5D BIM: TOOLS AND METHODS FOR DIGITAL PROJECT CONSTRUCTION MANAGEMENT

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ABSTRACT
The traditional workflows used to define construction costs are characterized by a series of common criticalities due to physiological inefficiencies of analogical or not-completely-digital processes. These include the waste of man-hours due to continuous requests for clarification by the computer scientist, or the transmission of partial or unverified information by the design team, or even inaccurate and approximate measurements based on 2D drawings. This can lead to lower levels of reliability of cost estimations with consequent design risks and the need for variants in progress, exceeding the project budget or the expected timeframe. The BIM approach can mitigate these risks, but it is necessary to define a planned and robust method that supports the consistency between the items of calculation and the elements of the model. This method needs to be based on a structured breakdown of the building and the activities necessary to the project, according to a clearly planned methodology. Therefore, it is necessary to define an approach capable of generating digital workflows and automatically updating quantities (especially in the event of changes to the project), as well as to ensure the correspondence between modelled elements and computation items, in order to have a consistent workflow and make immediate and clear the updating of information on each project document. The paper is oriented to the definition of a structure for cost planning process, which uses the experimentation of computer tools aimed at extracting the quantities directly from the model, allowing the automatic update in case of changes, through the use of a PBS (project breakdown structure), shared with the entire design team, and using a code system associated with the elements of the model, the calculation, but also to specialist reports, detailed graphics and schedules.
Keywords: 5D, cost estimation, BIM uses, rules set.

1 INTRODUCTION

The integration of BIM with 5D simulation models allows to associate the 3D model and the fifth dimension in order to view the progress of activities and the related costs over time. In fact a 3D BIM model represents the geometry and when attached time it will become 4D, and 5D when attached cost. Using a 5D model provides methods for extracting and analyzing costs, as well as evaluating alternative scenarios, resulting more accurate and predictable estimates, quantities, materials, equipment, and labor. A five-dimensional information model contains not only the physical and functional characteristics of a project, but can provide a project's time (4D) and cost schedule (5D) in addition to the standard 3D spatial design parameters. Therefore, it is important to note that the gradual enumeration of the fourth and fifth dimensions doesn't mean that they are to be necessarily consequent, as a cost estimation (5D model) can be provided independently from the time planning of the fourth dimension (4D model) and vice-versa.

The Computer Integrated Construction Research Group of the American University Penn State, codifies the use of BIM oriented to 5D modeling in the phase planning, describing it as a process in which, it is possible to plan efficiently the construction implementing the model with the fifth-cost dimension, and declines the main advantages:

5D modeling is configured as a powerful visualization and monitoring tool, which allows stakeholders to accurately control the information flow, effectively managing the planning and estimative aspects; one of the main advantages of using a BIM approach oriented to 5D,

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is the ability to improve and facilitate the cost control and planning, as well as to express the complexity of project management related to planning and supporting further and subsequent analysis.

Technological innovation is gradually allowing new quality standards to be reached, but this always makes it necessary for professionals to have specific experience in each of the many specialisations. In this regard, the Penn State University study also investigates the specific software, resources and skills needed for 5D, identifying as essential both the knowledge of 3D modeling tools, and the specific methods to transform an information model to a structured support for the cost planning and monitoring in a construction process [1].

The BIMe initiative is another important contribution to the development of knowledge and potential of BIM; it is configured as a network of experiences and declinations on the subject, as well as a sharing effort undertaken by researchers and volunteers from both industry and academia. The BIMe initiative provides a research-based alternative to prescriptive top-down BIM deployment policies, offering an innovative, consistent and timely response to the opportunities and challenges brought about by the adoption of BIM at all organizational scales, through an integrated methodology and modular language for performance evaluation, and process optimization.

As a first declination, by identifying the Model Uses, the information requirements to be linked-incorporated within the digital models are identified and grouped, thus developing a broader modular language that links these requirements to System Units, Defined Roles and Competency Items.

First, Model Uses are defined as a type of Information Uses that also includes aspects related to the use of data and documents.

