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A comparison between different approaches for 5D BIM in construction site surveying

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Abstract

It is well known that BIM technology offers many profitable issues by now. Its benefits are widely experimented and described, especially in terms of design efficiency and interoperability. However, it is not so common, at least in Italy, to see projects completely managed by BIM, especially considering medium and small intervention. This approach should change in the next years while Italian laws will make mandatory, step by step, the use of BIM for public procurement of a certain amount. With the aim of the implementation of BIM in each phase of the project, also in medium and small interventions, the presented research examines the use of 5D-BIM during the execution phase of the process, to assess construction advancements during works with the support of modelling advantages. Then, the research focuses primarily on the definition of proper requirements to outline a 5D site management throughout the whole construction process. After the definition of different needs for the different actors of construction process, the research moved to the possible BIM use for the satisfaction of these needs by the definition of customized parameters dealing with site spaces and facilities, quantities, time and cost management. The study includes also the levels development (LOD) definition of objects aimed to the scope of using information contained in the model for the works advancements checking during the realization of works. An approach was studied to realize the scope of work, tested in different construction sites with the aim to satisfy both the needs of clients, and the needs of a contractor. The considered construction sites are similar in terms of dimensions and amount of works. As will be demonstrated in the paper, the on-field management with the use of models, if correctly developed and used, can simplify contractors and clients' inspectors job during the works realization in terms of efficiency of inspection and calculations.

Keywords: 5D; Building information modelling; Construction site inspections; LOD; Medium sites.

1. Introduction

The use of Building Information Models for construction design and management is spreading very quickly all over the world thanks also to the legislations which are now considering the advantages of such a method in each phase of the construction process. With the aim of underlining these advantages and translating them in the scope of the presented research it is useful to consider which should be the main aims of the information models.

One of the most known treatment about BIM uses in the whole building lifecycle is inserted in the BIM Handbook by Charles Eastman et al. [1]. Among the others, we can list some main aims of the models according to the phase in which this model is used or managed:

1. Model for the design of an intervention
2. Model for the management of the construction phase
3. Model for the facility management of the building

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Such phases are confirmed also by Succar's BIM framework [2] which defines BIM as "a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building life-cycle". The lifecycle is identified in the three main stages expressed before, and it is valid for a certain number of models realized with specific aims such as structural or thermal analysis, architectural visualization, safety and maintenance managements and many others. Starting from this simple distinction it is possible to focus on the second one and on the model for the management of the construction phase.

1.1. Scope of work

The scope of work presented in this paper is indeed to provide a BIM-based workflow supporting clients and contractors in construction site surveying during works. It is well known that BIM technology offers many profitable issues that benefit owners, designers and constructors, especially in terms of design efficiency and interoperability. Moreover, it can become a powerful instrument for the client's team and the General Contractor all along the construction phase, starting from the construction site organization to answer the bid requests. It can also support the supervision of work progress and amount and allows to periodically reconsider them in compliance with available resources. Starting from these statements, the authors have developed some studies to obtain a systematic and methodological approach for site surveying and optimization. Then, the research focuses primarily on the definition of proper requirements to outline a 5D site management throughout the whole construction process. After the definition of different needs for the actors of construction process, the research moved to the possible BIM use for the satisfaction of these needs by the definition of customized parameters dealing with site spaces and facilities, quantities, time and cost management. The parameters have been identified to respond the needs of the on-field case studies analyzed. The first case studies concerned the realization of a residential building while the second concerned the realization of a school complex. The field tests permitted to refine the method also concerning the different disciplines of the building process. Both cases study concerned indeed structural, architectural and plants aspects proving efficiency and promptness to changes of the developed method concerning site inspections, scheduling optimization and visualization of works advancements. It is important to consider in this case that the modelling of objects do not represent, then, only the physical entity that will be present once the construction is finished, but also, if we consider the construction phase, the work to be realized during construction. Then the level of development of the objects needs to be managed according to the singe activities to be carried on during construction phase, and not according to the design needs. The site inspections here considered indeed deal with single components put in place in that instant of the construction and should be divided from the system which the component is a part. As an example, it is possible to consider a simple wall made by brick and plaster. In the construction phase such components needs to be considered singularly while the instant of their realization is very different.

The starting point of the research was then the study of the different levels of development standardized both internationally [3] and nationally [4]. Thanks to this study, together with on-field experience on different construction sites, it was possible to propose which should be the levels of development of construction elements with the aim of on-field work analysis. The research is evaluated using implemented tools in real case studies, two of which are here presented.

