CONSISTENCY VERIFICATION BETWEEN COST AND GEOMETRIC INFORMATION BASED ON IFC: APPLICATION ON STRUCTURAL ELEMENTS

Jacopo Cassandro & Claudio Mirarchi & Alberto Pavan
Polytechnic of Milan, Italy

Maria Grazia Donatiello & Carlo Zanchetta
University of Padua, Italy

ABSTRACT: *Cost estimation for tendering is one of the leading causes of legal disputes in the architecture, engineering, construction, and facilities management (AEC/FM) industry.*

The lack of a standardised support procedure to verify the association of cost data with the objects model causes waste of time and inaccuracy in the cost estimation.

This research work, starting from a previous study where the research group integrated a cost domain in the IFC data schema, investigated the possible applications of this IFC based cost domain integrated with an IFC geometrical information model. The current paper investigates a specific case study focused on a structural model to verify current and future applications.

Furthermore, rules for BIM information requirements will be defined through the Information Delivery Specification (IDS) to ensure an easy way for humans and computers to understand it. This will allow to specify which data must be present in the geometric model to subsequently ensure validation and verification of uniqueness of the cost data associated with geometric data.

The results show the possibility to define a structured cost items in IFC associated through relationships to other entities and then verify their association to geometric data to guarantee its consistency and uniqueness.

KEYWORDS: *IFC, cost ontology, BIM, cost item, Information Delivery Specification (IDS)*

1. INTRODUCTION

Cost estimation is one of the most critical tasks and still unresolved problem in the architecture, engineering, construction, and facilities management (AEC/FM) industry.

To be able to obtain a cost estimate for a building, it is generally necessary to classify all objects in the building project using articles and to record their quantities. Although this is an objective process, human errors can often be encountered relating to both the incorrect association of prices and the incorrect calculation of quantities. One of the problems facing the AEC industry today is precisely the lack of a standardised support procedure to verify the association of cost data (Adeli et al., 2001; Lu et al., 2016). With the advent of BIM, computing tools have changed and evolved digitally. Wu et al., (2014), Sacks et al., (2018), Elghaish et al., (2020), and Olatunji et al., (2021) reported on the possibilities of BIM to improve and support cost estimation, but the approach to computing has remained the same. So, the problem remains; in fact, while previously the costs were associated with measurements, they are now associated with model objects but there is no certainty that this association is correct and consistent.

Currently the computation software receives the information from a model exported in an open format, Industry Foundation Classes (IFC) and retains the cost listing within it. With this study, the aim is to compensate for the lack of standardisation in cost validation by creating an IFC-based cost semantics, thus identifying a common language between model objects and costs.

The IFC is standardized according to ISO 16739-1. This could provide a solid basis for the exchange of information resources between information systems (Froese T et al., 1999). The IFC standard published by Buildingsmart International plays a very important role in the process of exchanging BIM data between the various participants in a building construction or management project, as it is an open specification. IFC provides some entities to represent information in building management, including *IfcConstructionManagementResource* (building resource) *IfcWorkPlan* (planning), *IfcTask* (task), *IfcScheduleuleTimeControl* (task time information),

IfcCostSchedule (cost planning), *IfcCostItem* (unit cost estimation item) and *IfcCostValue* (value).

This research work, starting from a previous study in which the research team integrated a cost domain into the IFC data model (Cassandro et al., 2023), investigates the possible development of a standardised support procedure to verify the uniqueness and correctness of the association between the new cost items and their written information within the IFC standard and the geometric objects contained in a specific case study, a structural model.

Currently, in Italy, the cost items are contained in the list of public works (in the specific case of the Price List of the Lombardy Region) a document based on unstructured data and characterized by a natural language.

Starting from a work previously developed by the research team (Cassandro et al., 2023), it was possible to initially create an IDS file for the definition of the requirements that must be present in the geometric model. This is fundamental to guarantee both the correct association of the entities of cost but also the analysis and the interrogation of the data in the successive phases of verification. Subsequently it is possible to verify the association between the cost items and the geometric objects to ensure the uniqueness and correctness of the cost-object relationships created.

Specifically, this would allow to:

- check the correct price association;
- ensure validation, uniqueness and comparison between attributes of a certain cost class and the attributes of the object to which it is associated;
- consider cost elements as standardizable and query-able computer classes.

The example of a structural model has been taken and a structure of relations between costs and geometry has been created to allow the verification of the uniqueness of associated data and validate the code developed.

The paper is structured as follows. First an analysis of the existing literature on cost estimation via IFC classes, current methods of checking compliance and the Information Delivery Specification standard (IDS) is presented. Currently there are not BIM authoring software that can write the *IfcCostItem* entity and as a result you cannot check this information; so, it was decided to rely on the IfcOpenShell library to initially create the cost items and then verify the association and accuracy of the data of the entity through the code developed for this research.

2. THEORETICAL BACKGROUND

Within the BIM process, one of the most relevant parts is undoubtedly the validation of the model and the information it contains for a proper exchange of data. There may currently be different types of project's validation, or model checking, and they may be the following:

- verification against geometry (clash detection);
- verification against design settings (e.g. the specifications within the BEP, BIM validation);
- checks against regulations (code checking)

The purpose of these checks is to ensure that all data entered within the model is correct from a geometric and informative point of view, and that it meets all standards.

Currently, this check is a process that, while being facilitated using software and tools, still remains time-consuming, expensive and prone to errors (Dimyadi & Amor, 2013). The main problem of model checking always concerns the validation process (Ghannad et al., 2019).