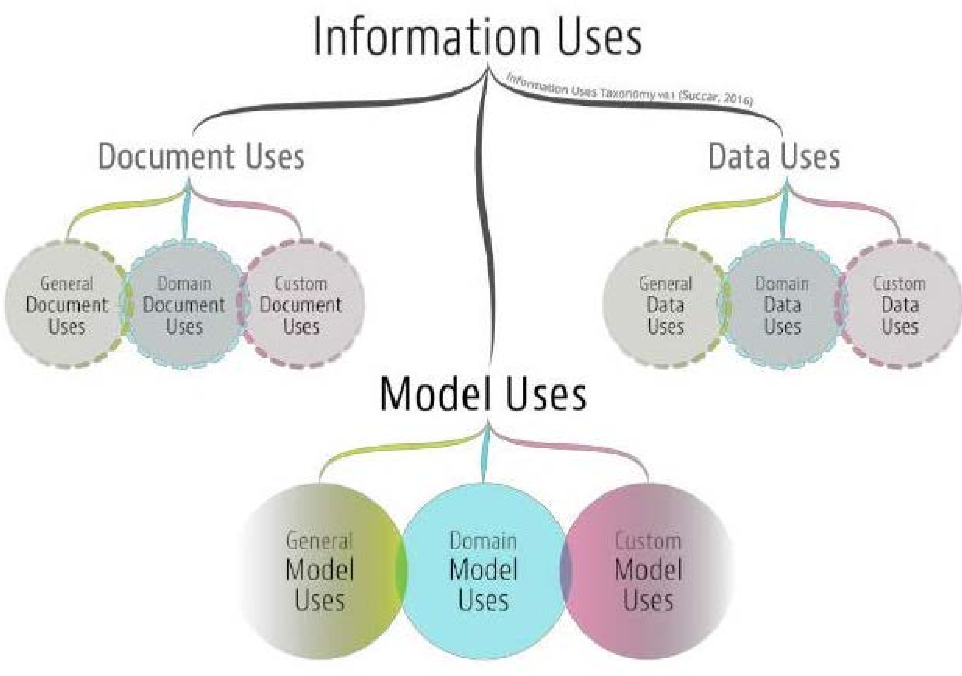

Figure 1: Information Uses: BIMe.

Model Uses are divided into three categories:

Category I – General Model Uses: The general uses of the model are applicable to all sectors, information systems and knowledge domains; including the word "modelling" in their name, they are generally measured using principles such as the level of definition or development. Examples of General Model Uses are: Architectural Modelling, Conservation Modelling, HVAC Systems Modelling etc.

Category II – Domain Model Uses: Uses are industry-specific, in particular construction uses identifies: Capturing and Representing, Planning and Designing, Simulating and Quantifying, Monitoring and Controlling etc.

Category III – Custom Model Uses: The "customized" uses of the model are a combination of the first and second category as they are tailored to each project, customer, client or specific modeling requirement. (e.g. the scope of application of a Custom Model Use can be the modeling of security systems for a tourist accommodation).

This specific articulation of Model Uses can be exploited and applied in different areas, simplifying for example the identification of information requirements within the project protocols, facilitating the configuration of organizations, the assessment of the supply chain and the programming of project activities [2].

In the specific field of Domain Model Uses, the 5D characterization is mainly identified in the field of Simulating and Quantifying. In fact, modeling represents the starting point for the creation of the database which contains the information that allows to simulate the realization and determine the quantities of machining to be performed by defining the cost within a parametric computing environment.

In the construction process, project time and cost planning are closely related activities and both fundamental for an effective achievement of the final result. Time Planning is indispensable and strongly affects Cost Planning, since its increase (often) is directly proportional to the extent of the delays that can be suffered. In fact, the responsible for estimating costs often works with designers and determines costs in relation to the progress of the project or construction at the time of the preliminary estimate [3].

This becomes even more possible by using a BIM-oriented approach, according to the specific regulations about information management processes [4], [5], configuring a shared and collaborative environment in which, progressively with the design development, it becomes possible to extract quantitative information directly dependent on the created model, in order to obtain a result in terms of costs (budget) to be incurred for its implementation. Therefore, scheduling the project budget means defining costs in advance, setting the cash-flow trend and scheduling the necessary financial resources in time to meet expenses relating to labor, materials, equipment, etc.

