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BIM for infrastructure:
an efficient process to achieve 4D e 5D digital dimensions

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Abstract

The introduction of Building Information Modeling (BIM) approach in Civil Engineering practices allows an optimization of design through both an improved control of all the components of the project and an increased efficiency in the collaboration between all the professionals involved. In Italy, an increasing attention is being paid by scientists and professionals on the matter, especially due to the publication of the national law DM 560/2017, which will gradually rule the integration of the BIM-based procedures for contractors in major public tenders. The present paper aims to propose a methodology for implementing a dynamic model that permits to optimize time (4D) and cost (5D) efficiency in the different project phases. To achieve this goal the process relies on several authoring tools and 4D/5D modeling software, capable of enclosing the multiplicity of the project data in a unique and shared environment. This study focuses on the most effective methodology to maximize the interoperability between the various used codes. To this effect, a dynamic model involving an optimization-oriented approach for both the quantity surveying and the definition of the design management timeline is presented, which stand as two of the major issues concerning the evaluation criteria of a civil engineering project. Finally, it is important to underline that this bidirectional process allows for an advanced costs estimation of the project and an optimized timeline of the construction activities. Moreover, in case of unavoidable changes during the design phase, it permits to effectively reiterate the process with significant reduction on the overall computational times.

Keywords: Project Management; Infrastructures; BIM; Time and Cost Optimization.

1. Introduction

Recently, the Building Information Modelling (BIM) process has been progressively implemented worldwide in the Architecture, Engineering and Construction (AEC) fields (Eastman et al., 2001).

The development of BIM in civil engineering applications is supported by an European political momentum trying to improve the efficiency of the construction industry. In fact, as mentioned by the European Union Public Procurement Directive (EUPPD) (EU, 2014) "*the 28 European Member States may encourage, specify or mandate the use of BIM for*

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publicly funded construction and building projects in the European Union by 2016" (Wang et al., 2014; Sacks and Gurevich, 2016).

In Italy, BIM-based procedures for contractors have been integrated in major public tenders by decree of Ministry of Infrastructures and Transports (MIT, 2017), which targets a greater efficiency and effectiveness in the entire public works sector. The decree defines timetable and details of the progressive introduction of the requirement of specific electronic methods and tools and identifies their field of application. Furthermore, it imposes these methods and tools to be applied in all aspects of the design construction and operation of a civil structure (e.g. bridge, buildings and infrastructure).

It is well known that BIM is a conceptual model that allows a parametric approach able to store all the data related to a specific project within the proposed model. In fact, a wide range of information converge and collaborate to a civil structure design, in the various design process phases. The level of detail (Levels Of Definition – LOD) of the BIM model increases as the project proceeds: in the first phase the information contained in the model are usually limited to the preliminary project, while in the subsequent phases it passes from a simple conceptual model to a virtual model ("As-built") until the constructive level. The LOD are required for all the objects in the BIM model, in the different design phases.

A BIM Execution Plan describes for each specific project the LOD that every BIM authoring discipline must guarantee in the established deadlines. Seven levels of LOD are defined in function of geometry of the element, graphic representation and attributes.

To analyse in depth the multi-aspects of design information required to control the entire design process, many other dimensions need to be added to fulfill requirements of a BIM process. In fact, according to Lee et al. (2005), the nD model is an extension of the 3D BIM model having multi-aspects of design information required at each stage of the lifecycle of a building facility.

To achieve a greater control of the project, time factor quickly became the fourth dimension of BIM environment (Lopez et al., 2016; Zhang and Hu, 2011). Using 4D BIM, different plans can be compared by visualizing the work sequences along with the duration of each task. In addition, by incorporating information regarding the resource consumption, 4D BIM simulations turn into 5D BIM simulations, which can help understanding resource utilization over time. 5D BIM has been studied and improved by only few researchers (Lu et al., 2016; Mitchell, 2012, Matejka and Vitasek, 2018).

Although the fourth and fifth dimensions seem to have gained a certain rate of prominence, they will be explored in this study to optimize the entire design process. Therefore, a novel dynamic approach is proposed with a view to the integration of time and cost in a synergic system that allow to support the design process.