1.2. Literary review

Many authors suggest the thesis that a graphic visualization and management information system may incisively assist Project Managers in decision-making [5, 6]

The very last introduction of BIM technology certainly guarantees an improvement of quality, reducing time and costs [7] and is rightfully going to be compulsory in the design-bid-building process eventually. The latter insight is also supported by international administration trends that provide guidelines for using BIM in construction site standard, such as Finland standards Series 13, NYC Building Information Modeling Site Safety Standards and UK AEC BIM Protocol and the latest review of Italian law for public works (D.lgs 50/2016). Nowadays, several clients yet require the delivery of an as-built BIM model at the closeout stage. On the international stage, the interest in BIM technology has already been deeply ascertained. A survey conducted by Stanford University Center for Integrated Facility Engineering revealed the following results: up to 80%-time reduction generating cost budget with up to 40% elimination of unbudgeted change, and up to 10% deduction of the contract value through clash detection (CIFE Technical Reports, 2007). Suermann's survey, at the Facility Information Council National BIM Standards Committee, confirms that the major benefits derive from savings of cost and time requested for project completions [8]

While overall benefits concern the design phase with cost and time savings and communication improvement [9], BIM technology also provides great help in site management, and a BIM project is likely to be integrated with other KPI, especially regarding health and safety.

BIM automatically presents data both visually and analytically, information is clearer and easier to understand, and 4D models serve as platform for detection of potential conflicts and risk analysis [10]

Having observed that an intrinsic limit of 4D visualization in BIM models is the lack of economic features, we propose system to integrate BIM technology and EVM, following Haque [10] and Jrade and Lessard's intuition [11]. The basis of the study comes from the idea of Construction Site Information Model (Co.S.I.M.) and databases to focus on technical and operation information of construction site production elements [12]

Concerning digital models this paper will focuses on the objects Levels of Development (LOD) useful for the description of works realized. Considering LODs it is possible to say that can be described as the level of information quantities and specificity required for a element at a particular stage of the project. Then also in the modelling of an existing building, or of the works to be carried on it, it is very useful to manage information according to the stage in which the building is considered, adding further information if other stages are considered in different times.

Regarding Levels of Development state of the art is important to start any consideration from the existing standards on the theme developed internationally and nationally.

In this context of phases definition, a great importance is to give to the level of development of the model according to the phase in which the model itself is used. Definition of information contained inside BIM models is a matter of extreme relevance that cannot be entrusted. Without a set of rules, BIM models frame would vary depending on project complexity, its peculiarity and the amount of time reserved to modelling.

Level of Development (LOD) Specification is a reference that enables practitioners in the AEC Industry to specify and articulate with a high level of clarity the content and reliability of Building Information Models (BIMs) at various stages in the design and construction process. [13]

Starting from this point this paper analyses which are the minimum amount of information to be guaranteed to a digital model to manage the work advancement on site in a simple way and calculate automatically the amount of works carried on and related costs.

About works advancement control on site it is interesting to cite the work of Golpavar-Fard et al. [14]–[16] which try, among the other things, to integrate on site survey and scanning with automatic control of realized work. Other studies on site monitoring was made by Roh et al. [17] which use digital models for reporting construction progress thanks to interactive and visual approaches.

1.3. Research method

The context of this study is represented by a wider research considering the use of Building Information Models to design and manage construction activities starting from the first concept of the design stage to the construction phase of a building process [18]. Such a research is strongly related to on-field analysis and application. Developed methods and tools were in-fact continuously tested in real case studies to evaluate research and to refine it giving real applicability on site to the implemented theories.

The presented research takes into consideration indeed a solid background developed during years about construction site planning and management. It consists on some principles, in continuous development thanks to research on the topic, supported by many direct experiences carried out especially in relevant construction sites. These experiences permitted to get and remain in touch with the trends and developments of professional work to whom our research activities are dedicated. For this reason, our research method consists in a simple path that begins from the on-field observation for research development and returns at the end to the on-field application of the research. The research aims mainly to facilitate and make more efficient designers tasks in terms of on field work feasibility and construction site planning and operation. Thanks to the experiences given by a direct on-site observation is possible then to make a system between the developments of the research and the increasing needs of designers. This in order to develop methods and tools for enhancing efficiency to site planning and management of construction projects.

