Innovative standardized cost data structure: application on price list document for estimating public tendering

Jacopo Cassandro, Chiara Gatto, Antonio Farina, Claudio Mirarchi and Alberto Pavan

Department of Architecture, Built Environment and Construction Engineering, Polytechnic of Milan, Italy
jacopo.cassandro@polimi.it, chiara.gatto@polimi.it, antonio.farina@polimi.it, claudio.mirarchi@polimi.it, alberto.pavan@polimi.it

Abstract –

In the construction industry, managing cost data represents a major challenge. One of the main issues is the inaccurate cost estimation of a project. This study, based on an innovative approach, standardizes and restructures unit cost items defining a new cost ontology starting from fundamental resources (materials, labor, and equipment) and then moving to construction work. A new methodology has been proposed to reduce errors, verify the uniqueness of the cost items, and ensure the correctness of cost estimates. This approach will allow, both humans and machines, to read and use information more easily and accurately. In conclusion, this new structure will provide a standardized and structured cost domain.

Keywords –

Cost Item, Cost Management, Price List, Price Analysis

1 Introduction

Building construction is a complex and time-consuming process involving various participants in the Architecture, Engineering, and Construction (AEC) industry. Specifically, cost estimation is a crucial task in construction projects, involving the calculation of quantities, project costs, and product classification, where all participants must interact with each other to share these various information [1]. In order to minimize the risk of human error when choosing the cost items useful for cost estimation processes, the study proposes creating a structured cost ontology that can be relied upon and applied consistently. This will enable the identification of a standardized procedure for creating, storing, and selecting cost information.

In Italy, a price list is utilized to manage cost data during public tendering. Each region has its price list, which contains construction materials, equipment, labor, services, and construction work. These price lists are used to process economic offers and regulate payments in public contracts. However, the current price lists have a hierarchical and inflexible structure designed for printing purposes, which makes it challenging to link and cross-reference the various components of the price list. Furthermore, an analysis of the ontology and semantics of the cost items in the AEC/FM sector revealed several shortcomings and critical aspects.

This study aims to establish the basis for developing a standardized cost data structure that will form the foundation of the new digital platform for public works prices in the Lombardy Region to ensure better cost management. The cost data have been broken down and transformed into a new ontology, resulting in more detailed and granular information.

This new standardized structure will contain both elementary resource information and construction work items obtained from elementary resources and based on price analysis. Data structures will be based on specific fields/attributes, consider cost items no longer only as text strings but as replicable computer classes, and ensure future validation and comparison between attributes of a certain cost class and the attributes of the object to which it is associated. This structure will be interrogatable, standardized, and understandable by humans and machines. This will allow to structure not only the data within the proprietary context, as is already the case thanks to the tools currently available (Oracle, SAP, etc.); in the construction sector, in fact, the association of these elements outside their context "owners" remains an unresolved problem.

Therefore, a cost ontology can be used to model and represent knowledge about the cost domain specific to construction projects. It is a system that describes the relevant entities of a domain and the relationships between them in a shared, explicit, and formal way.

Currently, data on cost items are described in natural language without specific structure, which makes them unclear to digital tools and leaves a subjective interpretation of the data open by users such as professionals, architects, and quantity surveyors. This causes errors and a waste of time in understanding, choosing, and evaluating cost items to be associated with geometric objects.

2 Background

According to the Project Management Body of Knowledge (PMBoK) as outlined by the Project Management Institute (PMI), project cost management consists of all those procedures related to planning, estimating, budgeting, financing, funding, overseeing, and regulating expenses to ensure projects are accomplished within their allocated budget [2].

Before the start of the construction stage, cost management is centered on cost estimation and cost planning. In the implementation of this phase, work breakdown structure (WBS), bill of material (BOM), and bill of quantity (BOQ) are carried out.

The inaccuracy of the quantity take-off and bills of quantities was demonstrated to be one important factor affecting the cost performance. The management of elementary resources is therefore fundamental in the planning activity of a production process[3], [4]

Planning and optimizing resource utilization can lead to a significant reduction in the duration and cost of construction projects [5]. Within this section an investigation is performed related to how elementary resources are managed in the state of the art during the production phases, not only focusing on the AECO context but also extending the analysis to other industrial sectors.