2.1 Model Checking

Model checking is a key element in information modeling and management (Ciribini et al., 2015). In standard design processes, according to studies, only 5-10% of the information content of the project is systematically checked (Trebbi et al., 2020).

Clash detection means the verification of geometric interference; this could become a problem during the construction of the work which is not checked in advance within the 3D model (Akponeware & Adamu, 2017). These are divided into two types; the "hard clash" referred to two objects that collide and occupy the same physical space, and the "soft clash" referred to objects that do not collide but are too close.

Code checking is the verification of the compliance of the digital model with the corresponding regulation (Trebbi et al., 2020). The use of specific software that supports these controls can reduce time and error, thereby improving several aspects of building design, including efficiency and model quality (Greenwood et al., 2010).

It is essential to verify the compliance of the models with regulatory and technical requirements, and therefore an automatic control of the frequency and uniqueness of the information would have a significant value within the AEC industry (Solihin & Eastman, 2015). Furthermore, it may be necessary to verify compliance with the requirements of "Employer Information Requirements" (E.I.R.) or of "BIM Execution Plan" (B.E.P.) (PAS 1192-2:2013).

The first study on automated code compliance checking is the Singapore project CORENET (Construction and Real Estate Network) an initiative based on the complete integration of the life cycle phases. Similarly, in the USA SMARTCodes was born and Autodesk Revit provided some plug-ins such as UpCodesAI which supports some parts of the International Building Code but also some parts of other standards from other jurisdictions, in Australia DesignCheck.

2.2   Existing Applications

Model checking is normally done by use of standalone applications as Solibri Model Checker, SMARTcodes, ePlanCheck, AEC3 Compliance or EDM Model Server (Ismail et al., 2023). An often used example of model checking is clash detection to validate if for example different types of pipes intersect each other. Another example can be to check if the width of the doors is according to codes of accessibility in the regulations or national standards. The most used for model data verification are Solibri Model Checker and Naviswork.

Solibri Model Checker (SMC) is a prominent BIM software application which assist designers in visualizing any issues or problems regarding the design model before and during construction. It is one of the few software packages that leaves the end user with a minimum of scope for action. The rules set in SMC are set for the Norwegian State Administrative Agency handbook but can be modified by the end user by changing the rule set or deleting some. The creation of new rules is possible but has limitations. To be able to create new rules, it is necessary to act on the API, which is not public.

Naviswork, is one of the most widely used tools on clash detection and coordination of models from different disciplines. The software detects intersections or conflicts between elements in the 3D model, helping to identify and resolve construction or design issues promptly, reducing errors and costs during project execution.

3.   PROBLEM STATEMENT

As can be seen from the literature analysis above, typically the verification is done within the geometric model considering only one domain (that of the model itself). Instead, the goal of the research is to validate data between a plurality of domains linked together (in this case the geometric domain and the cost domain) and that can be contained in the same model. The architectures of cost items cannot be considered exclusively as strings of text in natural language because they are not machines readable. For this reason, to verify and validate the consistency and uniqueness of the data, it is necessary to structure according to a semantic defined cost items in more complex architectures thus creating a cost domain. This should ensure that the consistency of associated data between cost and geometry can be verified.

Starting from this statement, the research focuses on the key aspect of:

-    How to define a procedure for checking and verifying data between geometric and cost domains.

4.   RESEARCH AIM & METHODOLOGY

This research investigates the development of a standardized support procedure to verify the correspondence between the cost items and the data they contain with the objects contained in the information models.

The cost data in this research are stored in a new cost database based on architectures developed in openBIM format and structured according to the IFC data model (Cassandro et al., 2023); currently, in Italy and in the specific case of the list of public works of the Lombardy Region, cost items are present in unstructured format within textual documents in natural language. This causes problems and possible errors both in the association and in the verification of the associated costs. In fact, currently one of the most challenging issues for building design

compliance checking is the translation of human-readable rules/documents into a computer processable code to allow the understanding also by computer tools.

For this work a specific case study focused on a structural model containing cost items, structured and in IFC format, already associated with their geometric objects, is analazyed to verify the current and future applications of this methodology.

Furthermore, rules for BIM information requirements are defined through the Information Delivery Specification (IDS) to ensure an easy way for humans and computers to understand it. This allows you to define which data must be present in the geometric model to ensure first a correct cost association and later validation and verification of the uniqueness of the cost data associated with geometric data.

First, it is described the state of the art of current practices and research related to compliance checking. The idea is to standardize cost element data as a structured class in the IFC data model. This in fact contains a set of attributes that allow cost data to be stored, as is already the case for model objects.

A simple unit cost database has been created (the new digitised price list) based on IFC files relating to cost items of structural works (concrete casting, reinforcement laying, formwork laying, etc.). These files can be called in any geometric model for the definition of the cost to associate to the objects of the model.

The next step is characterized by the definition of the requirements that must be present in the geometric model for a better and correct association between IFC entities, *IfcCostItem* and *IfcElement*.

It is defined the Information Delivery Specification (IDS) that will be delivered to the modeler and after that a code is developed that will allow to verify if the association of the cost is coherent or not with the object identified.

The entity will allow to translate the current cost items, in natural language, in a defined and standardized data structure (definition of the framework and the semantics of the costs through the entity *IfcCostItem*).

