem* (unit items of cost estimation), and *IfcResource* (construction resources such as material, product, labor, and equipment resources).

Methodology

This research aims to define a new method for cost estimation using IFC. The method is based on the use of entities within the IFC standard and the relationships that these can create to develop a cost estimate. Specifically, the method used provides for:

- Definition and structuring of the new architectures of the unit cost of the construction works, contained in the Price List of the Lombardy Region, based on what was validated in a previous study by the same research team (Cassandro, et al., 2023);

- Identification of a case study relating to a structural model in IFC format;
- Development of a code for the implementation of the new cost estimate based on the relationship between IFC classes;
- Identification of the measurement criteria of the unit cost items useful for the correct quantification of the cost items (no manual entry of the quantification rules already defined in the price list).

This methodology will also allow the validation of the IFC model obtained to assess the percentage of correctness in the association of identified cost items and estimated costs. This has already been tested and validated in a previous work of the same research group (Cassandro, et al., 2023). Figure 1 shows the workflow performed in this research.

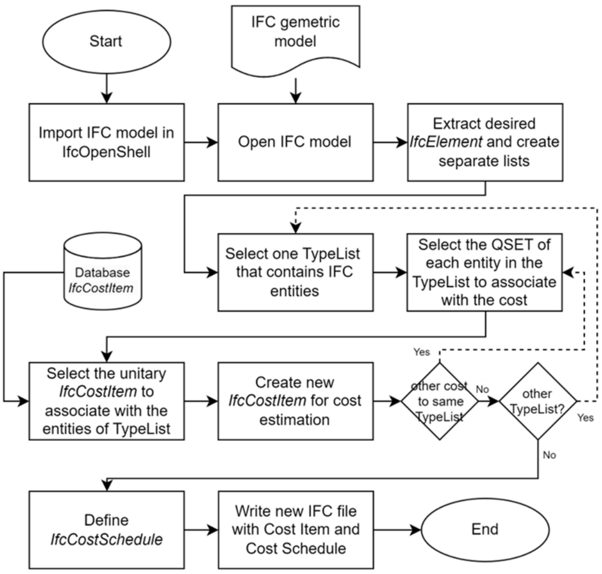

Figure 1: workflow performed in the study

Key Concept

Cost Estimation

According to Samphaongoen, cost estimating is essential for budgeting and tendering in any construction project (Samphaongoen, 2010). It reflects the inherent risks, and direct costs of a project (Olatunji et al., 2010).

The unitary cost of construction works is the sum of the unit costs of resources (materials, labor and equipment), overheads and profits. This sum is calculated through the logic of price analysis and the amount of resources used in the price analysis differs for each construction work. The cost estimate is obtained by multiplying the unitary cost of construction work with corresponding product quantities. The sum of the costs for each construction work provides the total amount of the cost estimate, as shown in equation (1):

$$Cost_i = \sum_{j=1}^{n} (R_j \times Q_j) \qquad (1)$$

Where i denotes the category of construction work, j represents the index of the cost item, n is the number of cost items, R is the unit price of resources from the Price List, and Q represents the quantity for each construction work.

Cost estimation helps stakeholders determine project resources and enables better cost and technology analysis from the start of the design process. Furthermore, it is possible to simplify later phases such as construction and operation by clearly defining cost management (Bryde et al., 2013). So, anticipating economic management during the design phase provides significant advantages for project management (Plebankiewicz et al., 2015).

Generally, the cost estimate can be divided into two distinct phases. These are the physical quantities of design components (volume of concrete columns), that have substantial impacts on the outcome of the cost estimation (Monteiro & Poças Martins, 2013), and the process quantities that are related to specific construction processes (labor hours for concrete casting) (Marzouk et al., 2018). The cost estimation cannot be separated from the extraction of quantities (Aram et al., 2014), (Khosakitchalert et al., 2019). Literature shows that the most used process is to connect the code inserted in the digital objects as matching keys with various price items (Pavan et al., 2017).

The comparison between the traditional estimating process and the 3D BIM-based estimating process is visible in Figure 2 (Sacks et al., 2018).