Fig. 2 is the typical diagram representative of the characteristic budget curve of a building, where in the first period the construction costs are lower and then increase over time with the intensification of building activities and the concomitant construction of masonry, finishes, systems, etc.

The approach to 4D and 5D BIM succeeds in this sense to facilitate and complete the phase of planning that impacts on the programming phase, having as input the models in an interoperable format, and as output the same computations deriving from the parametric designing/modelling. The execution times are grouped by Work Package and the relative costs, developed over time, generate the S-curve that represents the baseline of the site budget.

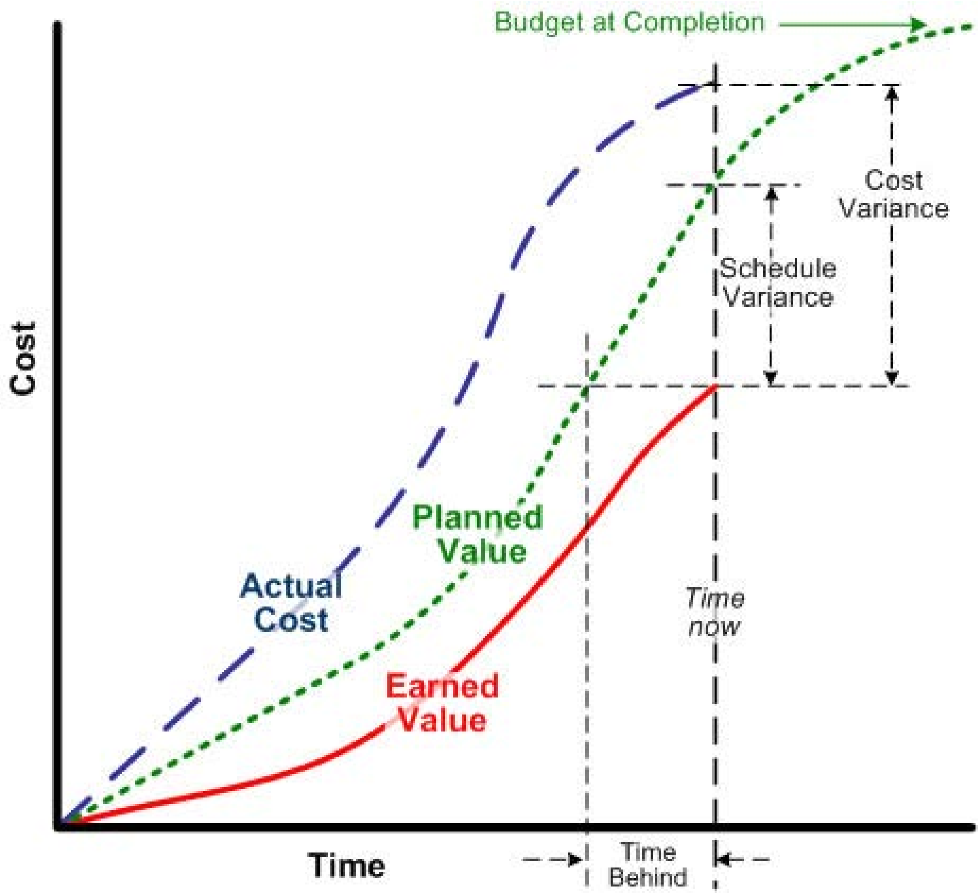

Figure 2: S-shaped budget curve.

The quantity take-off schedules exportable by the model and containing the most varied quantitative information is therefore necessary but not sufficient for the estimation process. This in fact evolves in a subsequent phase, within an environment in which the parametric object (architectural, structural, plant engineering, etc.) are linked to a work activity (deriving from the price list, or cost analysis), allowing the time and cost planning to be managed during the execution phase.

The budget of a project must be prepared in such a way as to be able to predict all types of cost and structured as to create a simplified scheme of intersection between PBS (project breakdown structure) and CBS (cost breakdown structure).