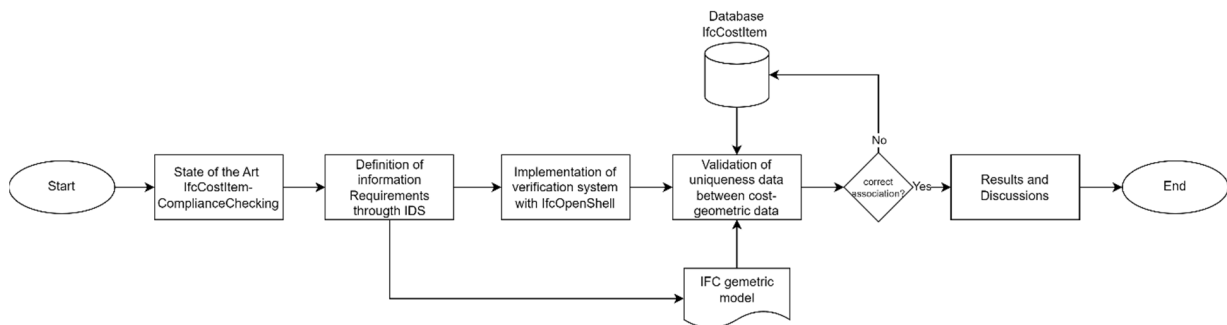The methodology adopted is characterized by the steps presented in Figure 1.

Fig. 1: Research Methodology

5. KEY CONCEPT

The IFC, an open and interoperable standard, aims to "allow interoperability between industrial processes of all different professional sectors in civil engineering projects by allowing IT applications used by all project participants to share and exchange information about the project" (BuildingSMART, 2023). It is an open international standard, standardized according to ISO 16739-1:2018; it is designed to be a vendor-independent data model and usable in a wide range of hardware devices, software platforms and interfaces for many different use cases.

5.1 IfcCostItem

IfcCostItem is a non-geometric entity, subclass of *IfcControl*, within IFC. *IfcCostItem* describes a cost or financial value with descriptive information that describes its context (BuildingSMART, 2022). It represents the cost of assets and services, the execution of works by a process, lifecycle cost, cost estimates, budgets, and more.

IfcCostItem is also described through a set of attributes. Some of them are inherited instead the attributes PredefinedType, CostQuantites and CostValue are those owners of the class. 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. The quantities can be given as individual quantities, or those quantities are provided as element quantities by one or many building elements. Another key aspect is that *IfcCostItem* can activate some different relationship. Among these it can be nested to create cost assemblies through the relation *IfcRelNests*, it can be assigned to a *IfcProduct* through the relation *IfcRelAssignsToControl* but may also have a product associated through the relation *IfcRelAssignsToProduct* or a resource through the relation *IfcRelAssignsToResource*.

5.2   Information Delivery Specification

The Information Delivery Specification (IDS) is a standard defined by BuildingSMART to define the required level of information in the specific project (BuildingSMART, 2023). IDS defines the information requirements that a geometric model must contain for the correct exchange of data in a way that is easily readable by humans and interpretable by the machine. It defines how to deliver and exchange objects, property, even values and units of measurement. An IDS file may contain several requirements independent of each other and without reference to other requirements in the file. This allows you to create replicable blocks and use them in different files.

Currently the information requirements are shared through excel sheets or PDFs; these are not directly interpretable by a machine and difficult to read by people given the large amount of data.

The IDS focuses on 'information delivery specifications' defining what information is needed and how it should be structured. This should improve automated workflows by receiving information that can be processed automatically. The definition of an IDS also serves to standardize all the different approaches that there may be in modelling. An example of different approaches may be the use of slabs instead of landings.

6.   EXPERIMENTATION & RESULTS

In this article, part of a larger research work carried out by this research group, the uniqueness and correctness of the association of cost items with geometric objects has been analysed and validated. This has been achieved by defining a standardized data structure translated within the IFC standard, as cost data is in natural language (unstructured data). This allows you to define a database of cost data within the IFC standard through the classes currently present (*IfcCostItem*, *IfcCostValue*, etc.) and the relationships that these can activate.

The current paper investigates a specific case study focused on a structural model.

Not being the objective of the article and having been analysed in (Cassandro et al., 2023), it will not be explained as it has been defined the structure and the relations of the single item of cost inside the standard IFC and as this is related to the geometric entity. Figure 2 shows a simplified example of the possible architecture behind the cost item related to the concrete casting for a foundation; this item like all the others will be stored in the new database of cost items.
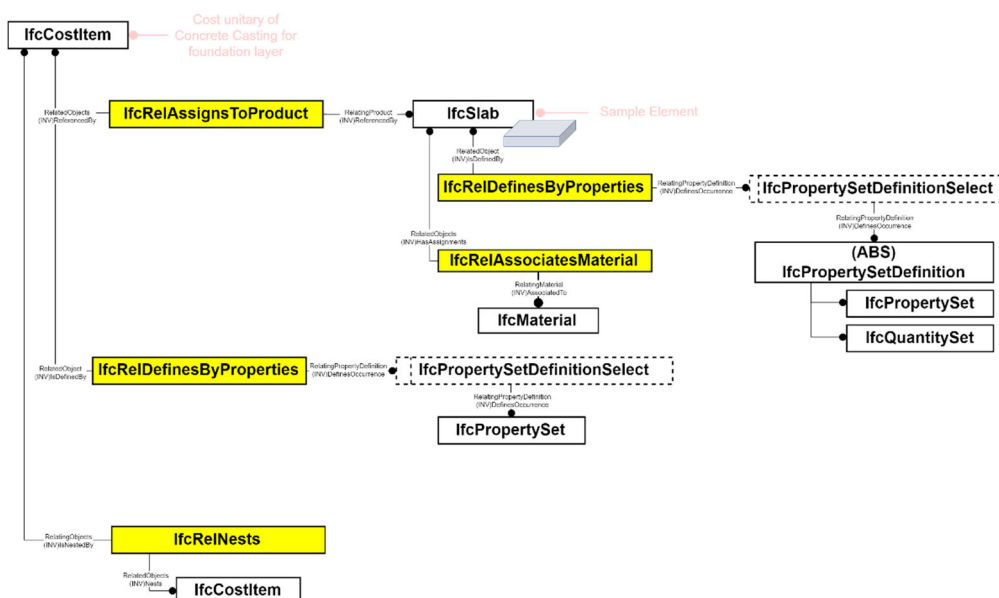