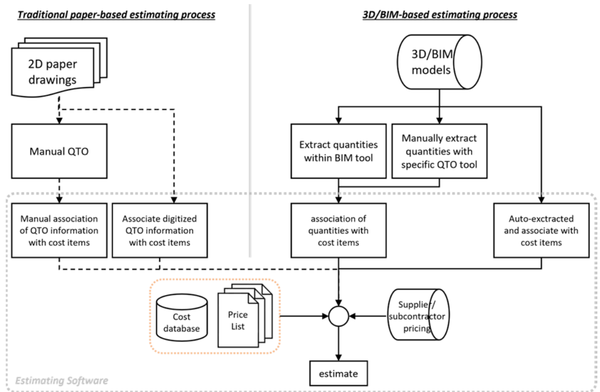

Figure 2: Conceptual diagram of an estimating process

BIM technology has had a revolutionary impact on the conventional QTO process (Smith, 2016). The use of BIM methodology automates and improves QTO processes compared to conventional 2D drawings, resulting in reduced time and errors (Smith, 2016), (Sacks et al., 2018). Nowadays some leading software in the field are Navisworks, CostX, Innovaya, iTWO, Vico, and so on (Abanda et al., 2017).

However, the accuracy of the output quantities from BIM is another major concern (Smith, 2014). The limitations of BIM data hinder a smooth QTO. The material quantities calculated from BIM authoring software rely heavily on the geometry of 3D objects and sometimes may not be sufficient for QTO (Azhar, 2011).

IfcCostSchedule and IfcCostItem

An *IfcCostSchedule* is used to consolidate instances of *IfcCostItem*, for explicit identification of cost information, for example in cost estimation of construction projects.
A Cost Schedule, like all entities in the standard, is also described through a set of attributes (Name, Description, PredefinedType, Status, etc.).
IfcCostItem is the entity that represents the cost of activities and services, the execution of works through a process, life cycle costs, cost estimates, budgets, and other financial aspects within the IFC standard. It functions as a non-geometric entity and is a subclass of *IfcControl*. The *IfcCostItem* abstract entity describes a financial cost or value, including contextual information, in a format that allows its use within a cost schedule.
IfcCostItem is also described through a set of attributes (Name, Description, CostValues, CostQuantities, etc.).
An *IfcCostItem* can link one or many *IfcCostValue's* representing a unit cost, total cost, or a unit cost with one or many quantities used to generate the total cost.

Case Study

The research, to validate the proposed methodology, focused on the implementation of a cost estimate based on the new IFC cost items and an IFC model of a structural project. This model contains 82 objects: 7 *IfcSlab*, 45 *IfcColumn*, 27 *IfcWall,* and 3 *IfcBeam* (Figure 3).

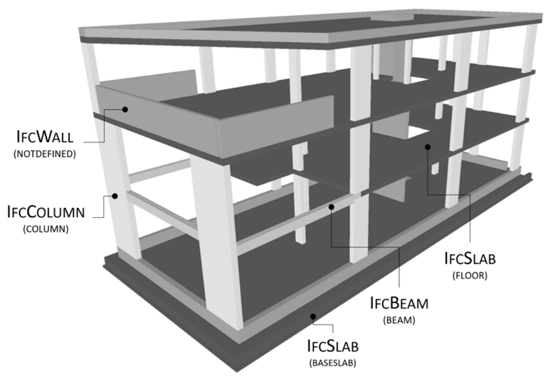

Figure 3: IFC model and the different entities contained

The developed method was implemented using the IFC4_ADD2_TC1 - 4.0.2.1, IfcOpenShell v0.7.0 and Python 3.10.
As a first step, the geometric model was interrogated to identify the IFC classes. The lists of geometric objects based on IFC classes have been identified (*IfcWall*, *IfcSlab*, *IfcColumn*, *IfcBeam*). Subsequently, these were divided into additional sub-lists according to the PredefinedType attribute in the model (for example, all *IfcSlab* were divided into BASESLAB and FLOOR). After that, each sub-list was divided into additional sub-lists according to the Object Type of entities. Finally, a query of these Object Type lists was performed to analyse the entities, verifying the LOADBEARING attribute; this allowed to verify if all objects were characterized by structural properties (LOADBEARING: True) or by non-structural properties (LOADBEARING: False). This analysis was conducted by questioning the "general" PropertySet (Pset) related to each entity, useful for a first verification of the structural model. In Figure 4 an example regarding an IfcSlab.BASESLAB (GUID 1VMFjRH1zBGg8s6Mq2oKI5) with Pset_SlabCommon and property "LOADBEARING: True”.

