Implementation of an Open and Interoperable Process to Optimise Design and Construction Phases of a Residential Building Project: a Case Study using BIM in a Public Procurement

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ABSTRACT

Building Information Modelling (BIM) represents a long-term investment that could allow reduction of time and cost control by optimising design and construction processes. It also ensures greater effectiveness of control systems. The paper is focused on a public procurement case study regarding the BIM-based validation and construction optimisation of an actual residential building designed in a compact urban context of Milan, in a confined construction site affected from lack of space and coordination problems. The scope is the implementation of an interoperable IFC-based process to perform advanced model and code checking and to effectively manage the construction phase through 4D modelling. Architectural, structural and MEP models were enriched with alphanumeric attributes as required for semi-automatic validation processes. Auto matching between BIM objects and construction activities was also achieved. The experimentation project showed the possibility of a rapid validation of the model and an advanced coordination between design disciplines. The construction site simulation allowed the comparison of different layout options and baseline schedules. The research also tested the joint use of model checking and 4D modelling tools to manage the percentage of completion of the construction progress and to support H&S management through the IFC export of a specific configuration of the plan of work directly from the 4D BIM software. The proposed process created an open, interoperable and multidisciplinary approach involving designers, project managers and construction companies.

Keywords -
BIM; IFC; Open BIM; Interoperability; Collaboration; Model and Code Checking; 4D BIM; Construction Management

1 Introduction

The proposed case study represents the first Italian BIM experimentation for a Public Administration (PA). The aim was to test advantages of BIM compared to traditional design and construction management practices in a public procurement. Architectural, structural and MEP designs of a new three-floor residential building with two underground floors were modelled by using an OpenBIM approach. The various disciplines were modelled in dedicated BIM authoring software and then merged into a federated model through the Industry Foundation Classes (IFC) interoperable and neutral data format [1].

Nemetschek Allplan 2014 was used for structural and architectural models, while DDS-CAD of the Norwegian Data Design System was the BIM authoring tool used for modelling MEP systems. Model and code checking was implemented with Solibri Model Checker (SMC) v9 in order to check quality and internal consistency of building information models and regulatory compliance of the project. Synchro Professional was the software chosen for 4D Building Information Modelling (4D BIM) and construction management.

BIM benefits were obtained from the very first steps of the experimentation. Coordinated 2D drawings were extracted from the federated model and a better control of quantities allowed more accurate cost estimation. Moreover, geometrical and alphanumerical attributes were defined in the building information models and they were used for further BIM-based analyses.

2 Building Model Preparation

Model Checking and 4D modelling are the BIM-based analyses conducted during the experimentation. The purpose was the implementation of an interoperable and semi-automatic IFC-based process to perform advanced model and code checking and to effectively manage the construction phase through 4D modelling. To this end, the information model was enriched directly in the BIM authoring tool of all the informative content needed to proceed to the next phase of analysis. A preliminary BIM Execution Plan (BEP) defined BIM-goals as a function of which geometrical and, above all, alphanumerical attributes were embedded in architectural, structural and MEP models. In order to achieve a certain level of automation, a careful and detailed modelling and information management phase was needed. Allplan native data were exported to Microsoft Excel to add the required attributes directly in the spreadsheet. The updated Excel file was imported back in Allplan and the building information model was automatically modified. The external link to the Allplan database allowed the easy management of the necessary BIM requirements for checking the model against code checking rules. The same process was implemented for the 4D BIM: in order to ensure the automatism of the connection between the 3D model and the plan of work an appropriate parameter, called Activity ID, was associated to each element.

3 Model Checking: BIM Validation, Clash Detection and Code Checking

IFC models of the various disciplines were exported from Allplan and DDS-CAD and imported in Solibri Model Checker. During the model checking phase geometrical and alphanumerical information embedded in the models was used to check different aspects of the Building Information Model, and so of the project. A customised parametric ruleset was created in SMC and organised in three consequential checking phases [2]: BIM Validation, Clash Detection and Code Checking. During the modelling phase, as well as at the end of it, IFC models were regularly checked for quality and internal consistency by the BIM Validation ruleset. After that, clashes were detected, before in individual disciplinary models and later in the merged one. Compliance of the model to Italian codes and regulations was the last checking phase.