Fig. 2: Simplified example of architecture behind the cost item related to the concrete casting for a foundation.

All data used and related to cost items come from the price list of the Lombardy Region. In Italy the estimation of the prices in public tendering takes place using a price list. Each region has a catalogue containing price items, called price list, which is the basis of the economic offer and regulates payments in public contracts.

6.1 Model Requirements

Starting from a detailed analysis of the cost items, the minimum requirements (Level Of Information Need) that the geometric model must contain to ensure the subsequent association, verification and validation of data between geometric objects and cost items have been identified. It was possible to define the basic requirements to be delivered to the modeler on the basis of a work of analysis and breakdown of the current cost items for the identification of a new standardized architecture in which to insert and structure the current cost items.

The information that a single geometric entity must have in the model (called Facet in the standard IDS) have been defined. In the first part of the facet (applicability section), it was defined to which type of objects the specification applies and then it was defined the requirements (requirements section) that is required for the objects specified in the first part, such as required properties or classifications. Each specification has metadata (name, description, or instructions) to help describe the goals and instructions of how to achieve it before the applicability section (Figure 3, Figure 4). In the following example we ask as fundamental requisites that all *IfcSlab* entities of the geometric model (applicability) have compiled both the attribute "PredefinedType" according to the specific values defined by the standard (only these values are accepted: BASESLAB, FLOOR, LANDING, ROOF, NOTDEFINED, USERDEFINED) and the attribute "Name" with unspecified value (requirements).

THE ENTITY IFCSLAB MUST HAVE NAME AND PREDEFINEDTYPE

APPLIES TO:

ALL *SLAB* DATA

REQUIREMENTS:

SHAL BE *SLAB* DATA WITH A TYPE OF EITHER BASESLAB OR FLOOR OR LANDING OR ROOF OR NOTDEFINED OR USERDEFINED

THE *NAME* SHALL BE PROVIDED

Fig. 3: Simplified IDS user visualization with "IfcTester" web application.

```xml
<ids:specification ifcVersion="IFC4" name="The entity IfcSlab must have Name and PredefinedType" minOccurs="0" maxOccurs="unbounded">
    <ids:applicability>
        <ids:entity>
            <ids:name>
                <ids:simpleValue>IFCSLAB</ids:simpleValue>
            </ids:name>
        </ids:entity>
    </ids:applicability>
    <ids:requirements>
        <ids:entity>
            <ids:name>
                <ids:simpleValue>IFCSLAB</ids:simpleValue>
            </ids:name>
            <ids:predefinedType>
                <xs:restriction base="xs:string">
                    <xs:enumeration value="BASESLAB" />
                    <xs:enumeration value="FLOOR" />
                    <xs:enumeration value="LANDING" />
                    <xs:enumeration value="ROOF" />
                    <xs:enumeration value="NOTDEFINED" />
                    <xs:enumeration value="USERDEFINED" />
                </xs:restriction>
            </ids:predefinedType>
        </ids:entity>
        <ids:attribute minOccurs="1" maxOccurs="1">
            <ids:name>
                <ids:simpleValue>name</ids:simpleValue>
            </ids:name>
        </ids:attribute>
    </ids:requirements>
</ids:specification>
```

Fig. 4: IDS document in machine-readable xml format.

The rules for the BIM information requirements that have been defined have been collected in Table 1. Two examples of requirements for modeling structural and non-structural foundations are given. We can see how the "Req.1" defines the requirements that each individual object of the model exported as *IfcSlab*.BASESLAB with Loadbearing value false (applicability) must have.

The ACCA software "usBIM.IDS" was used to verify the requirements and the correctness of the geometric model. It was therefore possible to verify the information contained in the geometric model and to detect discrepancies from the requirements initially defined and necessary.

Table 1: Examples of requirements for modeling structural and non-structural foundations

Applicability	Requirements		
IfcSlab.BASESLAB	Attribute	Name	-
Loadbearing FALSE		ConstructionMethod	In Situ
	Pset_ConcreteElementGeneral	StrengthClass	C16/20
		ExposureClass	X0
		StructuralClass	S4
		FireRating	-
	Pset_SlabCommon	IsExternal	-
		LoadBearing	FALSE
		Status	NEW
		Depth	-
		Width	-
		Length	-
	Qto_SlabBaseQuantities	Perimeter	-
		GrossVolume	-
		NetVolume	-
IfcSlab.BASESLAB	Attribute	Name	-
Loadbearing TRUE		ConstructionMethod	In Situ
		StrengthClass	C25/30
		ExposureClass	XC1
	Pset_ConcreteElementGeneral	StructuralClass	S4
		ReinforcementVolumeRatio	100
		ReinforcementStrengthClass	B450C
		FireRating	
	Pset_SlabCommon	IsExternal	-
		LoadBearing	TRUE
		Status	NEW
		Depth	-
		Width	-
		Length	-
	Qto_SlabBaseQuantities	Perimeter	-
		GrossVolume	-
		NetVolume	-

Requirement 1 applies to the first block, *Requirement 2* applies to the second block.