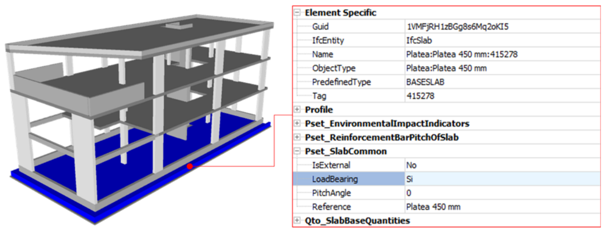

Figure 4: Example of a structural IfcSlab.BASESLAB entity

At this point, the structural objects identified previously were analyzed and through the interrogation of the individual entities, it was possible to extract the relative quantities (*IfcElementQuantity*). However as highlighted in the literature review chapter, quantification is one of the fundamental processes and cannot be based solely on the quantities contained in the 3D model. Therefore, different measurement rules are needed depending on the type of processing that needs to be economically quantified. For this reason, the code developed contains the measurement rules for the correct quantification of cost items according to the type of processing not modifiable by the user (the volume of the concrete casting, the wet surface for laying the formwork, or the weight of the steel for laying the reinforcement bars); in the specific case, these rules are in accord with how much defined in the list prices of the Lombardy Region.
At this point, the analysis performed by the code provides the first of the two manual inputs that the users have to perform. This input is the choice of the construction work (concrete casting, laying the formwork, laying the reinforcement bars, etc.) for which it is necessary to extract the quantity from the IFC model. The user does not need to define measurement rules or perform calculations as the code will perform these operations automatically based on the chosen construction work.
The formulas used by the code, in this case study, to calculate the final quantities contained in the IFC model are summarized in Table 1. These follow the rules defined in the price list of the Lombardy Region for the correct quantification of cost items.
After that, once the quantities were defined (Volume, Wet Area, Weight), the price list was queried. However, this is not a standard price list but a new cost database with cost entities based on IFC. Each of these cost items is characterized by an architecture defined and validated in another study carried out by the research group (Cassandro, Donatiello, et al., 2023). Once questioned, it is possible to identify the unit cost item (*IfcCostItem*) from which to extract the cost value (*IfcCostValue*) useful for the cost estimation and to associate with the geometric object.

Then after the selection of the unit cost item (the second and last manual input), a new cost item (*IfcCostItem*) is automatically created within the new IFC model that updates the previous geometric model and relates to the geometric object. It was possible to define "n" relationships based on how many cost items are necessary for the cost estimation of the specific workings. This new cost item contains the quantity (*IfcPhysicalQuantity*) defined previously according to the rules of measurement of the machining automatically applied by the code from the quantities extracted from the geometric objects and the unit cost value (*IfcCostValue*) extracted from the unitary cost items in the cost database (Figure 7).
Finally, the last step involves the creation of the *IfcCostSchedule* (cost sheet) in which all the cost items previously created have been collected. It will be possible to define an "intermediate" *IfcCostSchedule* to obtain the cost sheet of each set of similar construction work even if related to different objects (for example all C20/25 concrete castings for foundations, beams, slabs, and masonry) and then the final *IfcCostSchedule* corresponding to the entire cost estimate.
This will then be linked to the *IfcProject* and will allow to define the total cost estimate for the structural model.
In the end, a new IFC model was obtained which contains the *IfcCostItem* and *IfcCostSchedule* entities with the cost value and the cost quantity of the construction works for the definition of cost estimation. This new IFC file was validated through the FZK Viewer (Figure 5 and Figure 6).