3.1 Ruleset Creation

Solibri Model Checker contains a library of rules whose parameters can be customised by the user. Some of these rules were properly configured and used to create a new ruleset through which the various aspects of BIM models were checked. The ruleset is divided into three phases of BIM Validation, Clash Detection and Code Checking. Each of these sections is in turn organised into rulesets of lower level, divided by themes and types of control, and contains within it both parametric rules and simply textual ones with references to BIM requirements and Italian regulations (Figure 1). Titles and description fields were filled in the Italian language in order to facilitate the implementation of the tool for the internal use of the Public Administration. BIM validation and clash detection rules were enriched with references to the best practices of information modelling and management specified in the Finnish Common BIM requirements 2012 (COBIM 2012). The reference is primarily to Series 1 - General Part [3] and Series 6 - Quality Assurance [4]. Some rules can be checked semi-automatically while others require a manual control. In the latter case the rule itself represents a sort of reminder for the checking phase.

Code checking rules were implemented by translating in parameters some parts of different Italian codes and regulations for residential buildings. The RASE (Requirement, Applicability, Selection, Exception) Methodology was applied to translate the normative text into a computable language [5]. The building information model was checked against sections of the current residential building code of Milan and against sections of the Italian fire safety code for residential buildings.

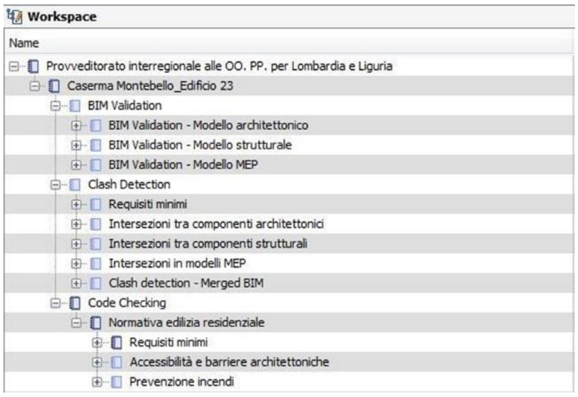

Figure 1. The ruleset is organised in three phases: BIM Validation, Clash Detection, Code Checking

3.2 BIM Validation

The BIM Validation ruleset analyses quality and internal consistency of the model. This check guarantees the production of a high quality building information model from which it is possible to extract reliable data for further BIM-based analyses. This ruleset checks geometrical and non-geometrical attributes carried in the model in order to validate property values and modelling procedures. In this case, BIM Validation rules were divided into three lower level sets to validate architectural, structural and MEP disciplinary models. This check was used to identify two types of error: design issues and modelling ones. It was possible to find out, for example, building elements incorrectly located and modelling errors such as wrong constraints of structural elements (Figure 2). Non-geometrical data were validated too. For example, it was possible to check if the Activity ID attribute had been linked to all the building elements. Moreover, the value of the Activity ID attribute was checked. That kind of check was fundamental for automatically matching the 3D BIM to the construction schedule.

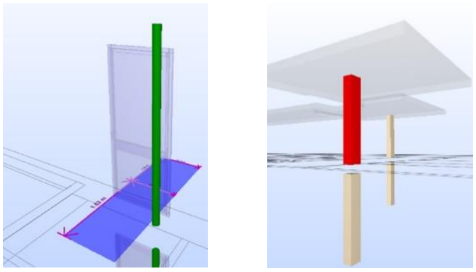

Figure 2. BIM Validation detected design issues and modelling errors

3.3 Clash Detection

Solibri Model Checker can be used to validate two different types of data: geometrical data and alphanumerical ones. Clash Detection is one of the basic potentialities of SMC, but also in this simple application, it is possible to analyse and group clashes according to severity [6]. Clash detection was used to check coordination and collaboration between different design teams. It was possible to detect clashes between MEP systems and architectural design but, moreover, clashes between MEP systems and structural elements. When the latter case occurs, either openings in structural elements are to be designed or route of MEP systems are to be changed. The aim was to demonstrate that this type of tool, if effectively implemented into a Public Administration, could significantly improve the project validation process and avoid errors that, if detected in late during the construction phase, would lead to additional time and cost.