6.2 Verification of the uniqueness and completeness of data

As already widely discussed in the section of "RESEARCH AIM & METHODOLOGY" the article aims to identify a method of verification of the uniqueness and correctness of the association between cost item and geometric object.

Starting from structured cost data and a geometric model that meets the information requirements identified by IDS, a code has been developed for the association of IFC cost entities - *IfcCostItem* with IFC geometric entities - *IfcElement* (will not be discussed in this article), and after that another code has been developed for the verification and validation of the correctness and uniqueness of the process of association of cost items to geometric objects. This verification process is completely different from the current ones; in fact, currently the verifications are focused exclusively within the same domain. What the research does is verify the correctness and uniqueness of the information between two different domains (in the specific case geometric domain and cost domain).

The developed code was implemented using Python 3.10, IfcOpenShell, an open-source library (IfcOpenShell v0.7.0) and the IFC4_ADD2_TC1 - 4.0.2.1 (currently the official version).

Through the developed code it is possible to perform an analysis of the geometric model containing the price items. The analysis involves a detailed verification of the information contained in the geometric object of the model (PropertySet, Material, etc.) against the information contained in the price item (Sample Element, PropertySet, Material of Sample Element, etc.) stored in the cost database. In fact, the architecture of the cost item is not present inside of the analyzed geometric model, which contains instead the single entity of cost (*IfcCostItem*) useful for the definition of the estimate of the costs (cost schedule); this retrieves some key data from the unit cost item, such as name, description, or unit cost value (*IfcCostValue*). This will allow to maintain a constant relationship between the item from cost estimation and the unit cost item without weighing down the model of information stored in an external queryable database (Figure 5).
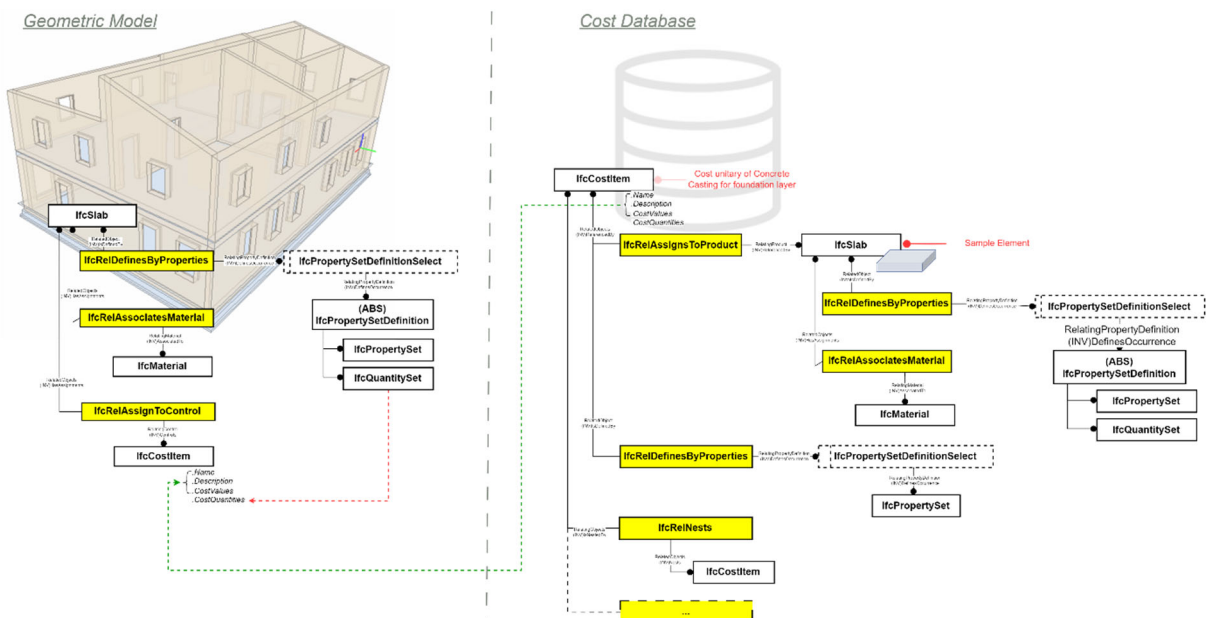

Fig. 5: Relation between geometric object data and cost item data

Due to the scope of the article the verification was performed on a limited number of geometric entities of the structural model: a sub foundation, a foundation, a slab and concrete masonry. Each of these entities is made of concrete cast in place and armed but having different characteristics (exposure class, strength class, structural class, etc.).