Currently, the Bill of Materials (BOM) tool is one of the most widespread and used for the quantification and identification of elementary resources in the production processes of various sectors. It involves the classification and quantification of elementary resources concerning the examined project.

Han et al. [6] research activity propose a framework that analyzes design changes' impact on project cost and emphasizes controlling changes during the project. This framework ensures that no information is missed or lost among 2D drawings, 3D models, and the Bill of Materials (BOM).).

Qiao et al. [7] simplified the project planning process by using a genetic algorithm Petri net cell rules to create a Bill of Materials (BOM) view. By adjusting the optimal start time of non-critical activities, the resource can be balanced when multiple projects are running in parallel. The study makes it possible to decompose the plan process into a BOM, maintaining the leveling of the elementary resources.

In a further theoretical study, the focus is placed on the importance of correctly choosing labor, product, financial, and informative resources. The resource that most significantly impacts the success of a project is the human resource. A competent professional team ensures 75% of the project's success. Many find it wrong that financial resources are the most important. The mistake lies in the way financial resources are invested, no matter how "rich" they are, if spent inefficiently they are as if non-existent [8].

Wang et al. describe BOM, in the field of mechanical product manufacturing, as a central datum in the complete life cycle management of complex products. In this study, a framework for building the BOM of a complex product is developed, to correctly integrate design information that often varies during the various steps preceding the assembly stage. The developed methodology integrates all BOM information using digital twin models [9].

Regarding the construction sector in the cost estimation and cost control phase, greater interest is placed especially on digitizing the process to increase the accuracy of the cost estimation process using BIM methodologies. The state of the art is affected by a general deficiency in the state of the art regarding the absence of frameworks or guidelines to support practitioners in decision-making, especially when integrating time-related aspects into BIM models for cost management in projects [10]. Hillebrandt et at. study collects some examples of the consequences of failure to plan and indications of instances where resource planning was ineffective[11].

Li et al. [12] found that project planners in the AECO sector overlook details activities while focusing on the master program. They lack a mathematical method to analyze resource allocation. This paper proposes using virtual prototyping to optimize construction planning schedules. Building detailed 3D models requires significant resources. Selecting problem models to be built as detailed models is crucial for saving resources. Building a construction model and resource model database is also crucial for future projects.

An interesting research activity describes an Intelligent Scheduling System (ISS) that uses simulation techniques to allocate resources and prioritize activities to create an optimal project plan that aligns with goals and constraints.[13].

Poshdar et al. [14] developed the Multi-objective Probabilistic-Based Buffer Allocation (MPBAL) method for complex projects. It uses a visual representation of mathematical optimization results to help decision-makers achieve the best outcome. Tested on a bridge project, MPBAL outperformed numerical analysis.

Said et al. [15] developed the Automated Multi-objective Construction Logistics Optimization System (AMCLOS) to help contractors plan material supply and storage efficiently. By automatically gathering project data from scheduling and BIM files and optimizing material supply and site decisions, AMCLOS reduces overall logistics costs.

In the AECO sector, the primary focus is on scheduling on-site activities to complete projects efficiently. However, there seems to be a general lack of standardization when it comes to the knowledge delivered by cost estimation tools such as BOM and BOW. This creates a missed opportunity to use uniformity of information as a cost control methodology, which has not been explored in any study so far.

3 Methodology

The followed methodology is based on an in-depth analysis of the current state of the art related to the resource analysis theme, and subsequent price analysis, to structure the cost item data which currently is conveyed in the form of unstructured natural language. These themes, as noted in the previous section, do not only concern the construction sector but are found in different fields (automotive, etc.) having a common theoretical basis, albeit with different complexities due to the variability of the working environment.

The research aims to define a new cost item data structure (materials, equipment, labour, and construction work), to ensure the standardisation of information, the definition of a new cost domain, and the possibility in the future to validate the correctness of the cost item information and the objects or documents to which it is associated (geometric model, time schedule, informational specifications). In addition, this new structure will make it possible to obtain cost items that are also understandable and queryable by machines because they are characterised by structured information and no longer in natural language.