Fig. 3 shows the typical PBS/CBS relationship matrix that links the deconstruction of the project in its individual activity packages, with the costs structure related to each Work Package. As shown, through an optimal destructuring of the work in activity, the allocation of the relative costs is simplified and the Construction Manager, after the definition of the WBS (work breakdown structure), plans the budget for each work package and consequently for the whole project.

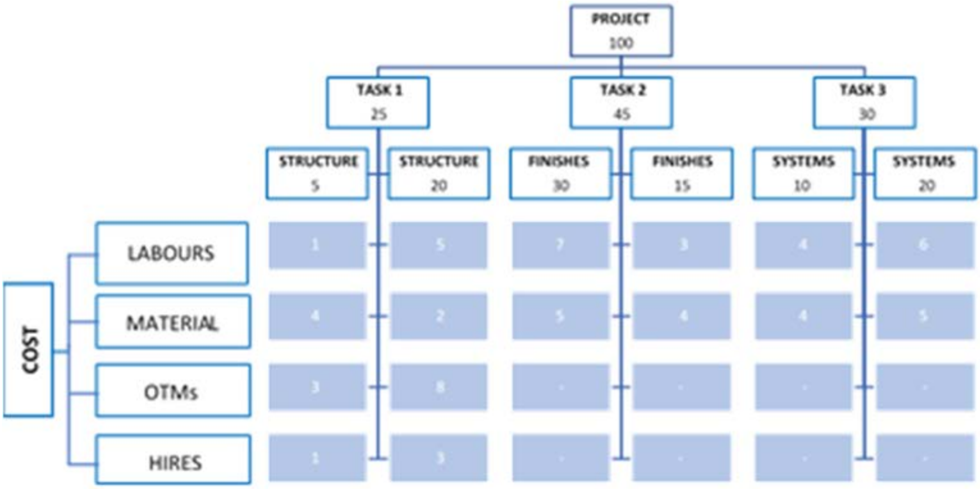

Figure 3: Example of a PBS/CBS matrix.

This scenario can be realized with a BIM approach by assigning a code to each element referred to the WBS, defining a tree structure within the parametric computing environment that can be easily managed and interrogated (integrated with the cost values related to the individual work packages) that returns the quantitative data required for each activity package. The information model reflects a unique relationship between the object, the price list item (and therefore the calculation), and the activities of the work programme.

Of course, this approach is closely linked to the above principles and tools of project management, in fact the model is divided by products that create the so-called PBS, while the computed processes are divided into activities organized in a WBS. In fact, each object is assigned a unique WBS code that reflects its processing phase with respect to the chronological order defined by the work program; this code can also contain an item of CBS, which has the same meaning as the WBS, but in relation to the costs of implementation [6].

2 TOWARDS A NEW SCENARIO

To realize a model oriented to the fifth dimension means to experiment methodologies linked to a parametric computing environment able to extrapolate tabulated information such as quantity, unit costs and totals, according to structured data schedules and to previously shared rules, with which the elaboration of the cost estimate and its different alternatives becomes computational. Structuring the formulation of the problem, defining the expression of the solution, executing and evaluating the solution, builds a robust process of cost estimating related to the construction life cycle [7]. This approach shifts the contribution requested by the user from an analogue correspondence between processes, parts of work, cost items and dimensions, to the definition of a unique and unambiguous algorithm performed by computer that solves any problem using a finite number of elementary parts. In this context, the BIM method allows the construction of a database object-structured for Data Lake use that simplifies and potentiates the management and analysis of Big Data, using information from potentially diversified and uneven sources. The potential of such a method amplifies the possibilities of integrated design leading to the construction of an integrated project delivery (IPD) approach. This method integrates people, systems, structures and business practices in a process that collaboratively involves all participants to optimize the results, increase value, reduce waste and maximize the efficiency through all stages of design, manufacturing and construction, going beyond the design to areas that are generally considered separate from the project itself and creating a structured decision support system [8].