The field analysis permits also to have at disposal different case studies useful for testing implemented systems, evaluating their efficiency and, if necessary, refining them. Thanks to this approach we developed step-by-step many issues related to construction site design of construction project concerning also, especially in the last years, IT tools use and implementation. Thanks to this approach authors developed step-by-step many issues related to construction site design and management

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2. BIM approaches for on-field works analysis

As said the scope of work is the realization of an on-field work analysis with the use of a BIM. The first task is obviously the development of the model representing the facility. However, the realization of such a model is not so simple and the level of detail of its objects basically depends from a case to another according to the main aim of the model and to the other disciplines involved. Considering only the construction analysis and the site monitoring it is possible to say the level of development of the building model should be simplified compared to real representation and characterized by few information directly related to the work to be carried on. If we consider indeed a model realized for multiple purposes, such as design and facility management, it is possible to consider a different way of information insertion in the model. In order to simplify the dissertation, only information useful to construction analysis will be here considered, as if the BIM needs to be used only for that specific purpose. Starting from this point the main aim is to visualize, design and manage the works to be carried on and the related working area.

The level of graphical detail of the elements representing the works should be very simple for the presented purpose. It indeed to be associated, considering the AIA scale, to LOD 200 or 300. Considering instead Italian scale inserted in UNI 11337-4 it is possible to say that it is like LOD B or C. In this case the choice is to remain, in each phase of the project, to a low level of graphical detail, and increase, step by step, the level of development by adding further information useful for works analysis, advancement predictions and checking.

The proposed approach aims to enhance construction progresses analysis with the goal to avoid as much as possible accounting errors and to make more efficient future performances, according to collected data. The starting point of the analysis is, as said, the Building Information Model organized according to a Construction Breakdown Structure set up in line with the Bill of Quantity structure and the Work Plan. The output of this model, with the addition of cost analysis, is then a 5D model, to be managed during construction phase for advancements evaluation.

The system proposed is based on a pre-configured BIM template able to be used in each project and set with proper parameters that facilitate users in construction information management. Such a template is already set with objects related to the previously described LODs. Starting from this point the authors propose a methodological approach to assess project performance based on the percentage of physical work carried out, and to allow to periodically reconsider them in compliance with available resources.

3. Construction progress on-field monitoring

After the modelling of the objects with the approach explained in the previous chapter, it's the time to understand how to use such a model during on-field checking. To do this some information need to be implemented in such objects in order to have at disposal on field a tool able to check the work without implying any further modelling effort.

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In fact, such a model is realized to let clients and Project Managers to supervise the progress of the works during the construction phase and redact Building Progress Reports (BPR) according to what planned. At the same time, contractor needs such analysis for monitoring resource availability according to work advancements. The visualization and computation of the advancements is possible thanks to the parameters added previously in the 5D BIM (see table 1). The determination of any element is unique thanks to specific parameters related to the position of the elements (works) inside the building and the effective beginning-date and ending-date of the work. The model graphically shows, for a chosen time window, which elements have been realized and their position.

This task is made in the design phase to foresight advancements during future works and then compare them with the actual works simply updating the parameters related to the date of realization of the single elements. The BIM visualization and the information related permit to realize such updates in a very short time and directly on field.

Then, automatic BIM quantity take-offs, grouped under homogeneous Work Packages, automatically provide as output the percentage of physical work put in place against the total amount. The Project Manager should periodically update dates accordingly to works progress by monitoring the construction site. This way it is possible to check times and costs of the completed works verifying the progress of the planned Work Plan highlighting any delays or advances. The more frequent site inspections are (e.g., monthly or weekly), the more in-depth forecast solutions will be.

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The information can also be stored into pivot tables (Microsoft Excel©), in which the realized quantities costs are fully itemized and grouped again referring to the work categories voices of the Bill of Quantity for the selected time window. Granting a total view over the advancement of the works, General Contractor monthly presents the partial bill to the client (BPR) and identifies the subcontractors to be paid. A proper organization of monitoring work, which can consider also supplier payment dates, allows the contractor to collect data for BPR and evaluate advancements according to resources availability.

Table 1. 5D parameters inserted in the model.

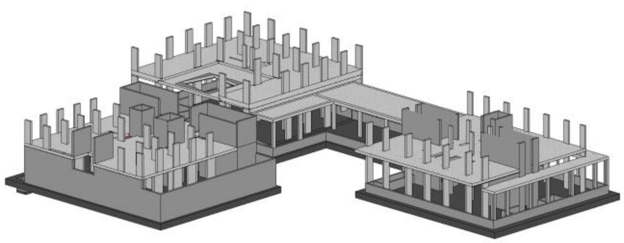
Element	Information
Technical element	- Quantity - Work programme ID - Beginning date - Ending date - Material cost - Manpower cost - Delivery charge - Bill of Quantity work category identification - BPR (number and date) - Activity duration

4. Case studies

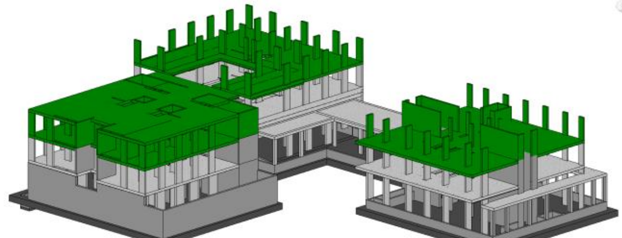
The proposed method has been tested on real cases study, two of which are here presented. As said the first one consists in the realization of a residential building for university students. The research project concerning this case study concerning the use of BIM for construction and maintenance management. In this case the work of on-field analysis was carried on with the aim of helping the contractor to keep monitored costs of the construction site during works and to calculate the costs due to the subcontractors.

