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OpenBIM methods and tools for schedule and cost management

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Abstract.
Building Information Modeling (BIM) methodologies and approaches are becoming topics of increasing interest within several infrastructural engineering applications. As far as Construction Management (CM) is concerned, BIM technologies provide a valid support-decision tool, which includes a repository of CM-related data, useful for any further development and use.
This work presents current Infrastructural Building Information Modeling (InfraBIM) implementation possibilities regarding the correlation between information digital modelling, schedule and cost management dimensions.
The methodology is applied to case studies simulation of excavation and construction phases in underground structures to generate budgeted cost and time schedules linked to BIM models.
The major benefit in applying such approach results in obtaining a model with different types of information that can be updated during the design and construction phases**.** Also, the associated workflow management system allows to update the 3D model, time schedule and cost estimation while maintaining relations and interconnections previously defined between model components and specific information on their activities and cost. Another key result is about the chance to communicate design and construction schedules via Virtual and Augmented Reality (VAR) techniques, which provides a consistent support tool for the visualization of infrastructure projects.

Keywords: InfraBIM, Interoperability, database, 4/5D, WBS, CBS

1 Introduction

The development of BIM models linked to project schedules is an interesting topic for the Architecture, Engineering and Construction (AEC) sector, which is undergoing its digital transformation process. In particular, the process is even more important when it comes to infrastructures: the application of BIM for infrastructure construction projects is rapidly accelerating in the AEC industries [1] and construction records (e.g.,

cost information, field test results, and inspection procedures and results) are a significant component for the management tasks of infrastructure construction [2]. For instance, when approaching the construction of underground structures, the excavation and construction phases are so closely connected that the construction schedule must take into account constraints and necessities of both processes.
The objective of this study is twofold. It presents the development of specific implementation procedures regarding the correlation between information digital modelling and schedule and cost management dimensions within the environment of Infrastructural Building Information Modeling (InfraBIM) and the testing of the integration among platforms in order to define the best process to follow related to a specific focus. To this end, it is necessary to define a proper methodology able to keep the relationship between BIM model objects and WBS code-based project tasks updated with the progress of the project. In particular, the aim is to test the openBIM interoperability, to distance from the use of plugins and proprietary files in exchanging BIM-related and time/cost-related information among platforms and professionals. OpenBIM means a process in which professionals work with BIM using open Standards and namely Industry Foundation Class (IFC) format [3], developed by buildingSMART to enable interoperability among several disciplines both for design and asset-management.

2 Available methods

Current methods mainly use proprietary formats for the exchange of information because of data losses still present when using standard formats. For this reason, direct links and plug-in are often included within the data exchange process, mainly when linking BIM elements to cost estimation, for instance Sage Timberline via Innovaya, U.S. Cost, Nomitech and Vico Estimator [4]. IFC standard, in fact, is used mainly for data storage, because of the difficulties in data modifications. The IFC format gives the chance to export an interoperable format, but paradoxically not readily “operable”[5], which means that parameters of the model remain as attribute, so they are no more linked to the geometry by contraints. This means that objects are no longer editable using same modelling rules coming from a specific parametric software. In recent times, BIM platform are introducing the chance to import IFC models coming from other BIM authoring platforms and transform those objects into native features. The development of such possibilities is moving the attention towards the increasing use of openBIM processes, in which data exchange is guaranteed thanks to the standard formats for BIM procedures.

3 InfraBIM Proposed Methodology

The management of time and cost dimensions involved within the BIM process in an infrastructural project is a key-concept in the future of Construction Project Management (CPM). In this case, the aim is to supply the actors involved within the process with a time and cost-related database to retrieve and share project information through

the same platform (or several platforms with integrated data exchange process) during the whole project lifecycle.

The starting point is the definition of the environment in which the BIM model and its database are going to be used, namely the Cost Breakdown Structure (CBS) information and construction records centered on the Work Breakdown Structure (WBS). Then, such heterogeneous data collection is performed using Common Data Environment (CDE), defined as an "agreed form of information for any given project or asset for collecting, managing and disseminating each information container through a managed process" [6]. Therefore, it is possible to define a structure of the CDE, which best fits the requirements of the project organization.