The data analysis begins by first identifying the geometric entities to which a cost had been associated. After that through a user interface based on manual input it comes chosen which relation object-cost to analyze. Starting from this choice, the code allows to extract the cost item associated with the geometric entity and, through a predetermined key (*IfcCostItem*.Name + *IfcCostItem*.Description), search the corresponding unit cost item within the cost database. Once the cost item is identified, the code proceeds by analyzing the properties and extracting the data to be verified; for example, the sample element associated with the cost item and the relative Pset_SlabCommon are analyzed to understand if it is a structural element (Loadbearing = True) or non-structural (Loadbearing = False), Figure 6.

```
#97=IfcCostItem('1$8jCZH8bFE97CyJuzD_2b',$,'Concrete casting for foundation layer', '...',.USERDEFINED.,(#96),(#95))
 - #45=IfcRelAssignsToProduct('3f5uwtK8r0ivS67zJKTVQU',$,'Rel cost-element','Rel between cost item and sample element',(#12),$,#14)
 - #14=IfcSlab('2942YU3sLCEvWbpvY3ug5Y',$,'Sample element of concrete foundation slab', '...',$,$,$,.BASESLAB.)
 - IfcSlab
 - BASESLAB
   ▸ #24=IfcRelDefinesByProperties('1qS4DR7EH8Yw0pP$KWTsjd',$,'Rel Pset','Rel between Pset-Sample Item',(#14),#23)
   ▸ #23=IfcPropertySet('3eHYyWf$j3o9iq4HBQt0uP',$,'Pset_SlabCommon',$,(#15,#16,#17,#18,#19,#20,#21,#22))
     ◦ #22=IfcPropertySingleValue('LoadBearing','Whether this component is carrying (YES) or not carrying (NO)',IfcBoolean(.T.),$)
```

Fig. 6: Query the cost item and the data it contains

The analysis continues by questioning the geometric entity and identifying the corresponding properties analyzed in the cost item; For example, we analyze the element class (*IfcSlab*), the PredefinedType attribute (BASESLAB) and its Pset_SlabCommon to check whether the element is structural (Loadbearing = True) or non-structural (Loadbearing = False), Figure 7.

```
#1881=IfcSlab('1r$l67n5fDrxE0IVJzq9my',#19,'FND_PLA',$,'Platea:FND_PLA_30',#1868,#1880,'242873',.BASESLAB.)
 - IfcSlab
 - BASESLAB
   ▸ #1900=IfcRelDefinesByProperties('2zqfiK0TxYZV_kPQ7PQE8u',#19,$,$,(#1881),#1887)
   ▸ #1887=IfcPropertySet('2Unrwa5Dqbjdie587QU4TO',#19,'Pset_SlabCommon',$,(#242,#718,#719,#1883))
     ◦ #242=IfcPropertySingleValue('LoadBearing',$,IfcBoolean(.T.),$)
```

Fig. 7: Query the geometric object and the data it contains

After the IFC model query phase, the results are analysed and validated. A comparison of the data identifies any inconsistencies (Figure 8). These are reported to the user who can then decide which choice to take:

- keep the cost-object association unchanged while knowing that the cost item is not completely congruent with the geometric object. to identify a cost item;
- modify the cost item originally associated through the query of the cost database and choosing between the proposals identified or if they are not present to create a new cost item to be added to the database.

This last mode (creating a new entry to be added to the database) has not yet been implemented and will be part of the future developments of the research.
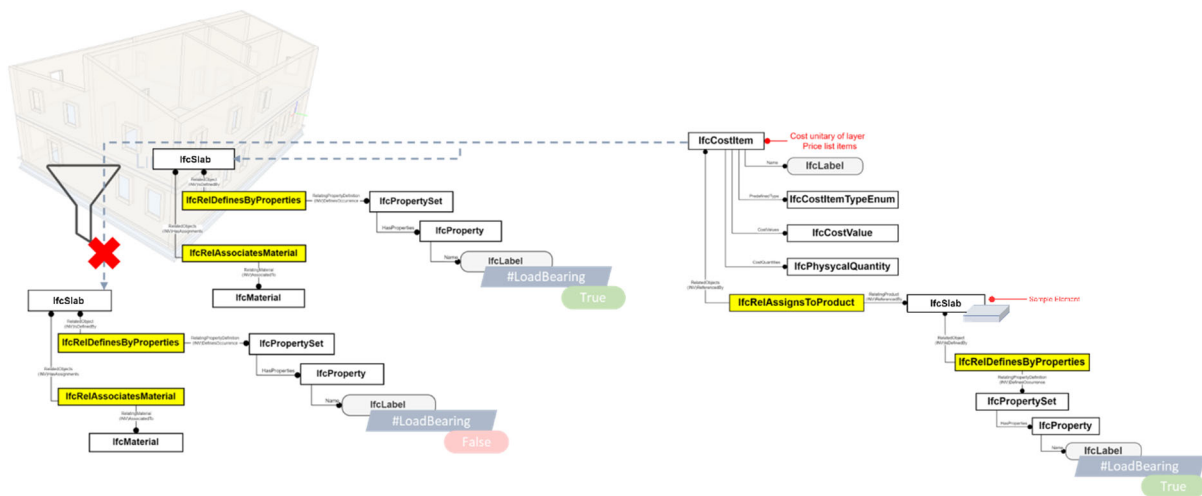

Fig. 8: Example of verification of the correctness of the association of the cost item to a geometric object