In order to obtain reliable results from the clash detection phase it is necessary to model according to some BIM requirements. First of all it is essential to model with a high degree of geometric accuracy [3] in order to avoid intersections and to identify and correct any problems that might otherwise arise in the phase of installation of MEP systems. In this case, MEP geometric accuracy was such that the installation of MEP components could be conducted based on the building information model. Parametric rules were set to verify positioning and dimensions of components and any spatial conflict was identified. To this end, every discipline was internally checked before detecting clashes between different disciplines (Figure 3). It was verified if there was a sufficient tolerance to install and maintain MEP elements. It was possible to identify, for example, that one of the vertical elements of the sewer system was a size greater than that of the shaft designed for its installation. The geometric accuracy allowed the measurement of the maximum height reached by pipes and ducts where different systems intersect, and it was possible to check, for example, the sizing of screeds for the installation of facilities in flooring. (Figure 4)
In order to avoid errors that would lead to unusable results, a reminder to minimum requirements was added to this ruleset. A manual control is required to check that BIMs of different disciplines are represented in the same design version. Similarly, coordination and proper localisation of the Cartesian coordinate system have to be checked.

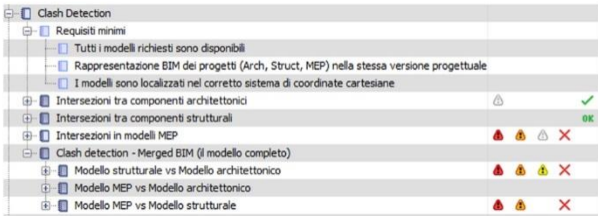
Clash Detection
Requisiti minimi
Tutti i modelli richiesti sono disponibili
Rappresentazione BIM dei progetti (Arch, Struct, MEP) nella stessa versione progettuale
I modelli sono localizzati nel corretto sistema di coordinate cartesiane
Intersezioni tra componenti architettonici
Intersezioni tra componenti strutturali — OK
Intersezioni in modelli MEP
Clash detection - Merged BIM (il modello completo)
Modello strutturale vs Modello architettonico
Modello MEP vs Modello architettonico
Modello MEP vs Modello strutturale

Figure 3. Clash Detection checked the coordination between different design teams

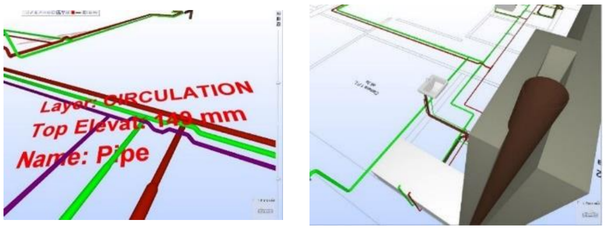

Figure 4. Geometric accuracy of MEP systems allowed the team to identify any potential issue

3.4 Code Checking

Automated Code Checking validates the BIM, and so the project, against current codes and regulations. The experimentation project was checked against some sections of the residential building code of Milan and the Italian fire prevention code for residential underground car parks. Normative texts were converted in tables by the use of the RASE methodology. The code checking ruleset created was enriched with the Italian description of all the normative references. IFC models and their parametric attributes were managed with the necessary classifications. Once regulations had been translated in parameters and implemented into parametric rules, semi-automatic code checking was used to evaluate the project and to provide rapid analysis of issues for every single object contained in the BIM, otherwise the sampling analysis traditionally conducted on 2D CAD drawings. Attributes of every single BIM object were checked, both the geometrical and alphanumerical ones.

Preliminary BIM validation and clash detection guaranteed reliable results for the code checking phase.