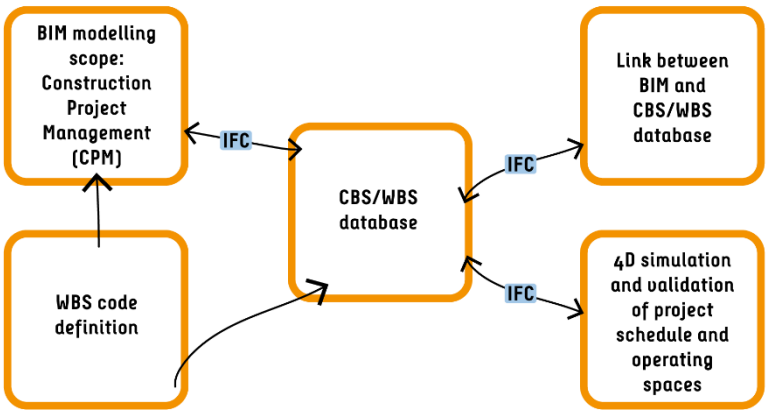


Fig. 1 Methodology framework

The methodology is then structured under five main sections (**Fig. 1**) : (i) the identification of BIM uses necessary for the modelling scope; (ii) the definition of a WBS code to classify BIM objects, based on constraints and requirements derived from the case study; (iii) the creation of the database for cost breakdown structure (CBS) and work breakdown structure (WBS); (iv) the link between BIM and CBS/WBS database; (v) the 4D simulation of the construction works and the validation of project schedule and operating spaces.

Firstly, it is paramount to have clear ideas about the scope of modelling, for instance Design or Facility Management, in order to approach the BIM process with a clear BIM use and calibrate modelling choices that could prevent mistakes.

Secondly, it is of paramount importance to define specific parameters for the modelling phase in order to set the BIM objects out for the next phases. Within this phase, a proper classification of objects has to be defined in order to match the digital components of the BIM model and project tasks. The BIM model is then exchanged using the Industry Foundation Class (IFC) standard format, in order to guarantee and openBIM procedure; for this reason, a shared and project parameter including the WBS and CBS code was associated to all components within the model.

The third step is the creation of a database for both the WBS and CBS; the present study develops a process in which the same platform is used for both database, linking

them to the IFC model through a definition of association rule sets. Once having completed the CBS, it is possible to use the same structure and model organization to define the WBS. Consequently, the schedule including tasks for the construction works and its attributes, such as name, start, finish, actual start, actual finish and status is developed.

The fourth step includes the settings of the automated linking mechanism among BIM objects and project tasks; thanks to the possibility to export parameters previously set in the parametric software as PropertySets, the IFC format contains the codes necessary to define rules able to assign IFC classes to the proper task.

After having proved the connection among objects and scheduling attributes, the 4D simulation of the construction works and the validation of project schedule and operating spaces can be performed, by simulating movement of work-site equipment vehicles.

4 Case Study

The present methodology is applied to the real case study of an infrastructural construction project to build one of the below grade stations of the underground metro line in the town of Torino, Italy, namely the Italia ’61 station. The case application of the methodology is illustrated in the next subsections.

4.1 Information model for Construction Project Management (CPM)

The term BIM itself implies the necessity to deal not only with 3D geometries but also with information, data, parameters, that define the real essence of the database behind the model. In particular, modelling with the scope of CPM means that digital objects are associated to information related to their classification useful in terms of construction activities. The case study presents several excavation and construction phases, that rule the breakdown of project tasks.

The construction method used for the case study metro station construction project is the “cut and cover”: it is characterized by a sequence of works, in which the construction progresses top down by successive steps. The excavation equipment digs a large trench in the ground, which is then covered by a concrete deck; once the desk is in place, the construction works continue below, repeating the sequence of excavation and slab cast. In the case of this underground station, after the consolidation of the soil realized through solid injections, the first step involves the installation of concrete diaphragm walls, before excavation starts, then soil is dig, to just below the slab level of the underground structure. Struts are then placed to support the diaphragm walls, which in turn support the soil at the sides, and roof slabs at ground and at first level underground are poured. The next levels of slab are then cast-in-place, so the process continues downwards until the base slab is complete. Such phasing structure is reflected in the model organization, so the model is divided in macro and micro phases.

The definition of a WBS code to classify BIM objects in order to link them with project tasks is considered one of the results of this phase, because it is strictly connected to the valorization of parameters assigned to objects in the model. The coding system has a four-level structure; Level 0 is referred to the general work, in this case the code is ITA61; the Level 1 indicates the field of competence of each element; the

Level 2 shows the progress stage of the general work and is structured in two codes, the first related to the macro-phase and second to the sub-phase; the Level 3 refers to the element type; the Level 4 indicate the progress code, useful when elements are part of other elements, for instance the element type code for reinforcements of diaphragms is related to the element in which the reinforcement is included.