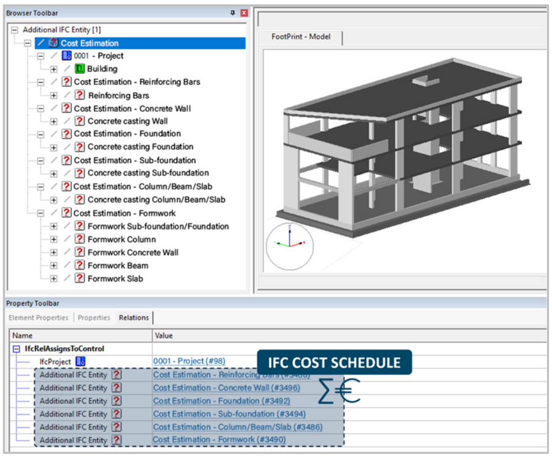

Figure 5: IFC Validation of the cost schedule on FZK Viewer

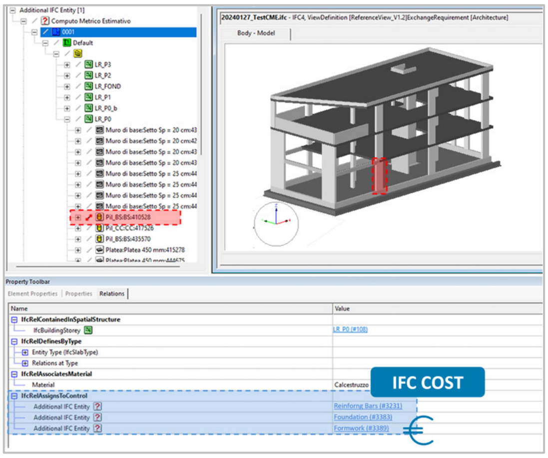

Figure 6: IFC Validation of the cost item on FZK Viewer

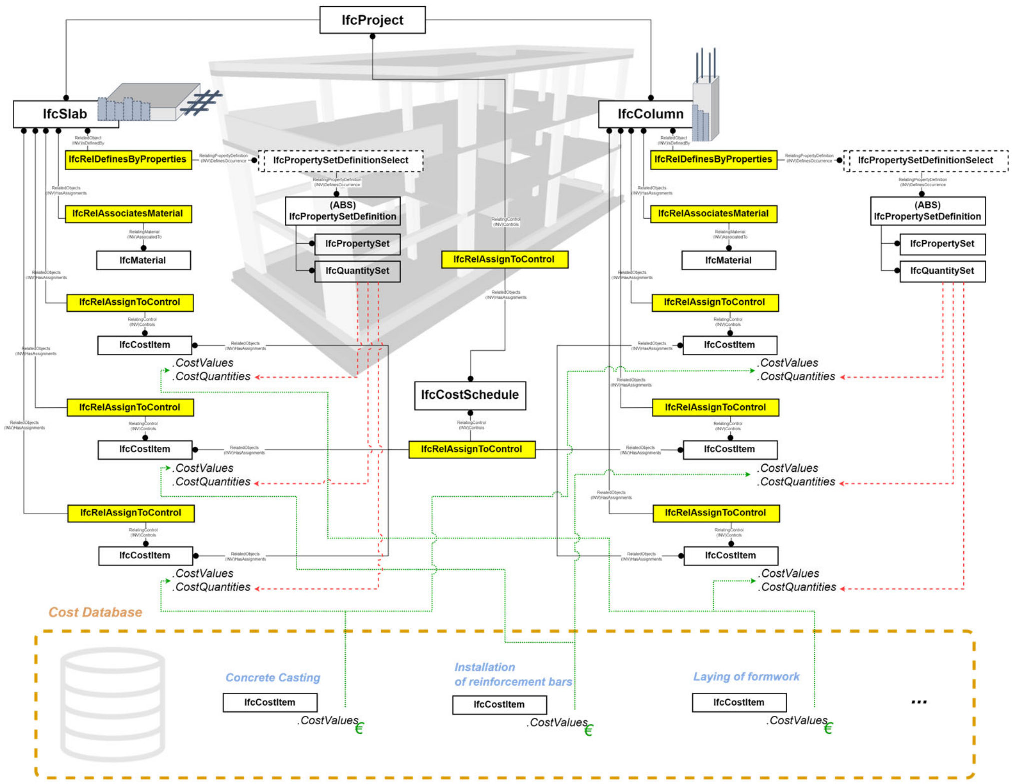

Figure 7: Example of relationships between IFC entities for estimating the costs in IFC of a slab and column

Table 1: Formulas used in the cost estimation process

Working		*Quantity*	*Formula*
Formwork	Slab (foundation)	Wet area[1] [m^2]	Perimeter * Thickness
	Column	Wet area[1] [m^2]	Perimeter * Height
	Wall	Wet area[1] [m^2]	(2*(Length + Width)) * Height
	Slab (floor)	Wet area[1] [m^2]	(Perimeter * Thickness) + (Length * Width)
Reinforcement	General	Reinforcement per cubic metre[2] [kg]	Reinforcement at m^3 * Volume
Casting	Concrete	Concrete casting [m^3]	Volume*1,1

[1] The area is the area of the single face (the height for the length of the septum).
[2] The values used for reinforcement mass per volume unit for each structural element are (Table 2):