The study is outlined as follows. Section 2 shows the background on the potentialities of the 4D and 5D dimensions. Then, the entire modelling process with the use of various authoring and simulation 4D and 5D software, oriented to the optimization of the quantity surveying and to the definition of the works timeline, is discussed in Section 3. Finally, conclusions and future perspectives about this novel approach are proposed in the Section 4.

2. Background

Time and cost variables are two of the most important variables in a design process, especially for infrastructures, and their definition is sometimes object of several political issues. Considering time and cost variables in a project means solve a typical engineering problem by trying to find the best solution in terms of efficiency and effectiveness. The *optimum* is achieved when the project maximizes the quality and the effectiveness of the solution and minimizes time and cost of realization.

From a practical point of view, to optimize the design process of an infrastructure an iterative process is required, starting from the proper design process, passing through to the quantity surveying and finally ending with to the timeline definition.

In the traditional design approach, in the development of the subsequent phases described above, the quantity surveying and the timeline are closely related to the first design hypothesis in a one-way dialogue. Therefore, any change in timeline does not correspond to an update in design parameters and quantity surveying.

The novel approach presented in this study addresses the solution of this problem, proposing a dynamic model that can integrate time and cost variables in a bi-way model able to simultaneously update the parameters of the proper design model, the quantity surveying and the timeline at any modification. The proposed model is based on currently available commercial tools to orient the design process towards the optimization of the project.

3. Modelling

Due to the positive features of BIM procedures and technologies, a model able to manage and store all the data of a transport infrastructure project is built. More specifically, the choice of BIM-oriented software related to the proper design of infrastructure, the quantity surveying and the timeline are managed.

Furthermore, a standard project WBS is built and the procedure of time and cost implementation in the model is shown. Lastly, the advantages of a dynamic model that involves information related to times and costs of realization are described.

3.1. Software

3.1.1. Infrastructure model

First of all, the process provides the choice of the authoring BIM-oriented software more suitable for the modelling of a transport infrastructure. Currently, the most used software are: Civil 3D (developed by Autodesk), OpenRoads (Bentley), Roads (Sierrasoft). All three software effectively manage the infrastructure design and provide valuable support to designers. However, following an analysis of the tools offered by each BIM-oriented software, Civil 3D has been shown the most effectiveness to this purpose as it facilitates the integration between the structural or architectural elements, installations and the infrastructure axis, by allowing for the interchange of file formats. Furthermore, Civil 3D offers very useful tools to customise the parameters to be assigned to each digital object of the model.

According to the above, the BIM model was prepared for the development of the subsequent phases of the process by means of Civil 3D.

3.1.2. Timeline

The second phase is the choice of the software most fitting to the scheduling of the work phases. As for the infrastructure model an analysis of all the tools available to achieve the relevant objective is carried out. The timeline software is required to manage the scheduling of the work and to be interoperable with the BIM model and the software that will manage the quantity surveying. The following software weconsidered to the purpose: MS Project (developed by Microsoft), Primavera P6 (Oracle) and STR Vision CPM (Team System). Not all software allows to import an Industry Foundation Classes (IFC) file (ISO, 2016), but to overcome this problem, the possibility to connect the software through the creation of interface masks has been examined. As a result, due to the capability of import IFC files and the facility of management of timeline schedule process, STR Vision CPM was selected as timeline software in this study.

3.1.3. Quantity surveying

It is now necessary to define the software to draw up the bill of quantities. The most diffused software of quantity surveying are: Primus CAD and Primus IFC (both developed by ACCA software), STR Vision CPM (Team System).

After several tests with the three available software, Primus CAD does not seem to be the appropriate tool to implement in the infrastructure model the data related to quantity surveying. Indeed, the visualised model does not account for the geometric properties of the road solid prepared in the informative model, does not allow to consider IFC standards, and does not permit to compute the elements of the model and to associate them to a computation item.

On the other hand, despite Primus IFC considers both the IFC standards and the model properties, its major drawback concern the 3D model visualization and therefore, the reliability of the quantities read by the model that cannot be easily verified. The above is not valid for IFC models created with vertical authoring software, but for the model used in this application case, this visualization limit was decisive in the choice.

On the contrary, STR Vision CPM allows to view and read data and quantities of the IFC model exported by the BIM-oriented authoring software. Due to this latter, , it is possible to obtain an exact surveying that refers directly to the quantities of the information model of the infrastructure, through the procedures that will detailed later on.