As a part of the cost estimation, the related data sets are structured according to records that ensure the correspondence to work while allowing the development of specific data analytics and useful to different operators, who have an interest in the 5D. The compilation and automatic calculation of data significantly accelerates each procedure, optimizing the working time of the staff and ensuring greater control and processing speed, as leading to time savings for customers, designers and for the companies involved in the project.

The results of a cost estimate on a computational and parametric basis also have a positive impact on decision-making processes and planning: sharing and collaborate between all the actors involved in the process (prerogative of BIM), allows to constantly control the budget, being able to intervene with planned changes and integrations according to the operators' needs.

2.1 Information management

One of the most important aspects in the entire construction process, as well as the primary objective of BIM methodology applications, is the correct transfer of information between its different phases [9].

This need involves both the creation of information and the subsequent phases, as the need to compare alternative design solutions with a continuous updating of the models produced. In order to guarantee a correct transmission of information, it is necessary an effective bidirectional correlation between models and documents; in other words, the changes made to the information contained in a model connected to or deriving from another model, must generate a contextual update to the other.

The problem of identifying a certain real entity of the construction (such as a pillar, a wall, a window frame, etc.) in the different virtual models, to allow the correct transmission of information between them, also emerges in the cost estimates obtained as generated by BIM models [10]. In fact, in addition to what was previously mentioned, the price lists available today do not meet the needs of a BIM process, having been created in relation to materials and/or processes but not to the real entities represented by the objects used in the BIM authoring software; also languages, terminologies, criteria and construction techniques are significantly inconsistent.

It is clear that all this matters represent a deep impediment to the operational application of BIM methodologies. In fact it is necessary to introduce modifications in terms of lists specifically designed according to the needs of information modelling, rethinking the price lists as referring to the technical elements of the buildings and providing them with useful metadata for the definition of different parameters depending on the nature of the element itself.

The structuring of a metadata systems enables the following objectives to be achieved:

- *Identification*: verify the existence of an element;
- *Localization*: to trace a particular occurrence of the element;
- *Selection*: to analyze, evaluate and filter metadata;
- *Semantic interoperability*: to allow the search of classes of different technical elements with a series of equivalences between descriptors;

- *Resource management*: to manage the collection of elements through the intermediation of databases and catalogues;
- *Availability*: to obtain information on the actual availability of the element.

A metadata system identifies for each technical element one or more characteristics able to identify it from a performance point of view (e.g. mechanical resistance, thermal conductivity, fire resistance class, etc.). Each of these characteristics, consisting of its identifying name, units of measurement and other information, is an attribute made available as metadata, which can be used as an aggregator of information, recognized and used as search keys on a predefined data target. The list of metadata identified in each item of the price list can be reported in a single text string, defined according to taxonomies previously agreed [11].

2.2 Site digitisation and field BIM

The availability of metadata systems associated with the technical elements of the work corresponding to the objects that constitutes the information models also influences the IPD integration of the functions of construction sites management from the design phase and, particularly in relation to cost management [12]. First of all, it is necessary the definition and optimization of data and information flows coming from the operators and their surveys on site, in order to make production data collection more accurate.

In addition, it must be possible for these information flows to be fully transparent and shared between the professionals involved at different levels of responsibility.

Once the information model has been completed, it flows into a real-time operational sharing platform on site, which also has the possibility of controlling the access permissions of all the other professionals involved. At this point it is possible to carry out periodic quantitative and qualitative controls in the field, called Field BIM, using specific real-time management applications. The measurements made produce documentary information in terms of quantity, quality, time, cost, health, safety, environment and regularity, and are carried out jointly by the professionals in a timely, geo-referenced and documented manner.

Moreover, within the platform, it is possible to generate control panels (dashboards) that describe the performance of each company and subcontractors, site and safety managers.

As a result, it is the birth of the survey digitization, as the decision-making processes become easier because of the speed of detecting phenomena.