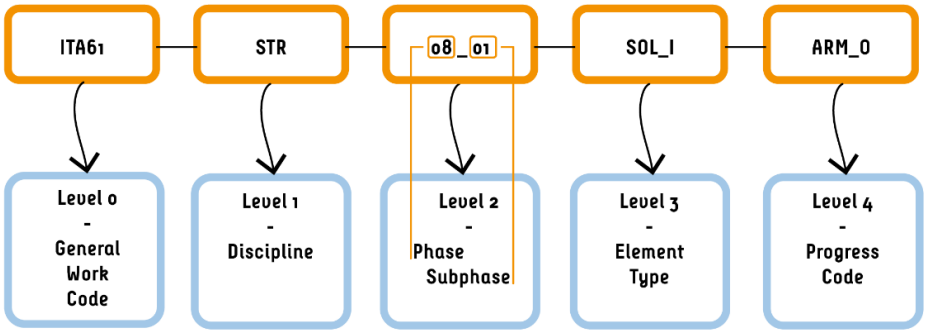


Fig. 2 WBS code structure in the case study

For example, the code "ITA61-STR-08_01-SOL_I-ARM_O" refers to the reinforcement of the intermediate slab (**Fig. 4**). The code is then assigned to elements and exported within the IFC format in the Property Sets in order to be stored within the BIM database and to be used for simulation and management purposes.

4.2 Linking the BIM model and the CBS/WBS in an openBIM environment

A theoretical goal of the current study is to test interoperability among software platforms within an openBIM environment; for this reason the process investigates the use of procedures able to guarantee an efficient data exchange process. The outcomes are the results of iterative tests useful to better understand the choices to be undertaken, in terms of modelling, parameters definition, etc. For instance, the tests related to data exchange using 2x3 IFC format give negative results in exporting parameters input from the user, such as the WBS code.

In order to establish the connection between the IFC classification and cost accounts, the software platform STR CPM Vision has been used; the choice was for this tool because it enables the recognition of BIM elements through IFC format and at the same time can manage both cost and time information.

Once the structure of the model is organized it can be used to perform both the cost estimation and the time scheduling. The framework is defined using "grouping tools" to better organize the model and its relative cost items in a hierarchical tree structure.

The BIM models have been uploaded using the appropriate section to import IFC models, then the cost items necessary to perform the estimation are imported within the project file. The quantities to be linked to the cost items are taken from the objects properties within the IFC model. The added value offered by the platform is the chance to set *Take off Rules* in order to automatically take off quantities from the models on the basis of the IFC Types or other properties included within the IFC. The link between

cost items and quantities from model properties enables the possibility to check how many elements are linked to cost items and their relative quantities. It is also possible to verify the accuracy of associations through graphical visualization, by selecting the cost item and under the BIM Tab selecting *Check estimated objects*. This connection is important when it is necessary to update the IFC model, by using the tool *Estimate update*. Here the user can decide which model in use has to be updated and afterwards the new model to substitute the previous one. In this way, thanks to the *Take off Rules*, the links are maintained. Furthermore, it is also possible to compare models and see highlighted the elements that have been changed from one model to the other.

After having defined the CBS database, the same structure of the model can be used to define the GANTT chart. In order to define the time to perform all the processing the parameter taken into account was the Hourly Production (P_o), then converted into the Unit Execution Time (T_u), which is the parameter useful in STR CPM Vision to determine the amount of time required to complete a specific processing. For instance, the Hourly Production related to the excavator is the following:

$$P_{O,Excavator} = \frac{1}{t_c} \cdot Q \cdot \eta \cong 120 \frac{m^3}{h}$$

tc = time for 1cycle = 20s = 0,0083 h
Q = bucket capacity = 1,3 m^3
η = yield = 0,75 [-]

After having calculated the Hourly production for each processing it was converted into the Unit Execution Time (T_u) as shown in the table [..], which in turn was implemented in the CBS to define the execution time of all items.