Once all the BIM-oriented software of the process have been defined, the steps to build a unique dynamic model, from which all the information relating to time and costs might be obtained, will be shown in the paragraphs below. Regarding the actual modeling phase, the technical aspects of the single software will be omitted but some considerations regarding the prerequisites necessary of the model in the subsequent phases are provided.

3.2. Standard project WBS

To ensure that the BIM model be effective, a unique identification code for each item must be defined. Furthermore, it could be useful to give to the code a recognizable structure in order to compute separately the different elements. Therefore, for this purpose the use of the standard project WBS seems to be the most suitable.

The requirements of the project WBS are: i) uniqueness of the code for each element; ii) structure based on several levels as the macro-activities; iii) structure able to filter the elements that are realised in the same phase of the time schedule. Once the WBS code creation rules have been defined, the BIM Coordinator will define the shared parameters that each element of the model must have (a parameter for each level of the WBS structure) and the BIM Specialist will valorise each field of the different parameters with the code.
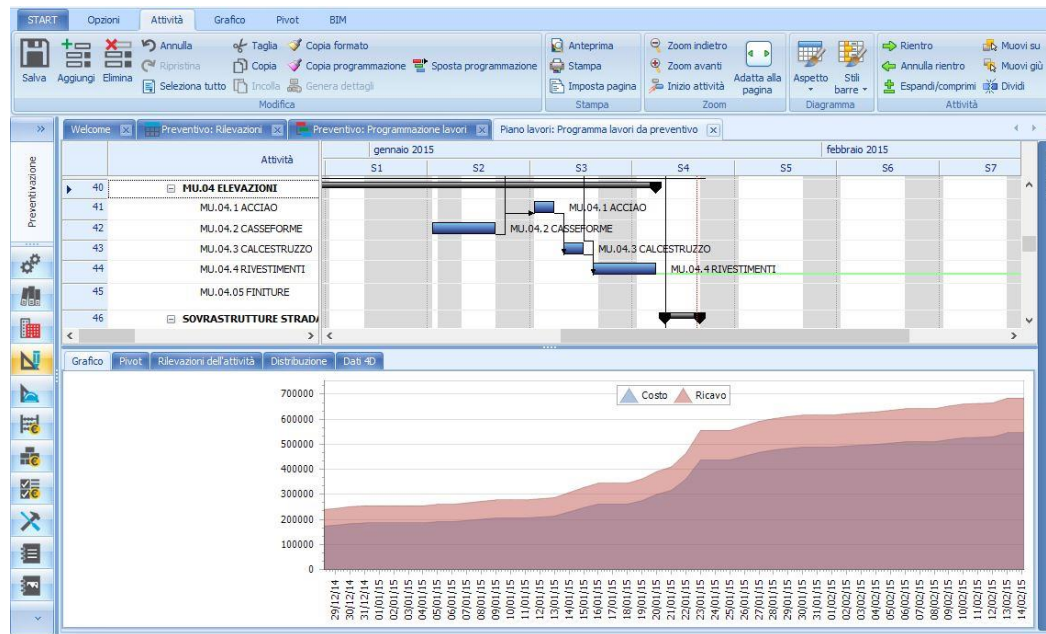
Fig. 1. 4D software interface.

3.3. Procedure

3.3.1. 4D – time variable implementation

The time variable implementation allows to link the different elements of the infrastructure model to the realisation phases identified in the timeline. This phase is made up of two sub-phases, the first one to be carried out in a project management software as STR Vision CPM (Fig. 1), the second one to be performed with a 4D simulation software such as Synchro (developed by Bentley), Navisworks (Autodesk) or Fuzor (Kalloc Studios).

The former sub-phase allows to create and analyse the timeline starting from the previously defined WBS, assuring the complete coherence between the items of the calculation and those in the project Gantt.

The second sub-phase provides to export the timeline from STR Vision CPM and import it in the simulation 4D software platform. In this way, the "dynamic interferences" are analysed, i.e. the interferences not related to the construction elements but rather due to the simultaneous presence of construction site vehicles in the same area for different activities.

Since this analysis is not always immediate it is necessary to refer again to the project WBS, which allows us to use the same parameters used for the calculation phase and then to ensure consistency with the rest of the documents.

3.3.2. 5D – cost variable implementation

After the implementation of the time variable, the procedure requires the implementation of the other variable that plays a key role in the design BIM model, the cost.