The definition of a standard cost data sheet, based on predefined attributes, that can be used for the various types/gender of cost items (material resources, equipment, labour and construction work) and the relations between this information are crucial, in the logic of price analysis.

According to the objectives, the research structure develops in these different stages:

- Study of the state of the art and identification of the problem statement;
- Analysis of current cost items related to construction works and resources in the building sector linked to the civil and infrastructure part;
- Definition of a new data structure for cost items in natural language through meetings and dialogues with industry experts (practitioners, manufacturers, national associations, etc.) and a detailed analysis of cost items;
- Identification of a new price analysis structure based on the link between the new identified data;
- Validation of the structure through application in a practical and real case (the project of digitization of the price of the Lombardy Region);
- Discussion of the results obtained, limitations and possible future developments.

4 Framework

This study is a crucial part of a larger project that aims to create a new digital pricing platform for the Lombardy Region. The research focuses on the structure and standardization of the cost items related to Material, Equipment, and Labor Resources, which together will form the structure of the Construction Works. It is noteworthy that the project will establish several categories of resources and construction works (Figure 1 and Figure 2). To estimate the cost of a project, it is important to have accurate data on the resources needed to complete the project, as well as the associated prices. This information is obtained through a process of analyzing the prices of resources and quantifying the amount of resources needed to complete a unit of work. Therefore, it is crucial to structure the data starting from the Resources, as they are the fundamental building blocks of any project.

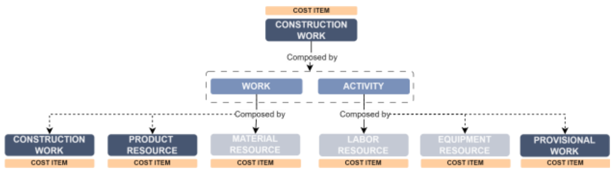

Figure 1. Structure of construction work and the resources/construction work that compose it

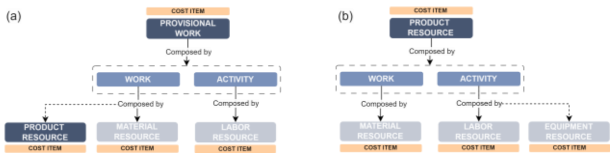

Figure 2. (a) Structure of provisional work and the resources/ product resources that compose it; (b) Structure of the product resources and the resources that compose it

Cost items are currently identifiable in materials, labor, equipment, and construction. Two main groups have been defined to structure the data (Figure 3): one relating to elementary resources (material resources, labor resources, equipment resources) and one to construction works (product resource, provisional work, and construction work).

Elementary resources are the basic elements/components for defining construction works; the latter, on the other hand, are composed of two abstract entities, activity, and work, which together constitute exactly the cost of the construction work. The material resources will allow defining the group "work" while the human and instrumental resources will allow defining the group "labor”.

Construction work is the result of the process of combining work and activity (Slab formation).

The work corresponds to the physical part of the construction work, what will be realized and created (for example, the "slab"); the work consists of elementary resources products/materials (hollow clay blocks, prefabricated joist) or other construction works (Stiffening layer formation).

The activity corresponds to the action that must be performed to carry out the construction work (for example in a new construction activity the "formation/creation" of the slab or in a maintenance activity the "restoration or demolition"); the activity will consist of elementary resources such as equipment (tower crane), labor (construction worker) and other provisional work (Formwork formation, Props formation).

The peculiarity of the structure allows for each identified work ("Slab") to be identified and associated with different activities ("formation, restoration or demolition").

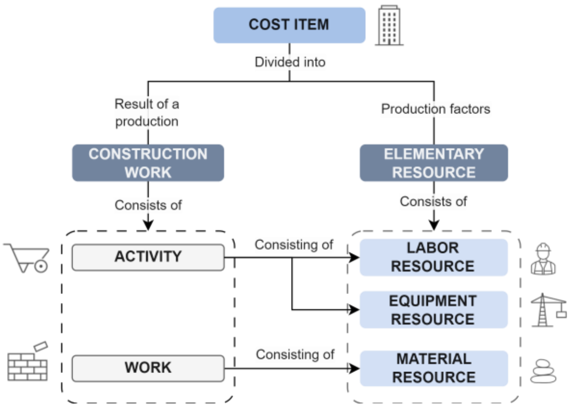

Figure 3. Two main groups of Cost Items

Cost items are structured using a cost data sheet with specific attributes for Elementary Resources (Materials, Labor, Equipment), Product Resources, Provisional Work, and Construction Work.