The monitoring process to produce the BPR started at the beginning of the construction phase and is updated weekly to see works progress. The updating of the model, once correctly set, resulted very simple and quick, so as also BIM new user can manage it. It is in fact necessary only to realize a site inspection for evaluating advancements and simply compiling in the model that specific parameters values related to realized items. Thanks to prepared filters and customized settings in the above-mentioned template, such a procedure permits to view the single monthly advancements and automatically takeoff from the model the quantities of the realized work.

Figure 1 shows the automatic filter of the works realized in a month considered compared to the previous month.



a



b

Fig. 1. (a) Visualization of the previous month; (b) Visualization of the considered months with advancements.

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It is important to underline how both visualization and calculation of quantities related to the green objects, is automatic since the model is set to show in this way the elements specifically marked with the parameters of the advancement in an inspection. The graphic in Figure 2 summarizes the work progress by showing the comparison between the percentages of the considered month (light blue) with the percentages of all previous work (blue) for each identified work category. Such a graphic is automatically generated from the quantity takeoff generated directly from the BIM model thanks to the 5D parameters inserted.

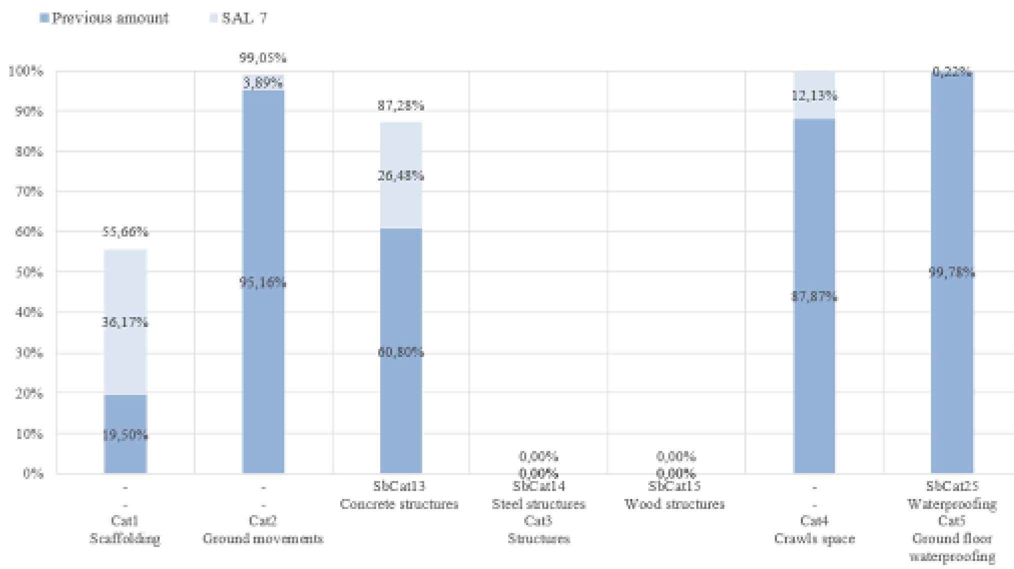

Fig. 2 Monthly work progress (light blue) related to the previous realization (blue).

Thanks to this approach, it was possible to create reports able so simply visualize and manage realized quantities in order to make simpler the dialogue of the contractor with its subcontractors.

A similar approach was used to another case study represented by the new construction of a school complex composed by two buildings. While these buildings are smaller than the first one, they are represented by some particularities due to the shape, the envelope and the plants.

As said, this second case study had the view of the client. It was in fact developed during a research project that involved the research team with the municipality that funded the project of the school. The aim of this project was the cost control during the works carried out by the client's team in order to check the real progress of the works according to the budgeted cost.

Figures 3 and 4 shows an advancement like that showed in Figure 1 related to one of the schools of the complex.