Up to this phase, the model contains a series of information on road element geometries, materials used and the timeline for each realisation that, by means of the WBS code, are associated with an item in the price list loaded in the computational software.

The IFC file is imported into the STR Vision CPM software and from the loaded model the quantities will be read and the price will be associated. In order to associate the price of any item from the list prices two procedures can be carried out, one manual and another automatic.

The manual procedure requires the selection of model elements directly from the software's internal viewer in order to quantify the costs of each element as the result of the product of the quantity read from the model by the item price. By repeating this procedure for all the characteristic elements involved in the project, an overall calculation of the work costs is obtained. However, this procedure takes longer respect to the automatic one and exposes to a higher rate of errors in the selection of the elements.

The automatic procedure allows the dynamic update of the calculation and the minimization of the manual work with consequent reduction of the probability of error at each operation. This procedure is referred to WBS code and it is based on filters.
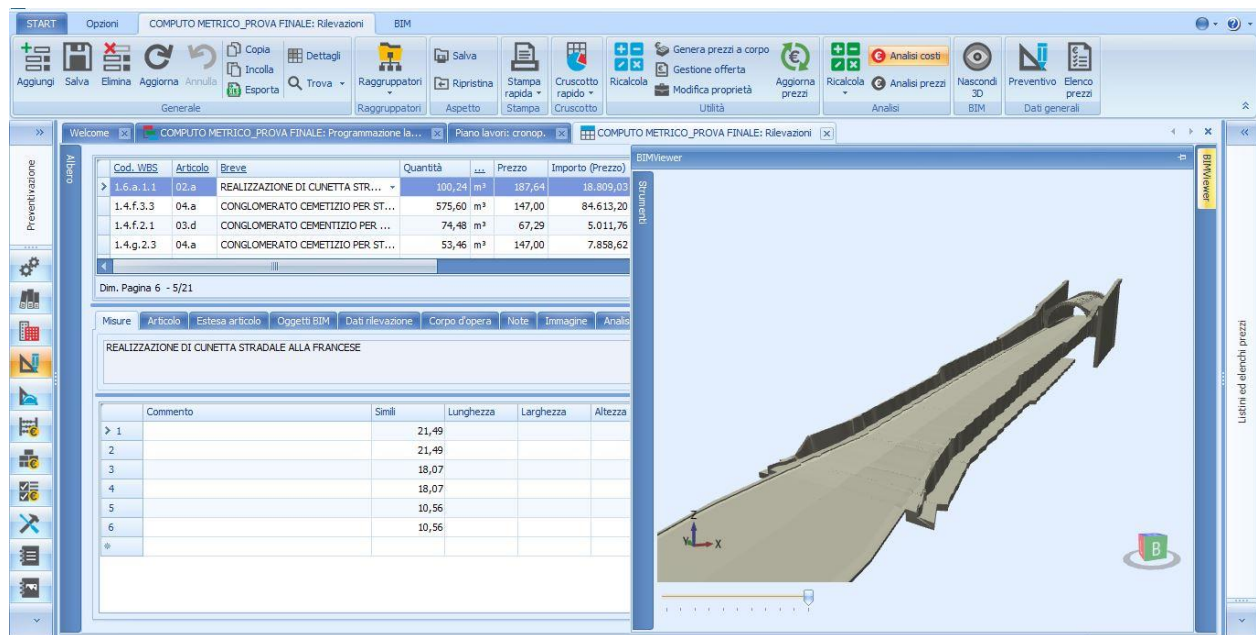
Fig. 2. 5D software interface.

The filtering rules of the elements called "BIM calculation rules" based on different levels of WBS depending on the type of activity must be set. These rules allow an advanced search of objects within the model through the property section containing the quantitative and qualitative information, the materials that make up the structure and other details.

Thanks to this function it is possible to update the calculation with every change of the project informative model instantly and in addition to that, the rules set out can be used in other estimates. In fact, by reloading the IFC file, and through the calculation updating function, the program automatically recognises the elements modified, deleted or added and dynamically updates measures, quantities and costs (Fig. 2).

It is important to underline that before importing the IFC file in the computational software, the validity of the file in all its parts must be assured by model checking and integrity validation procedures, being it model-dependent.