Cost data sheets are important documents that provide key information about cost items and their descriptions.

To such purpose, a first system of classification of the construction works is implemented to be able to structure them according to a common logic. There are three macro-categories in which to classify a construction work (Figure 4). The first allows to identify which family, category, and object of construction work is referred to (for example family=constructions, category=buildings, object=residence); the second allows to identify to which category, family, and object of activity refers (for example family=production, category=execution, object=formation/creation); finally, the third allows to identify to which family (discipline), category (system), object (technological unit) and matter of work are referred (for example discipline=architecture, system=slab systems, technological unit=slab, material=concrete and clay-brick). This example is visible in Figure 4.

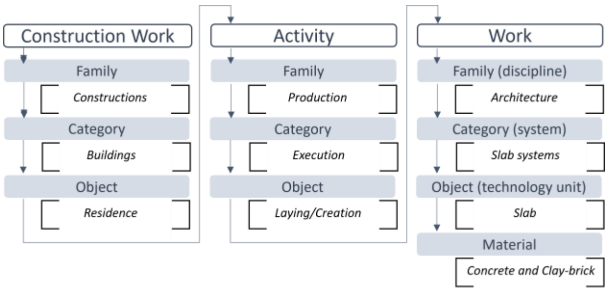

Figure 4. System of classification of the construction works

When linked to a cost value and a prefix consisting of a regional abbreviation, year of publication, and the current version, new price items can be created based on structured data (Figure 5).

Figure 5. Structure of new price items

About 60 experts/practitioners and trade associations in the construction industry were interviewed at least 3 times in a year each. The goal was to identify the essential information for each type of resource and construction work. This was part of a previous research activity where the research group analyzed and defined attributes through an iterative interactive process with practitioners [16]. Through this qualitative and quantitative analysis of the data currently available (about 20,000 lists of resources and construction work in the price list of the Lombardy Region), the various attributes in which to deconstruct the current information and to define the useful data to define the new structured cost items have been identified. Each of these attributes allows to storage of specific information useful to define a cost item.

The attributes were initially classified as mandatory. Subsequently, a validation was envisaged based on:

- type of choice: single/multiple;
- type of compilation: default values/free (with prevalent use of standardized language to limit the adoption of an unstructured natural language).

The mandatory attributes allow you to identify the coding associated with the description. These are gender, family, category, object, and material.

Other fundamental attributes are the "characterizing component", and the "auxiliary component" which is fundamental for defining the relations between the various cost data sheets.

Therefore, resource records (which will be associated with a price found following a market analysis) can be instantiated within other resources if it is necessary to define composite records or for the definition of relationships in the context of price analysis for the structuring of the work.

5 Validation and Results

This study is a crucial part of a larger project that aims to create a new digital pricing platform for the Lombardy Region. The validation of the structure has been performed on a dataset of 20 thousand cost items including elementary resources (materials, equipment, and labor) and construction work that are currently contained in the price list of the Lombardy Region.

5.1 Price List

The process of estimating costs for public tendering varies between different States. In Italy, the estimation of prices for public works is determined using a price list. Each region has its price list, which is a catalog containing price items. These price items are the basis for the preparation of the economic offer and regulate payments in public contracts. The determination of the unit prices of the works is based on former Article 32 of the D.P.R. 5 October 2010.

The price items consist of the following:

- A unique code for each processing;
- A description in natural language of the work;
- The unit of measurement of the work;
- The price of the construction work;
- The impact of labor equipment and materials on the unit price.

The protocols mentioned here are specific to the Italian context, but the methodology proposed can be implemented with any cost estimation approach. The factors that determine the cost of construction work, remain essentially the same across any approach, including labor, equipment and materials, overheads, and profits. These factors form the basic components of the final cost and help determine the total processing amount.