3.4.1 Residential Building Requirements

IfcSpace objects were classified according to the typologies specified in the normative text. Classification rules were implemented in order to automatically manage the information contained in the IFC models. In this way every time an IFC model was updated, the classification was automatically updated too. First of all code checking dealt with geometrical aspects. For example, rules were set to validate the minimal surface of bedrooms, distinguishing between those with one or two beds. The same type of check was applied to other spaces of the apartments such as living rooms, kitchens, toilet rooms and circulation spaces. Similarly, volumes and minimum heights of spaces were checked. Other checks were carried out on issues such as lighting and ventilation: by analysing the information contained in the IFC models, SMC was able to check the window-to-floor ratio and to identify, for example, blinded spaces for which a further check for mechanical ventilation requirements was necessary. Communication between spaces was also validated. For example, it was checked that direct access to a space named "toilet" was possible only from a space named "corridor" or "hallway" and classified as "circulation" rather than directly from other spaces where people stay. The design of stairs, modelled as parametric objects in Allplan, was also subjected to code checking (Figure 5). The conformity of design parameters was checked, such as minimum width of the ramp, minimum space for access to the ramp, minimum size of landings, maximum number of steps in a ramp and the sum of two risers and one tread. Settings were also differentiated in order to control both internal and external stairs appropriately classified.

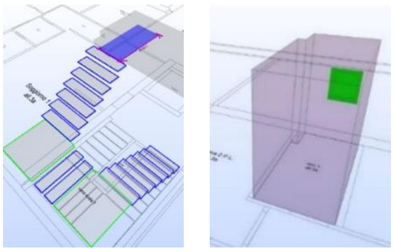

Figure 5. Residential building code automatically checked by use of a customised ruleset

3.4.2 Accessibility Rules

Accessibility is a topical design issue and a detailed set of factors not easy to interpret. To date geometrical requirements have been checked such as the ones related to maneuvering space of the wheelchair (Figure 6), but in the next future it would be possible to go further by including also sensory aspects as the presence of tactile signals, the effort needed to open doors and windows, the use of colors, light and noise conditions [7]. To this end, a demanding building model preparation would be required. In Italy and internationally, code checking is going to this direction.

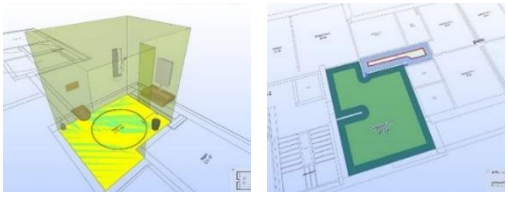

Figure 6. The accessibility ruleset checks the maneuvering space of the wheelchair

3.4.3 Fire Prevention

Fire prevention and egress analysis rules were implemented in order to check fire compartments and communication to emergency exits. Fire prevention rules depend on the parameters of the project, the location and the type of building. Moreover, rules provide results that are based on the information available within the BIM model. Such information could be inaccurate or false causing the generation of unreliable results. For this reason, all parameters must be carefully checked with a preliminary BIM validation. The necessary classification of data and the compartmentation view are to be configured in Solibri Model Checker. For example, emergency exits, that represent a fundamental information for egress analysis, have to be manual classified if they are not correctly specified in the BIM authoring tool. Meanwhile, fire prevention checking can be automated if necessary BIM objects and requirements are correctly embedded in the IFC model.