3.4. Dynamic model approach

The procedure described above allows to have a model dynamically updated according to the basic factors composing it, namely, the basic informative model of the infrastructural work, the time schedule, the price list and the project WBS. What is still lacking to automate the process and, therefore, to build a model that is actually dynamic, is the direct relationship between the bill of quantities and time schedule, which becomes crucial in the more advanced phases of the design and construction process (for example the construction project) where the methodology used to perform a given processing is fundamental for the definition of the calculation.

Below the authors want to propose a methodology to make the bill of quantities and the time schedule depending on each other.

In order to create a process that puts the BoQ (Bill of Quantities) and time schedule in relation one to another, it is necessary to further discretize the BoQ entries. It is here proposed to divide the BoQ into two sub-categories: BoQS (Bill of Quantities of Supplies) and BoQR (Bill of Quantities of Resources).

This is necessary to make the BoQ dependent on the model. In fact, in this way the BoQS only depends on the quantities outcoming from the BIM model (technical project) while the BoQR solely depends on the time schedule, as it is built by multiplying the different resources identified by the time schedule for the daily cost.

The method assumes the creation of the informative model of the infrastructure, complying with the project standards necessary for the preparation of the various elements for the subsequent valorisation phase with the multiple information previously discussed. One of the information that must necessarily be entered is the WBS code. This obviously can be done only after defining a project WBS that meets the criteria already described in paragraph 3.2, which now becomes indispensable given the next use of this code in the automated procedure.

After creating the informative model and assigning a unique and standardized code to each element, it is possible to proceed to the construction of the Bill of Quantities of Supplies. The first step is to import the BIM model created so far into the quantity surveying software.

Within the quantity surveying software, the fundamental step is the creation of an interface mask between the price list and the WBS codes.
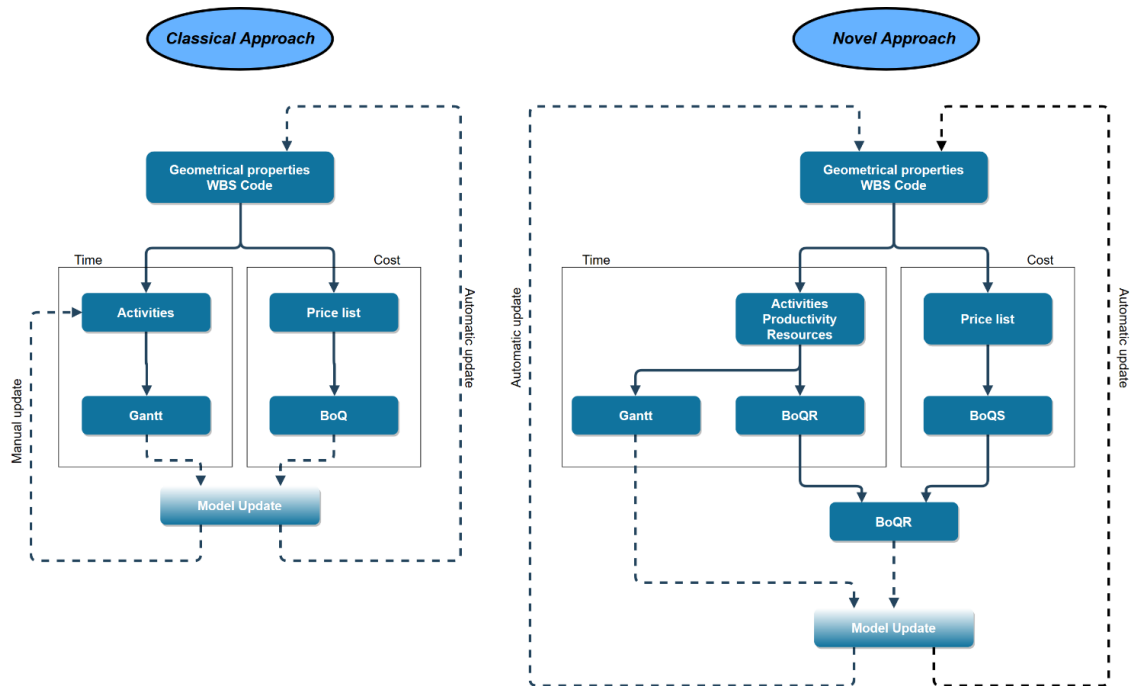
Fig. 3. Procedure flow chart.