Therefore, during the construction phase, quality and quantity controls are carried out on site on pre-established and periodic dates, and the data obtained are reported in the information model for each element subjected to control. Surveys then enrich and update the model with respect to the progress of works, defining a first Object POW (progress of

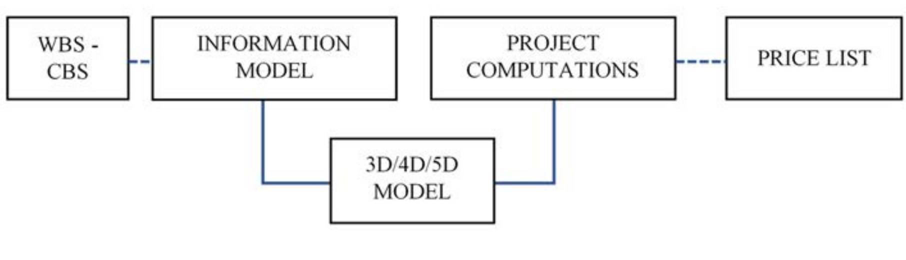

Figure 4: Overview of the execution phase in the proposed methodology.

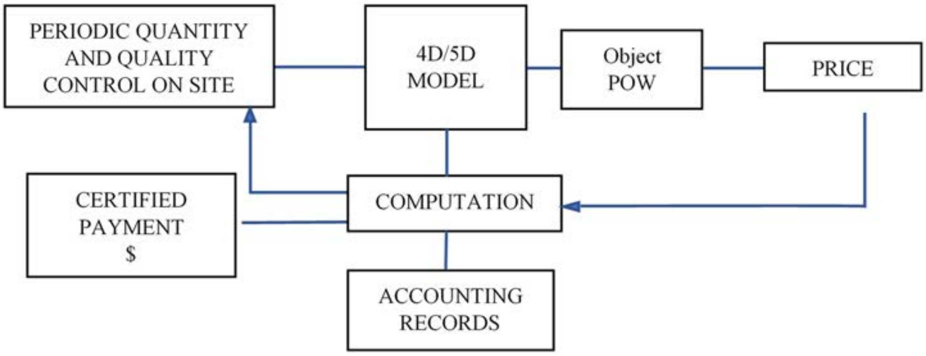

Figure 5: Overview of the construction phase in the proposed methodology.

work), which refers to the booklet of computations, which is updated following the initially chosen price list, filling in the accounting register. From here it is possible to draw up the "Progress of Work" (POW n.), relative to the works that have been concluded and for which the company is going to be remunerated.

The BIM methodology requires that the computation operations take place automatically and this can be possible only defining a unique coding system that connects the BIM objects with the project WBS, and simultaneously with the costs. This system is initially included in the information model and is a baseline for optimizing cash flows [13].

Following the POW issue, on the one hand a payment certificate is generated and consequently an economic exit is acquired, while on the other hand the process is repeated and the model is updated once again until it is verified the completion of all objects and each activity is finished. From this moment the construction can be declared completed and the Operating and Maintaining phase will begin [2], [14].

3 CREATION OF RULES SET FOR QUANTITY AND COST CHECKING

The use of models for drawing up the computations is one of the most frequent BIM uses, as already said, by modelling it is possible to create objects defined in their qualitative and quantitative characteristics, which can be used directly to determine the quantities of work to be carried out and to define the cost of each work [15].

Through the analysis of a case study it is shown a methodology that allows an optimal BIM-based estimation, and at the same time it represent a useful instrument to configure a verification system.

This experimentation, with reference to a specific project management activity carried out as part of the design and realization of an entire multifunctional district (consisting of six buildings for offices, hotels and commercial spaces), methodological purposes overlap with those of a purely instrumental nature, according to the macro-phases developed below.

3.1 Analysis of the information models received

The experimentation was carried out starting from the models produced by designers, who were analysed on their geometric correctness (ensuring that the quantities extracted from the model were conformed to the real quantities), on the completeness of the object information and the congruence between the content of the information models and that of the other processed products.

Figure 6: Example of export data from the IFC model.

3.2 Review of the information models to make them suitable for the set objectives

This phase involved an intervention on the models with the aim of solving the defects of correctness, completeness and congruence previously detected, in order to simulate a useful configuration to define a best practice and assess the potential of the adopted approach.