Alphanumeric attributes, such as fire resistance, were defined for structural and architectural elements such as walls, columns and doors directly in the information models. Direction of openings and panic handles were defined for fire doors. If these parameters are embedded in the BIM, the model checking software can read them directly from the IFC model as well as it reads dimensional geometric attributes of the objects themselves and automatism can be achieved. Fire safety attributes were linked to the model in Excel thanks to the possibility to manage Allplan native data by using a spreadsheet. In SMC it was checked that these attribute were added to every element and that the property values were correct. For example, it was checked that the attribute of fire resistance “resistenza al fuoco – REI 120” had been defined for every wall, column and door that divided the car park into fire compartments. REI 120 is the fire rating according to the Italian code for not sprinklered underground car parks. The car park was automatically portioned in fire compartments by architectural and structural elements for which the fire resistance parameter had been defined as REI 120 (Figure 7). Property values of the Italian normative text were set to check properties of fire compartments such as maximum area according to the type of compartment in residential buildings not equipped with a sprinkler system. It was checked that doors classified as “emergency exit” isolated smoke proof stairs and their size was in accordance with the minimum size requirements for escape routes depending on crowding density and flow capacity. It was verified that paths not longer than 40m were necessary to arrive at emergency exits. To this end, in order to allow a reliable analysis, all ancillary and MEP rooms were set as "restricted" and the path through them was not taken into account during the check. Rules checked components classified as fire protecting components: properties of the fire piping system and location and number of fire prevention devices was checked. Hydrants were checked for presence at each exit, as required by the regulations. The same control concerned the presence in sufficient numbers of fire extinguishers, the distance from each other and the positioning with respect to emergency doors (Figure 8).

This section of the ruleset does not cover all aspects of the analysis of escape routes. A manual control is necessary in reference to current regulations.

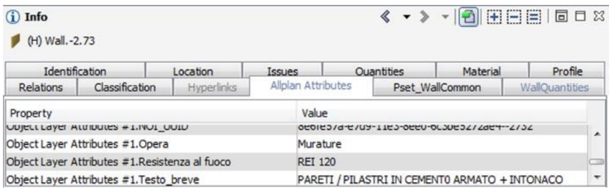

Figure 7. Fire safety BIM attributes were added to the building information model

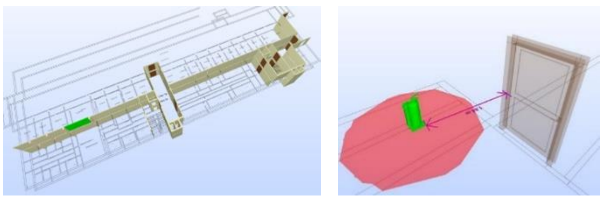

Figure 8. Fire prevention rules automatically checked the model

3.5 Results

Model checking as an iterative process allowed design optimisation and a consistent data flow between project participants. Design issues detected during the model checking phase were saved as images with comments and localisation of the issue. Reports were automatically extracted from the model checking software and shared with all the actors involved in the experimentation during coordination meetings. Critical issues were reported to the Director of the Public Administration who asked for a more thorough check of the building design and for corrective actions to be taken before the construction phase started.

4 4D Building Information Modelling

4.1 Traditional Approach to Construction Management

Construction planning is the key to ensure the success of a project. Without construction management, in fact, it is likely not to achieve project objectives, in terms of cost, time and resources usage. Construction scheduling is an iterative process done in consequential phases and with increasing levels of detail. The plan of work constitutes the point of reference against which to calculate the deviations and identify corrective actions as the construction progresses. To date, the burden of scheduling construction activities is, almost exclusively, of the project planner. In fact, the validity of the plan of work is mainly a function of his experience as there is no database to refer to gather the necessary information. This implies a high probability of making mistakes even for the most experienced planner, especially when there is not a strong collaboration with other actors of the process [8]. In fact, the planner is often required to know construction techniques, logical links between various activities, the time required to complete tasks without having the necessary relationship with designers and sometimes not fully knowing the actual availability of resources of the construction company. Often the tendency to work in a piecemeal way leads to realise a not adequate plan of work that distorts the prediction of the construction progress, leading to delays and other problems that are detected only during the construction phase, when the necessary corrective actions are expensive and little effective. Another lack of the traditional process is the ability to visualise and correctly understand the relationships between different activities and if there are no errors in the choice of these constraints. Typically, the construction site is represented with two-dimensional static CAD drawings that are disconnected from the time schedule [9]. This makes it difficult to understand the evolution of the construction site layout in relation to the construction progress. It requires to mentally reconstruct all that will happen in the construction site and to merge the scheduled work packages with what is represented in traditional 2D layouts. They often have not comparable levels of detail: detailed work packages versus macro-phases representation. Material storage spaces is another aspect affected by this lack of connection between construction schedule and construction site layout. In fact, the designated storage areas are displayed only related to macro construction phases, but they are not connected with the supply plan and so it is not possible to verify if these prove adequate. Moreover, only a few of the construction vehicles that will be used are indicated and this could lead to an inaccurate analysis of their suitability and maneuvering areas.