5.2 Break down price items and structuring of cost items

It is important to follow this process of breakdown because, from the initial analysis, it was found that the descriptions were unclear.

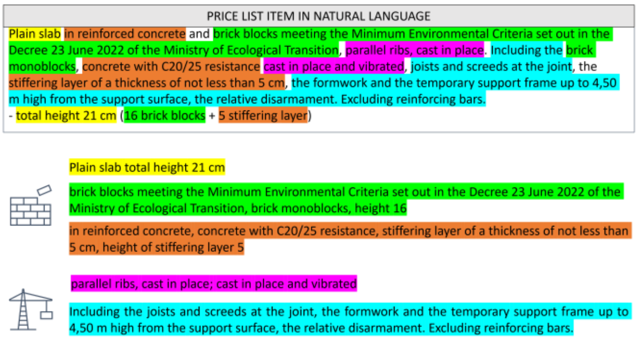

Figure 6. Nonlinear description of a slab cost item

This lack of clarity can lead to misunderstandings, inaccuracies, and errors when selecting and associating price items with their respective geometric objects during cost estimation.

Based on Figure 6, the description provided is non-linear, and information related to a particular processing object can be scattered throughout the description.

Through breakdown, to achieve this, a set of attributes has been defined to compile the information already expressed in the item descriptions.

Various cost data sheets have been identified that differ from each other by type and number of attributes according to the attribute “gender” of the cost item analyzed (construction work, material, etc.).

Once the phase of the breakdown of the data inside of the data sheet of cost, these are reorganized to define the new descriptions and the code of the cost items.

The process of structuring and standardizing cost items began with the analysis of elementary resources (materials, equipment, and labor) and then the construction work.

5.3 Elementary Resources

Elementary resources include material resources, equipment, and labor. Elementary resources are the basic elements/components for defining construction works.

The structuring of the data starts from the attributes contained in the cost sheet. As regards the description of elementary resources, two levels of information structuring have been identified: general and detailed.

The general level provides for the general information of the main resource (for example the data associated with the total ready-mix concrete).

The level of detail describes the constituent elements of the main resource and further specifies the data associated with the cost item (for example, the data associated with binders and ready-mix aggregates); the latter is not necessarily present in all cost items but only where necessary for a greater specification of the cost item. Each of these two levels, if within the same "kind" of resource, is based on an identical standard structure, facilitating the subsequent reading, and understanding of the data also by the machine. From these data structures, it is possible to define both the description of the cost item and the relative coding. Both are obtained through rules defined from the attributes of the cost data sheet.

Figure 7 shows an example of the cost item of ready-mixed concrete.

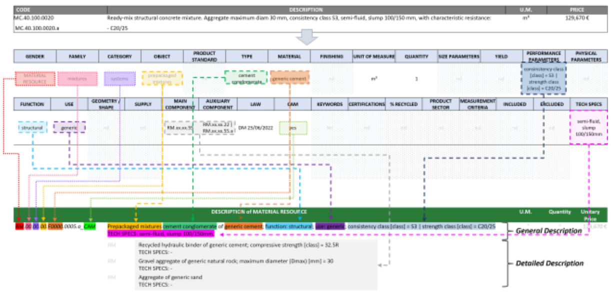

Figure 7. Cost item structure of Resource

5.4 Construction Work

Among the works, there are construction works, provisional works, and product resources.

Unlike the Elementary Resources, structuring the cost data in the workings is more complex.

The architecture of the construction works cost items is based on the logic of price analysis. From the single elementary resources, it is possible to quantify the number of resources (material, equipment, and labor) necessary to obtain the unit working and the relative associated unit price.

However, the research is not limited to the application of the traditional method of price analysis but aims to further structure the cost data to facilitate the understanding of the item and ensure a possible link of the new cost domain with other domains such as tasks, geometries, etc.

The new structuring of construction works involves the addition of a new intermediate level between the elementary resource and the construction work (section "4 Framework"); these intermediate levels breakdown the construction work into work (physical entity - floor stiffening layer) and activity (the activity to be performed on the physical entity - formation, concrete casting). Both have a standard but different cost data sheet.