A report on the analysis of the output data is also saved in parallel with the display of the results; this report is for each individual association. In Figure 8 is shown an example of test verification performed on the association of the cost item of concrete casting for structural foundations and its geometric object (foundation) with relative data feedback. As we can see from the report obtained at the end of the test (Figure 9), the verification of the association of the cost item to the analyzed object provides the assessments on the current data. Therefore, it will be possible to understand the consistency or not of the data that the geometric object contains with the data contained in the associated cost item as visible in Table 2.
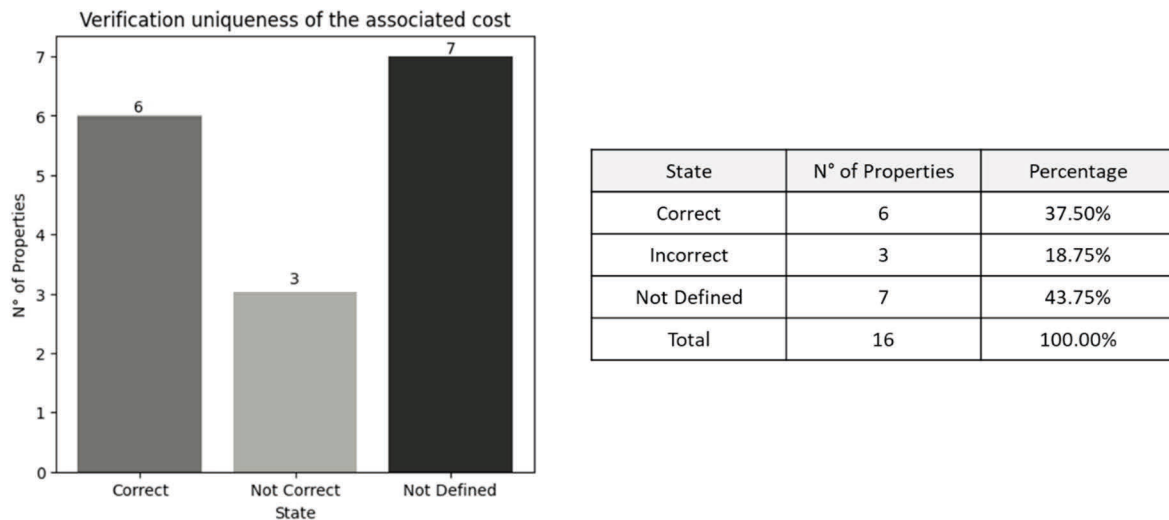
State	N° of Properties	Percentage
Correct	6	37.50%
Incorrect	3	18.75%
Not Defined	7	43.75%
Total	16	100.00%

Fig. 9: Report on the analysis of the output data

Table 2: Verified parameters between geometric object (*IfcSlab*) and associated cost item

Entity	Attribute/PSets	Parameter Name	Geometric Object	Cost Item	Check
IfcSlab	Attribute	PredefinedType	BASESLAB	BASESLAB	✓
	Pset_ConcreteElementGeneral	ConstructionMethod	In Situ	In Situ	✓
		StrengthClass	C20/25	C25/30	✗
		ExposureClass	XC1	XC1	✓
		StructuralClass	S1	S4	✗
		ReinforcementVolumeRatio	100	100	✓
		ReinforcementStrengthClass	-	B450C	ND
	Pset_SlabCommon	FireRating	-	-	ND
		IsExternal	FALSE	TRUE	✗
		LoadBearing	TRUE	TRUE	✓
		Status	-	NEW	ND
		AcousticRating	-	-	ND
		PitchAngle	-	-	ND
		ThermalTransmittance	-	-	ND
		Compartmentation	-	-	ND

7. DISCUSSION

This study is part of a larger research work that aims to digitize and standardize cost data and identify a new costs domain, that can ensure the verification of the correct association between cost items and geometric objects.

Considering the high uncertainty and inaccuracy of the information during the estimation processes is of fundamental importance:

- define the information requirements that the model must contain (Level Of Information Need) for a correct economic management;
- define an automated control procedure for the same information requirements (IDS) to avoid errors and time wasting;

- check the correctness and uniqueness of the cost items associated with geometric objects to ensure greater correctness of the cost estimate.

Nowadays cost estimation is one of the most critical tasks in the AEC/FM industry. Therefore, to support, verify and improve the quality of cost estimates, in public tendering, and reduce human error-prone, the study proposes the identification and applicability of a procedure for the verification of uniqueness of cost data assigned to geometric object within IFC data model. This scientific research has led technological attempts through the writing of a code in Python and through the support of the library IfcOpenShell. The results obtained are real, effective and scalable. The scalability of the hypothesized method has been demonstrated as it can also be implemented for other models. Currently, however, you can get these results only through code because current commercial applications do not allow user friendly implementations. The possibility of developing an executable to facilitate the verification of the model by an external user is being studied.

Currently, as seen in the literature, the approaches used do not provide for a verification of the correctness and uniqueness of the association between two different domains, cost and geometry. Typically, the verification is done within the geometric model considering only one domain (that of the model itself). In fact, usually only geometric interference and checks with the current regulations are carried out. While the goal of the research is to validate data between a plurality of domains (in this case the geometric domain and the cost domain) linked together and that can be contained in the same model. This causes numerous problems both in the phases of cost estimation and in the phases of construction of the work with consequent cost increases and possible disputes between customer/commissioning body and enterprise.

Nowadays, the only possible checks on the association of cost with a geometric object are made manually; there is no possibility for machines to understand information not structured and in natural language. For this reason, the goal of the research is to create a cost architecture to be associated with a geometric object, richer and more granular than a simple attribute associated in the model, allowing the verification of uniqueness and correctness of the data. The results of the research confirm the feasibility of the proposed method.

8. CONCLUSION

This research work is part of a larger project that will involve the relationship of the information of economic objects to the information of geometric objects. Specifically, the research shows how, in the AEC sector, it is essential to perform a verification of the associated information during the cost estimation phase for a correct management of cost data within construction projects. The research studies and experiments the application of a semi-automated method of verification of the cost data to ensure uniqueness and consistency of the information. This will allow to quickly and effectively verify if the cost information present in the project is consistent with what is stated within the geometric model.