4.2 Proposed Methodology

Synchro Professional was used for 4D modelling and project scheduling. A 4D BIM was created by linking all the elements of the building information model to the construction schedule in order to visualise and optimise the construction sequences [10]. A 4D BIM helps to solve some typical deficiencies of the traditional approach and to better schedule the project. A virtual construction site can be built and issues usually detected during the construction phase can be anticipated. In this way the construction site can be visualised by the actors involved so they do not have to imagine what would happen during the construction phase. In recent years the construction scheduling process has been more and more supported by 4D modelling tools but at present, especially in Italy, this kind of technology is not yet widespread as an integral part of the construction process.

To correctly configure the 4D BIM, it is necessary to decide how to proceed during both the modelling phase and the construction scheduling one. BIM requirements necessary for 4D BIM significantly affects the way the BIM model is to be created as well as the scheduling of the construction plan. It is fundamental to define the granularity of both 3D model and plan of work in order to successfully link the elements of the PBS (Product Breakdown Structure) to the WBS (Work Breakdown Structure) work packages. If the granularity of BIM and construction plan is not the same, two different situations may occur [11]: either the BIM granularity is higher than the one of the plan of work, or vice versa, the BIM granularity is lower than the one of the plan of work. The former case does not represent a problem since it is possible to gather more BIM objects and to link them to a single work package. On the contrary, the latter case represents a critical issue because it is necessary to link a single building element to a multiplicity of work packages. A compromise is necessary: the BIM object can either be linked to only one of the work packages composing a WBS element or it can be linked to every work packages, and so counted more times. The former solution does not allow the visualisation of the execution of different work packages in the 4D model. In the latter case resources are allocated in a wrong way because the element would be built or removed again and again. In this case, for a BIM granularity lower than the one of the plan of work, customised colour schemes were used in order to represent the incompleteness of the element until the conclusion of the chronologically last work package. To this end an extremely careful analysis of resources was required.

Once the WBS levels had been identified, work packages were defined and associated to the elements of the PBS. Resources and construction techniques were defined as well as duration for each activity. Logical links between the planned activities were assumed. In a first step it was necessary to add construction objects to the building information model. The target of the 4D model imposes what is to be modelled and which activities should be defined in the construction schedule. For example, a 4D BIM that has as its purpose the validation of the security plan requires safety and temporary devices, such as scaffolds and formworks, to be modelled. The same is for construction vehicles. The construction schedule has to be more detailed than in the traditional planning practice. It has to contain activities that are not usually covered, such as the ones involving the displacement of the storage areas.

The construction site layout was modelled in Allplan. Construction site offices, accesses, fences and temporary ramps were modelled. For obtaining a complete overview, surrounding buildings were also modelled as masses. A mock-up of the procedures of formworks construction, concrete casting and formwork removal was modelled, including temporary equipment such as scaffolds and safety devices (Figure 9). To ensure the auto matching between the 3D BIM model and the plan of work, a parameter, named Activity ID, was associated to each element. MEP models created by the use of DDS-CAD were imported as IFC models into Allplan and they were recognised as native in the architectural BIM authoring tool. Allplan native data were exported to Microsoft Excel to manage the attributes associated to every building elements, including elements resulting from DDS-CAD. The new “Activity ID” attribute was created and linked to all the building elements. At the same time, the construction schedule was extracted from Synchro Pro and imported into Excel. From that spreadsheet the Activity ID to be associated to every element was selected. At the end of this process, data were imported back into Allplan and an updated IFC model was extracted. The updated IFC model was imported in Synchro PRO where it was possible to read the created Activity ID parameter and configure an auto matching rule [12]. This allowed the parameter value to be read from the aforementioned imported file and the identification of the WBS element or work package whose Activity ID was coincident. Once verified that the proposed association provided by the rule was correct, the task was defined, indicating whether the item should be created, removed or retained during the task. Finally, the machinery needed to complete the works were defined. The 3D model of these resources was selected from the internal object library of Synchro.