3.3 Extraction of the information content in IFC format and verification of the obtained model

In this phase, it has been evaluated the results of the modelling interventions of the previous phase, in particular exploring the possibility of a coherent transfer of information through interoperable formats such as IFC, using its common property sets and base quantities to convey the quantitative attributes of each class of objects.

3.4 Importing the IFC model into the computing and budgeting environment

In this phase, it was developed the experimentation of Vision CPM software of STR – Team System Group for the verification of quantities from which the computations derive.

This solution combines the specific functions of a tool designed for computation with the guarantee of consistency between computations and project documents, as the quantitative data is obtained directly from the parameters of the information models.

Within the computing environment it has been created a specific calculation rule which, starting from a filter applied to the objects and to the information contained in the model, acts on the filtered data according to the defined specifications, linking the article to be applied (and a possible WBS code) to the identified objects. Once the calculation rule has been applied, it is possible to create a quotation line that derives from the processing of the quantitative data of the objects included in the filter.

The primary advantage of using calculation rules is the possibility to process simultaneously the quantitative data of a plurality of objects falling within the defined filter and the possibility to reuse them in different projects. In fact, an organization could create its own library of rules, as a catalog to be applied extensively, after checking the uniformity in the compilation of those parameters attenuated by the filter, taking care to update them whenever the reference price list changes.

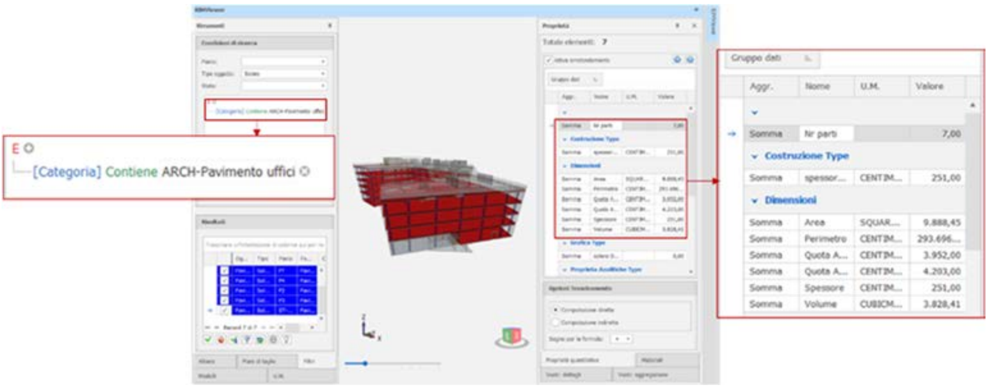

Figure 7: Example of a calculation rule filter-based.

3.5 Creation of a summary report comparing expected and detected quantities

The objective of this activity was to generate a summary report that would also graphically show the deviations between the quantities calculated in the verification phase and those expected from calculations, to identify the appropriate corrective actions to be implemented.

In this case, the 5D modeling allowed to obtain, after verification operations, infographic results that effectively describe this deviation, representing it automatically setting Pivot tables able to compare the values, one expected, the other detected, and to generate graphs and other summary outputs to describe the entities.

4 CONCLUSIONS

The construction industry is facing several changes generated by the use of information technologies, and in this context BIM methodologies is inserted as a new approach of project management, from its conception to the design and construction, up to the maintenance phase during the entire life cycle of the work. The objective of this study was to analyze how the phase of cost planning and scheduling can evolve in the construction process, up to the evaluation of new future prospects of digitization of the site management in its multiple and articulated aspects, while identifying needs and possibilities.

First, the main scenario to be implemented concerns the definition and optimization of data and information flows from operators and their surveys on site, with a view to a wide transparency of these information flows that can be fully shared by referring to a common and participatory database.

The change needed consists in increasing collaboration, transparency, formation of new specialized figures and aware of the technological development, always considering the need of new computational logics generally valid and bidirectional. The result of the application of these methods verifies the solid link between modelled objects and the associated information, which lay the foundations for the subsequent development of information models oriented to the fifth dimension.

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