This subdivision is useful and allows to structure of the information of the cost item that describes the geometric object contained in the 3D model (work) and the activity contained within the list of activities for the management of time 4D (activity). This will then allow to carry out checks on the correctness of the cost item concerning the geometric object to which it has been associated and concerning the timing established by schedule for the performance of the given task.

The two data sheets of work (Figure 8) and activity (Figure 9) costs are related to each other within the datasheet of construction work cost through specific attributes. This creates a more complex architecture for the cost item, structured, interrogatable, and standardized.

Finally, from these data structures, it is possible to define both the description of the cost item and its coding. Both are obtained through rules defined from the attributes of the cost data sheet.

In Figure is shown an example of a cost item relating to a stiffening layer of a slab.

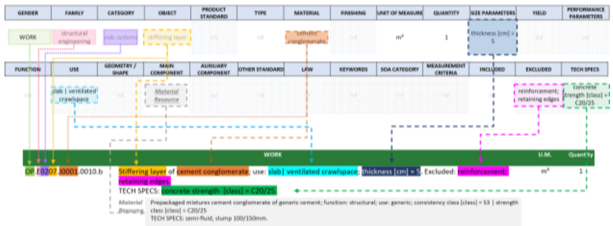

Figure 8. Cost data sheet structure of a Work (stiffering layer)

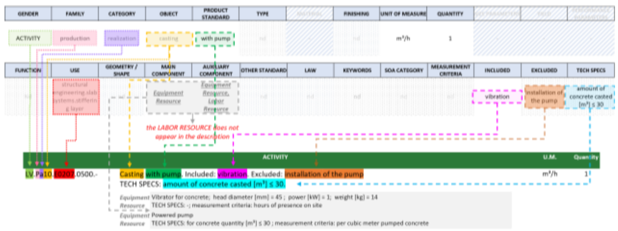

Figure 9. Cost data sheet structure of an Activity (formation)

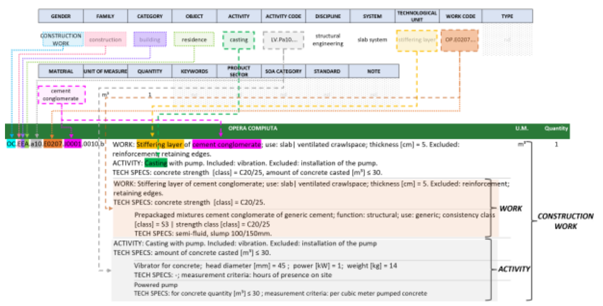

Figure 10. Cost data sheet structure of a Construction Work = Work + Activity (stiffering layer formation)

5.5 Relationships between cost data sheets and price analysis

From the relationships defined within the individual cost data sheets and the construction work data sheet, it is possible to obtain the structure of the associated price analysis. The structure will be created automatically based on the relationships and information defined and inserted in the different cost data sheets; these are all related to each other. Here is an example of price analysis for the realization of a slab (Figure 11).