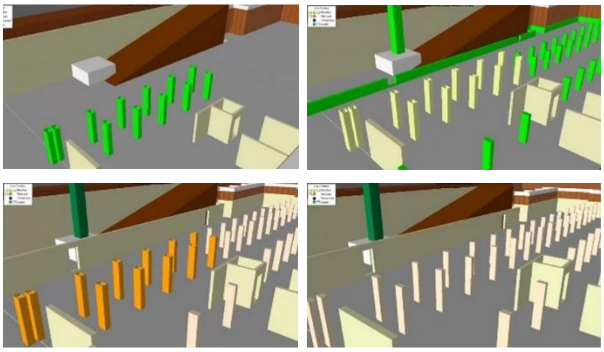

Figure 9. Procedure of construction of concrete formwork, concrete casting and formwork removal of the basement columns

4.3 Results

Through the 4D BIM it was possible to visualise the construction sequences (Figure 10). This methodology enabled the team to validate the plan of work and to identify errors in the logical link between activities. Once the macro errors had been resolved, it was possible to introduce some specific analyses. First of all, improving variations were analysed by comparing different baselines that would allow a reduction of the necessary time for completing the construction works. Every new baseline was compared with the original one considering advantages and disadvantages. In particular, alternatives that, compared to a reduction of the time, would not have compromised the safety of workers were sought. For example, baselines that included the simultaneous work of different construction companies in the same place were excluded. Synchro Professional allowed this comparison and the simultaneous viewing of the evolution of the construction site according to different baselines. The best construction schedule was defined through an iterative comparative process and subsequent correction of the baseline proposal.

The construction site was affected from lack of space and coordination problems. 4D BIM was used to compare different alternatives for positioning the crane in order to optimise the layout of this confined construction site. The best solution was defined in collaboration with the construction company. The impact of traffic due to the construction activities was evaluated too. The construction site was located in a compact urban context of Milan and a detailed analysis of the access to the construction site was needed. An alternative solution to the original one was identified to reduce to a minimum the inconveniences caused by the construction site.

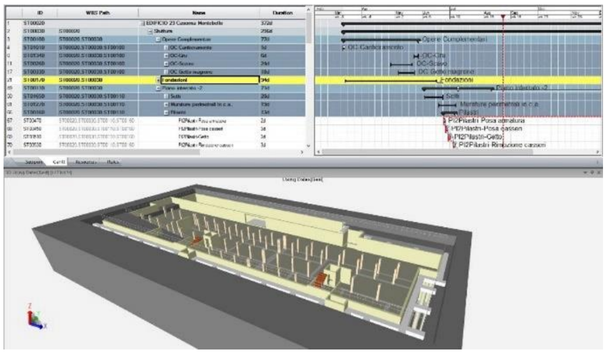

Figure 10. Visualisation of the construction schedule in Synchro Professional

5 Model Checking for Construction and H&S Management

IFC models enriched with construction management properties were directly exported from the 4D BIM built in Synchro PRO. This process allowed construction site configurations to be imported in Solibri Model Checker in order to be checked and analysed with different finalities. It is interesting the possibility to compare IFC models extracted from Synchro and related to different days of the construction phase in order to monitor the construction progress and see what is added from a configuration to another one (Figure 11). The Information Takeoff tool of Solibri was tested to be used to monitor the percentage of completion of the construction progress. Moreover, it could allowed the as-built model to be verified by comparing it to the original baseline of the plan of work. The joint use of model checking and 4D BIM was also tested to support the H&S Management. In fact, safety devices and temporary equipment were modelled and the plan of work was integrated with specific activities related to their placement on the construction site. In particular, construction site configurations in critical days could be extracted as IFC models from Synchro Professional in order to be validated by an appropriate health and safety ruleset created in Solibri Model Checker. Obviously, this finality requires integrating the 3D parametric model with data from a variety of construction safety documents by translating the multitude of traditional documents in a single coherent federated information model.