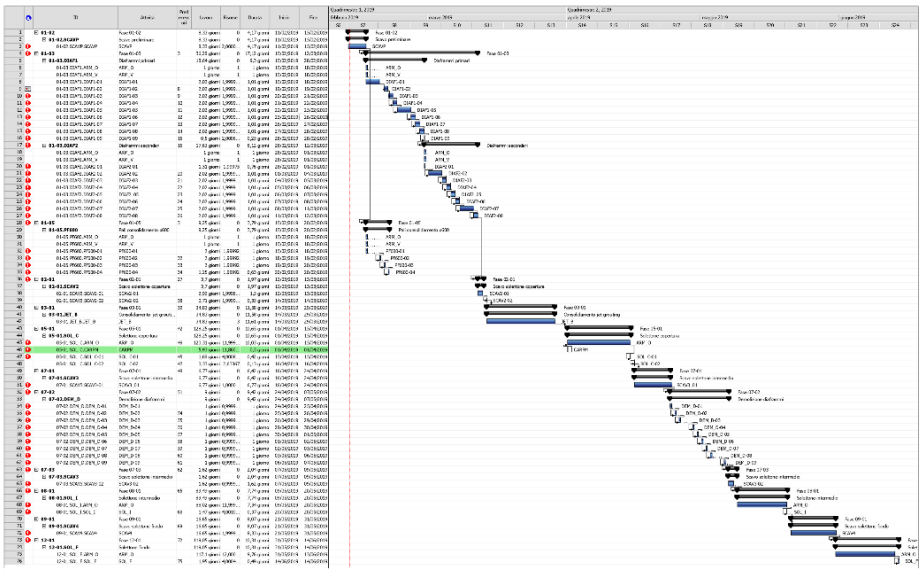


Fig. 3 GANTT chart

The following step involved the creation of the GANTT chart form the estimate; because of the association of unit execution time to each item, the schedule is created automatically, only the sequence of processing has to be defined. The code used to organize the time schedule is the WBS-code described in paragraph 4.1. and is set under the section *Job planning*. When the GANTT from estimate is launched for the first time all works start from the Project start date and each task is assigned a resource; so it is necessary to assign the correct number of resources to each task and to define the time order in which the activities must occur. The final result is shown in **Fig. *3***. The added value of the whole process is the link with quantities taken off from the IFC models; this means that once the models are updated, the execution time and Gantt chart associated with them and the costs of the works are updated automatically also.

4.3 4D Simulation and visualization

The time (4D) schedule of the construction works represents a valued tool to view and discuss aspects such as processing sequences, safety and specific relationships during the project lifetime. The maintained connection between object resources and schedule tasks allows for quick and easy changes and comparison baselines to alternatives, with the aim to organize a reliable and robust delivery process, saving money and time. In this case, the software chosen to perform this simulation is SYNCHRO PRO platform, which guarantees the possibility to use IFC models and link them to the project schedule defined previously, pursuing the goal of operating data exchange in an openBIM environment.

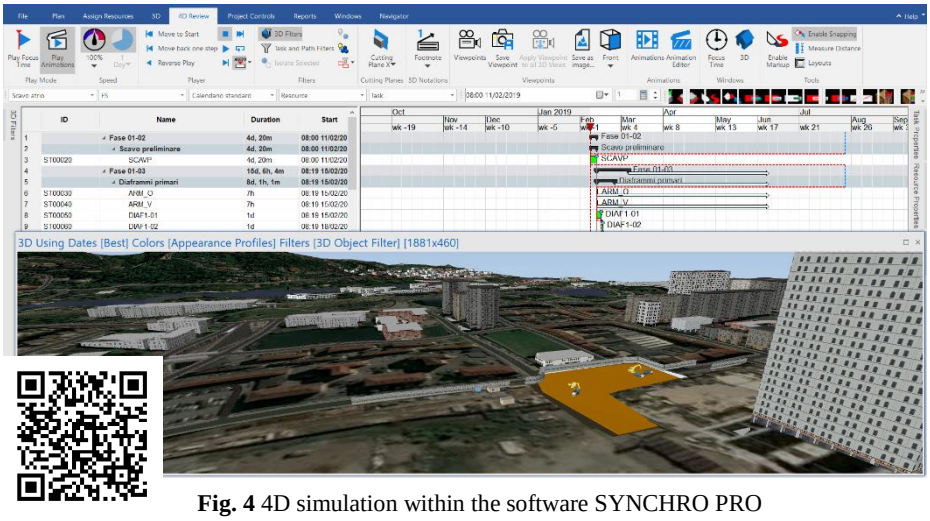


Fig. 4 4D simulation within the software SYNCHRO PRO

After both graphical and scheduling data are imported, the 3D *Resources* are associated to project *Tasks* with an *Auto matching* rule, using the progress code defined in paragraph 4.24.1 as parameter for matching. After having defined the rule, it is assigned to all Resources with specific value of progress code.

As far as visualization purposes are concerned, the *Resources* are assigned a graphical representation, which is coherent to the sequence of works. For instance, excavation activities are assigned the property of "demolition", so that in the animation the volumes excavated are gradually removed within the animation.

The output of this phase shows the construction works animated reflecting the progress of works as estimated in the project schedule; to make the simulation more realistic and comprehensible the context of the model and construction machines with their own animations are added to the model.

The visualization of such models is even more effective through the use of visualization technology such as Augmented Reality (AR), enabling the interaction among real and virtual worlds by adding virtual contents in the real environment. The application Synchro XR gave the chance to visualize the model created and managed on SYNCHRO PRO using Microsoft Hololens. Such a way of visualizing the construction works has a great impact mainly to "non-expert" people, so it represents a valuable tool for communication purposes.