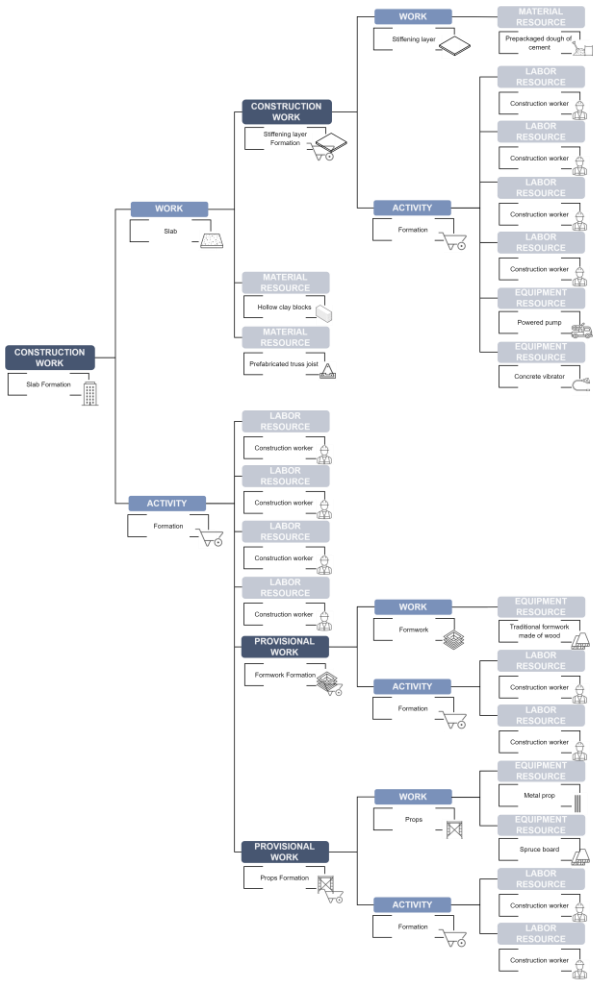

Figure 11. Relationships between cost data sheets and price analysis of "Slab Formation"

6 Discussion

The research has led to the definition of a new data structure that allows to build in a semi-automatic way the price items, relating them to the resources that characterize them. This new structure allows to standardize the information of the cost items that are currently described in natural language and not understandable by machines.

By analysing the state of the art and developing this study it was clear that the lack of uniformity of the language used in the different price items represents a main issue; this makes it difficult to understand and correctly choose cost items during the phases of cost estimation. A new structure based on cost data sheets with standard attributes is proposed to overcome these problems. This will facilitate the search of data both for users, as it will allow to query the system by general topics or by specific attribute searched, either by any future tools that will want to verify the correctness of the data associated between the cost domain and any other domains (geometric-3D, timing-4D, etc.).

In addition, to overcome these problems, it was also necessary to standardize the terms and define a clear vocabulary to use, avoiding this way duplication and misunderstandings.

Around 180 meetings and interviews were held with practitioners, manufacturers, and trade associations to develop a data structure that could be easily understood and used by end users. Those meetings proved to be necessary to refine the initial structure set and to integrate data on current cost items, leading to modifications and as a result a clearer structure more comprehensible for everyday use. This stage also demonstrates a deep understanding by the end user of the hypothesized structure, which was strengthened through active collaboration and a thorough understanding of the underlying logic of the new cost data sheets.

7 Conclusion

The complexity of the construction projects and the many activities that characterize them, entail a series of difficulties in managing the entire process that can therefore lead to important errors.

To reduce the conflicts that may exist between the design phase, planning, and project management, within this article, a new methodology of structuring elementary resources data (materials, labors, and equipments) has been developed, tested, and demonstrated to be useful in the realization of the construction work through price analysis. In this study, we propose a new architecture that defines the cost domain using a new ontology and semantics of costs. To create this new cost architecture, it is necessary to break down the current cost item into attributes, representing the fundamental parameter that substantiates the unit price value. This helps to increase their generality and abstraction, resulting in elementary constituent cost elements. These elements help to ensure order and standardize the prices, making them replicable in a variety of contexts. The study defines new descriptions of each cost item to make them more understandable, by humans and machines, and reduce the possibility of information misunderstanding. It also established an intuitive and standardized structure and defined a detailed and comprehensive price analysis for each construction work.

During the study, some limitations were identified in the implementation of a standardized methodology for costs. The first limitation is the market barrier; even if the structure proved to be understood by practitioners, the breaking down process has been performed to assist them. However, the development of a platform for creating, managing, and storing new cost items is currently underway, allowing an easier end-to-use by users. The second limitation is related to the use of terms that are commonly used to define an object but are often misused. To address this issue, a synonymous attribute has been added to facilitate the search. Additionally, the meaning of certain words can vary depending on the region, making it difficult to standardize without imposing specific definitions. The third limitation is due to the industry culture and resistance to change. This can make it challenging to implement new methodologies and practices.

For future work, it is essential to analyze the actual results of the new cost data structure. This analysis will help in estimating costs and verifying their correctness against other crucial project documents, such as 3D models and 4D time management. The research team has already carried out some tests in their previous work [16], [17]. However, these tests need to be extended to more complex case studies.

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