In fact, through this association it will be possible to link each item of the price list to each element of the model which, as already mentioned, will be characterized by a unique WBS code.

The assignment of the cost items at this point will be automatic and precisely for this reason free of errors (also in this case we must remember that the model with its elements and respective WBS codes must be verified very carefully, since an error in their modelling or compilation may result in an error in the BoQ).

At this stage, we are in possession of a model from which it is possible to extract the information necessary for drawing up a bill of quantities for what concerns supplies (BoQS). To this intent, it is possible, as usual, to structure the document in different ways, due to the item costs to be grouped. Also in this case, we can refer to the WBS codes by combining the items according to the different levels of the WBS itself.

The extraction of the BoQS at this point, having taken care to prepare a reference template, is immediate.

However, the BoQ is not yet complete as it has been divided into two parts, one relating to supplies and one relating to resources. The second, the BoQR, needs the definition of the time schedule to be constructed in the following way.

We will have to determine a rough work program that can be defined starting from the subdivision of the WBS used so far. It is also necessary to define the quantity, productivity and daily costs of the resources available, information that can be modified and updated even further.

At this point, in the project management software, it will be possible to assign the newly defined resources to the different activities and it is possible to have the execution times of the various activities automatically calculated using the resource productivity information and the quantities readable from the model elements previously assigned to those resources.

As an example, the activity of building the foundation of a retaining wall, to which a working team composed of different vehicles and workers of known productivity and hourly cost are assigned as a resource, is considered. The procedure described above allows, through the project management software, to read from the model the quantity of concrete of the foundation of the wall and this information, together with the team's productivity assigned to the activity, permits to known the time of execution.

This execution time will be then multiplied by the daily cost of the team in order to defining the labor cost for the specific activity.

To extend this reasoning to all activities it is necessary to go through the resource diagrams. As usual, it is possible to extract the Gantt and the resource diagrams. Thanks to the latter, the software can count the working days of each resource, simply multiplying them by the daily cost of the same.

A computational structure will be created as previously done for the BoQS and finally, adding the BoQR to the BoQS will lead to the complete Bill of Quantities.

The execution of the procedure described above allows a complete dynamism with respect to modifications concerning:

- The BIM model: with each change, the BoQS will be automatically updated, the duration of the time schedule and consequently the BoQR and therefore the BoQ;
- The time schedule: modifying the logical order of the activities in the schedule, the BoQR and therefore the BoQ will be updated automatically.

It should be noted that at each modification of the model, and therefore of the technical project, the time schedule will be updated only with regard to the duration of the activities deriving from a different quantity of a specific element, but the logical order of the activities will not change. In fact, this process will always remain at the discretion of the designer. In the same way, it must be remembered that, since this procedure is completely automatic, it will not be possible to directly modify the duration of the activities in the timetable since these depend strictly on the amount of resources assigned to them and their productivity.

In order to clarify the procedure described so far, a brief outline of the flow of information is proposed in Fig. 3.

4. Conclusions and future perspective

In this paper, a wide portion of the existing literature regarding the specific topic of BIM is reported. In particular, fourth and fifth dimensions are explored to have a better control of the project.

4D allows to link the tasks in a project plan with 3D model components and compare different proposal plans by visualizing the work sequences and duration of each task, enabling to: identify problems that may not be visible via traditional schedules; run scenarios to assess feasibility of execution and find the best solution; see the impact in 3D after updating the Gantt chart; analyse how the build process will appear at different project stages; identify e resolve potential dynamic interference between the different teams on site.

With 5D simulation, it is possible to generate models which show how modifications with materials, layouts, constructive methodology and other design elements influence the display of an infrastructure as well as the cost and can help understand resource utilization over time.

The construction costs are modified automatically in real-time with the alteration in the model and "What-if's" turns to be productive and captivating solution for the project team members in order to identify the best design layout.

A novel approach of the integration of time and cost in the BIM process of a transport infrastructure, orienting the design process to an optimization of the project is proposed. This approach aims to integrate time and cost variables in a unique two-way model. This allows, as the model changes, to dynamically update, in addition to the bill of quantities, also the time schedule and once the various parameters and constraints have been defined, gives to the designer further possibilities to analyse more design alternatives in less time.

Acknowledgment

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