5 Discussion

The process followed has brought successful outcomes in linking the IFC classification to the CBS/WBS database within an openBIM data exchange context, having as a result a structured organization of linking project cost and schedule elements to digital objects of physical components.

The added value is the chance to use standard file formats to exchange data among several platforms and professionals in an openBIM environment, in order to increase the flexibility in the choice of software to develop specific simulations.

The process also highlighted main weaknesses related to the use of a standard format, which is still under development for specific objects, mainly for the infrastructural construction sector. For instance, the information related to the weight of the reinforcement bars was not exported using the IFC file, so it was necessary to export schedules from the parametric modelling software and upload them in STR CPM Vision as reference for the quantity of reinforcing. This operation was not an automatic linking mechanism, so it represented a risk that could compromise the whole process.

Another weakness revealed was related to the version of IFC. By testing interoperability between the parametric modelling software and the WBS/CBS platform it was noticed a slight difference between the two formats IFC 2X3 and IFC4. The IFC 2x3 managed to properly export the geometrical information of the model, while all object quantities-related data was lost. For this reason, the suitable version of IFC used for the data exchange was the IFC4.

As far as scheduling information is concerned, to exchange WBS-related data it was necessary to export the GANTT chart from STR CPM Vision using the MS Project format, opening the file and saving it, before importing the schedule in SYNCHRO PRO, because there is still no direct link to exchange data from STR CPM Vision and SYNCHRO PRO.

In general, other issues were observed during the modelling phase in the fact that for some objects, for instance structural retaining walls of the underground station, there was no specific correspondence in categories of elements within the parametric modelling software. This is reflected in the absence of specific IFC classes and entities for infrastructural elements, which means that it is not possible to define rules to associate IFC classes with specific tasks. The result is that IFC class of IfcWall is used not only for regular external walls, but also for walls that have different function. This situation is going to be solved gradually by the implementation of IFC classes from the infrastructure domain.

As a result of modelling, the project virtualization and digitalization makes graphic documents available, when properly arranged, as well as non-graphical information, because the model and WBS/CBS database contain all alphanumeric data.

The 4D/5D simulations managed to link the parametric model to different data-source information, for instance the time schedule of the construction process. The construction animation shows the construction process, pointing out information such as day, time and percentage of work completion. As far as visualization is concerned, valid results were obtained mainly in the consideration of the visualization of construction works during the design phase, useful to prevent possible difficulties or unexpected events. The animations also gave the chance to have a preview of the final appearance of the underground station project and compare different construction scenarios among them, if necessary.

Within this context the visualization in Augmented Reality (AR) is useful in terms of checking and validating works during construction, because it enables an on-site supervision and model verification.

6 Implications

The case study has both theoretical and practical implications. On the one hand, it provides researchers with suggestions on how an openBIM process gives benefits, is structured and correctly set. Furthermore, the increasing use of openBIM procedures is triggering off interest research activities with the aim to implement new IFC Classes for the Infrastructure sector. For instance, IFC5 is expected to include extensive support for several infrastructure domains, such as IFCBridge, IFCRail and IFCTunnel [7].

On the other hand, it provides practitioners with a procedure that can be followed in order to appropriately and effectively organize the link between BIM models and cost/time-related databases within an openBIM process. The case study application can be extended to a general use purpose. The first step is to identify the BIM process for the development of the information modelling scope, on the basis of constraints and requirements imposed by the specific use case. Once the modelling is adapted to the identified scope, then a code to classify BIM objects and automatically link them to cost items and projects tasks has to be defined and used in the definition of rules. Finally, the 4D simulation of the construction works is performed in order to validate the project schedule.

7 Conclusion

To sum up, the present paper reports an openBIM procedure in organizing modelling approach towards the correlation between information digital modelling, schedule and cost management dimensions. The application shows major benefits in approaching the whole Life Cycle Assessment (LCA) of the infrastructure. It enables to obtain a model containing different types of information that can be updated during the different phases of design and construction of the asset, as well as during Facility Management (FM) activities. Also, the associated openBIM workflow management system allows to update the BIM model, time schedule and cost estimation while maintaining relations and interconnections previously defined between model components and specific information on their activities and cost.

Future research directions are related to the chance to use structured BIM/WBS/CBS database in order to develop further interactions among models and construction sites, in order to improve the real added value of such integration. An example could be the development of monitoring tools for construction sites that integrate laser scanning data and compares it with 4D model and schedules for a better installation verification.

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