Table 2: Theoretical values used for reinforcement mass

Element	*Reinforcement mass per unit volume*
Wall/Floor	200 *kg/m*^{3}
Column/Beam	250 *kg/m*^{3}
Foundation	100 *kg/m*^{3}

Discussion

The research group conducted a study based on the results of ongoing work on a project with the Lombardy Region. The study demonstrates the feasibility of estimating costs based on IFC classes, by relating new cost items structured according to the IFC data model and their geometric objects. The study also validates the use of openBIM methods for cost estimation. This has been made possible through the implementation in IfcOpenShell of the relationship between the new cost items (*IfcCostItem)* with geometric objects (*IfcElement)*, and the creation of the cost schedule (*IfcCostSchedule)* for the identification of the final cost estimate of the entire project (*IfcProject)*.
The methodological and scientific research conducted has led to technological advancements using IfcOpenShell, achieving efficient and scalable outcomes. The proposed methodology can also be applied to estimate the costs of different projects. Currently, these results can be obtained through code, as existing tools do not support user-friendly implementations.
The studied approach, which is based on entity relationships, is effective and flexible compared to the standard approach that uses cost allocation and cost estimation through Excel spreadsheets and associating costs as simple attributes. A reliable and interoperable cost management information base is essential. This process aims to implement and encourage greater data interoperability, not only within the 3D dimension but also extending to the dimension of costs (5D BIM).
The power of the proposed methodology will ensure the possibility of developing cost estimates through procedures that allow the selection in a semi-automatic way of new cost items characterized by a standardized architecture. In addition, it is possible to query this information, verify the correctness of the associations, and relate the cost items to the object automatically. It is no longer necessary to define an attribute for each geometric entity in the geometric model to include cost information.
The cost item will be defined as a single entity related to a specific number of geometric entities within the IFC model by updating it (Figure 6). This avoids duplication of information and ensures respect for the area of knowledge of the different domains.
Furthermore, the *IfcCostItems* are grouped in the *IfcCostSchedule* to create a cost estimate. It is possible to generate different "cost views" by creating multiple cost schedules (Figure 5). This allows the extraction of complete or partial cost estimates from the same model based on specific requirements.
In addition, some problems were identified at the start of the procedure after analyzing and examining the geometric model:

- not all IFC entities had the correct structural property, despite being part of the structural model (LOADBEARING = True);
- some quantities are not stored within the *IfcElementQuantity* entity (volume, perimeter, etc.). This can lead to difficulties in creating standardized automated rules and allocating quantities to cost items. Only standard and hardcoded IFC schema data are evaluated in the research and not proprietary data that may differ between projects.

Therefore, it can be deduced that the issues with cost estimation are not only due to an incorrect cost item selection or association but also due to inaccurate information in the geometric model.

Conclusion

The cost estimation process discussed in this study is based on the IFC standard. It establishes logical connections between products, resources, cost items, and property sets in the IFC data model ensuring greater interoperability of data within the AEC sector through openBIM languages. The possibility of using cost classes (*IfcCostItem* and *IfcCostSchedule*) as independent entities, that are characterized by granular architecture and logical relationships between entities, ensures the possibility of querying, verifying, and validating this relationship to reduce cost estimation errors. It also allows for automatic cost estimation updates by modifying the IFC file of input and identifying changes to cost items or objects without associated cost entities, tracking changes and additions to the project.

During the study, limits were found in the implementation of a standardized methodology for costs. The first is the market barrier with the lack of a user-friendly tool for creating relationships, currently possible through code. A second limitation is the need to have correct information for the realization of a correct estimate of costs; not always the geometric model contains all the information useful for the realization of an estimate of costs, for example, the lack of certain dimensions that do not allow the extraction of certain quantities or the absence of fundamental parameters for the choice of cost items to be reported.

However, this approach must allow for exceptions, as it will not be possible to make all possible cases of cost estimation.

As future work, and already in progress, there is a need to prototype what is studied on a larger scale and with different and more complex geometric patterns, demonstrating how a set of typical costing strategies and economic quantification of projects can easily be implemented in the proposed approach. Develop a user-friendly application with an intuitive interface for a better definition and visualization of this data. Verify the correctness of all the cost items linked to the geometric element. Automate the choice of cost item to reduce the manual input (second manual input in this method).

Data availability

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

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