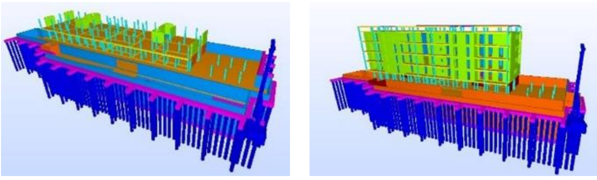

Figure 11. Construction progress Information Takeoff

6 Conclusions

The case study described in this paper is the first Italian attempt to implement the Building Information Modelling process into a Public Administration. Unfortunately, the experimentation did not started at the same time as the traditional public procurement process and BIM was only implemented before the construction phase. However, the entire design and construction management processes were simulated in order to help all the actors involved (owner/validator, designers and contractor) to approach this innovative methodology and, on the other hand, to take more advantages as possible from the model checking and 4D BIM analyses before the construction phase started. All the project participants had to coordinate their work and to collaborate in order to effectively implement BIM in the construction of the residential building, probably more than they actually wanted and they were traditionally used to doing.

BIM benefits were obtained from the very first steps of the experimentation. Coordinated 2D drawings were extracted from the federated model and a better control of quantities allowed a more accurate cost estimation. Moreover, model checking allowed the PA to effectively validate the design and avoid issues traditionally detected only on the construction site. 4D BIM significantly helped the contractor to optimise the construction phase.

Such an interoperable and collaborative approach is necessary for the implementation of the BIM methodology. Moreover, it inevitably reflects on the responsibilities to which designers are subjected throughout the construction process. 4D modelling, if effectively implemented, would help the PA to ask the contractor for a more efficient plan of work and to review the constructability of the project against scheduled time and cost. Moreover, the construction site layout has to be effectively designed since it represents an essential part of a true integrated process.

In order to obtain these results, collaboration between owner, designers and contractor has to be significantly improved.

7 Future works

Future works go to the direction of 5D BIM and construction management mobile applications. The fifth dimension of BIM, about cost estimating, overcomes almost completely the problems of the traditional process on the use of resources and their value [8]. 5D BIM manages the location of necessary resources according to a Lean Construction approach and it is necessary to work closely with contractors and designers in order to create a reliable 5D BIM. Construction techniques have to be identified and it has to be verified that the construction company is able, in terms of resources and technical expertise, to carry out the work in accordance with the previsions and, if not, to proceed to the analysis of the alternatives. Moreover, it is needed to associate with each work package the necessary material, human and equipment resources to bring it to conclusion and eventually to change the construction schedule based on the results obtained.

Another important future goal would be the use of the 4D BIM during the construction phase, directly on site. It is argued that the use of mobile tools for construction management could lead to considerable advantages. Currently the BIM research team of the University of Brescia is studying the best workflow for data management from Primavera Professional Project Management to Synchro PRO and consequently from 4D BIM to BIM field tools and back (Figure 12). The aim is to use the BIM methodology to constantly update the construction schedule for monitoring the project and the construction progress.

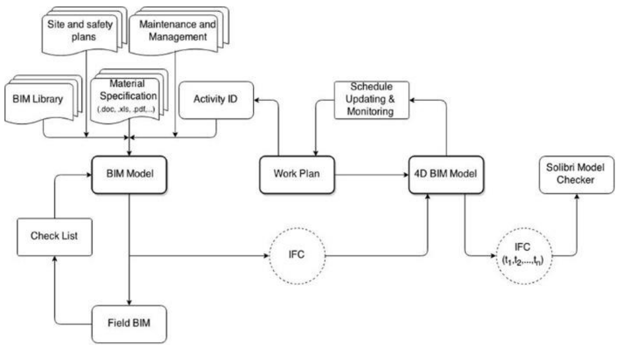

Figure 12. Data flow to support the construction phase

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