Despite the many advantages that this application can provide, some limitations have been found in the proposed method including:

- standardisation of information and identification of requirements that the model must have (if the model does not follow the specified requirements, it is not possible to carry out cost verification); it is not possible to test the method on any IFC model received;
- need for detailed analysis of the information in the IFC data model for a clear understanding of the geometric object; it is not possible to identify the geometric objects from the class attributes alone (Name, description, TypeEnum, ecc.) but it is necessary to deepen the relationships that the same creates with other entities (*IfcMaterial*, *IfcPropertySet*, ecc.). A practical example is found among the objects lean concrete and slab foundation; they are both *IfcSlab*.BASESLAB and one of the ways to differentiate them is to analyze the LoadBearing single value (True or False) in the Pset_SlabCommon.

Although the method has been applied to a specific case study in the structural field, the methodology can be applied for several case studies. Future developments should include testing it in different areas and models for construction and large-scale application to verify its reliability. In addition, an application with user-friendly interface must be developed to ensure easier use of the tool.

REFERENCES

Adeli, H., Karim, A., & York, N. (2001). Construction Scheduling, Cost Optimization and Management. In

Construction Scheduling, Cost Optimization and Management.

Akponeware, A. O., & Adamu, Z. A. (2017). Clash Detection or Clash Avoidance? An Investigation into Coordination Problems in 3D BIM. *Buildings 2017, Vol. 7, Page 75*, *7*(3), 75. https://doi.org/10.3390/BUILDINGS7030075

BuildingSMART. (2022). *IfcCostItem*. IFC4_ADD2_TC1 - 4.0.2.1 [Official]. https://standards.buildingsmart.org/IFC/RELEASE/IFC4/ADD2_TC1/HTML/schema/ifcsharedmgmtelements/lexical/ifccostitem.htm

BuildingSMART. (2023). *Information Delivery Specification (IDS)*. https://technical.buildingsmart.org/standards/ifc/

Cassandro, J., Donatiello, M. G., Mirarchi, C., Zanchetta, C., & Pavan, A. (2023, July 10). *Reliability of IFC classes in ontology definition and cost estimation of public procurement*. https://doi.org/10.35490/EC3.2023.230

Ciribini, A., Ventura, S. M., & Bolpagni, M. (2015). Informative content validation is the key to success in a BIM-based project. *Territorio Italia*. https://doi.org/10.14609/ti_2_15_1e

Dimyadi, J., & Amor, R. (2013). Automated Building Code Compliance Checking – Where is it at? *19th International CIB World Building Congress*, 172–185. http://dx.doi.org/10.13140/2.1.4920.4161

Elghaish, F., Abrishami, S., Hosseini, M. R., & Abu-Samra, S. (2020). Revolutionising cost structure for integrated project delivery: a BIM-based solution. *Engineering, Construction and Architectural Management*, *28*(4), 1214–1240. http://dx.doi.org/10.1108/ECAM-04-2019-0222

Froese T, Grobler F, Ritzenthaler J, Yu K, & Akinci B. (1999). Industry foundation classes for project management - a trial implementation. *Electronic Journal of Information Technology in Construction*.

Ghannad, P., Lee, Y. C., Dimyadi, J., & Solihin, W. (2019). Automated BIM data validation integrating open-standard schema with visual programming language. *Advanced Engineering Informatics*, *40*, 14–28. https://doi.org/10.1016/j.aei.2019.01.006

Greenwood, D., Lockley, S., Malsane, S., & Matthews, J. (2010). *Automated compliance checking using building information models*. RICS. https://researchportal.northumbria.ac.uk/en/publications/automated-compliance-checking-using-building-information-models

Ismail, A. S., Ali, K. N., Iahad, N. A., Kassem, M. A., & Al-Ashwal, N. T. (2023). BIM-Based Automated Code Compliance Checking System in Malaysian Fire Safety Regulations: A User-Friendly Approach. *Buildings 2023, Vol. 13, Page 1404*, *13*(6), 1404. https://doi.org/10.3390/BUILDINGS13061404

Lu, Q., Won, J., & Cheng, J. C. P. (2016). A financial decision making framework for construction projects based on 5D Building Information Modeling (BIM). *International Journal of Project Management*, *34*(1), 3–21. https://doi.org/10.1016/j.ijproman.2015.09.004

Olatunji, O. A., Lee, J. J. S., Chong, H. Y., & Akanmu, A. A. (2021). Building information modelling (BIM) penetration in quantity surveying (QS) practice. *Built Environment Project and Asset Management*. http://dx.doi.org/10.1108/BEPAM-08-2020-0140

Sacks, R., Eastman, C., Lee, G., & Teicholz, P. (2018). BIM Handbook. In *BIM Handbook* (3rd ed). John Wiley & Sons, Inc.

Solihin, W., & Eastman, C. (2015). Classification of rules for automated BIM rule checking development. *Automation in Construction*, *53*, 69–82. https://doi.org/10.1016/J.AUTCON.2015.03.003

Trebbi, C., Cianciulli, M., Matarazzo, F., Mirarchi, C., Cianciulli, G., & Pavan, A. (2020). Clash detection and code checking BIM platform for the Italian market. *Research for Development*, 115–125. https://doi.org/10.1007/978-3-030-33570-0_11

Wu, S., Wood, G., Ginige, K., & Jong, S. W. (2014). A technical review of BIM based cost estimating in UK quantity surveying practice, standards and tools. *J. Inf. Technol. Constr.* https://www.itcon.org/paper/2014/31