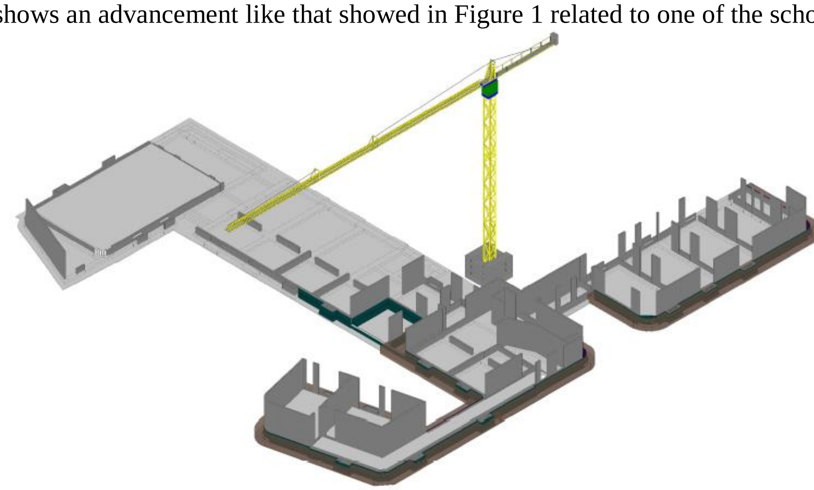

Fig. 3. Visualization of the previous month.

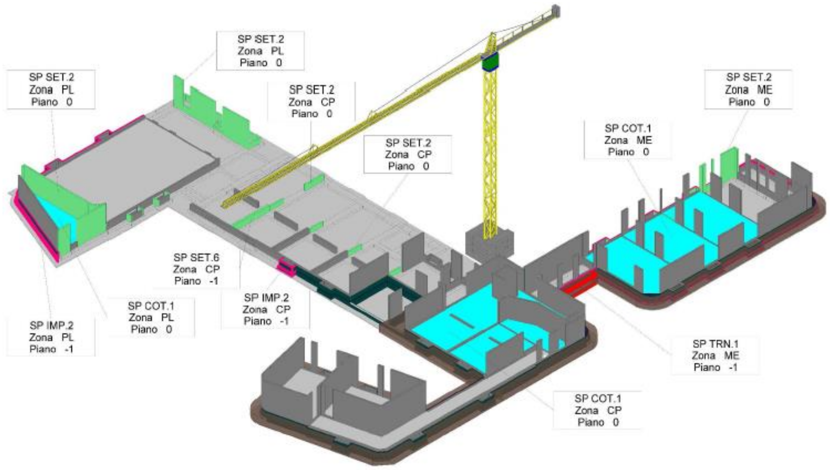

Fig. 4. Visualization of the considered months with advancements.

As visible, the visualization output was slightly improved in order to match the needs of the client's engineers team. The tags and colors match in fact the categories identified by the client during the design of the intervention. A particular approach was here used for the plants advancements identification. The peculiarity and the quantity of plants inserted in the model made very difficult to visualize their specific advancement month by month. Then the plant model was used for the 5D parameters and the quantity take-offs. However, to simplify the visualization was used the approach visible in figure 5. Each part of the plant is in fact represented by a colored cube filled with the exact percentage of the realized works. This view makes simpler and clearer the identification of the realized plants without representing them in their totality.

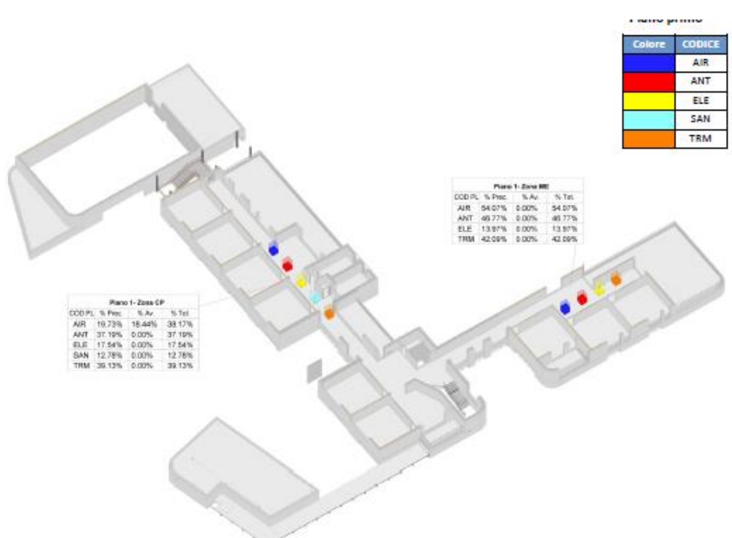

Fig. 5. Visualization of the plants advancements.

5. Conclusions and further developments

The two case studies showed how a similar approach can be used both to satisfy the need of a client and to satisfy the needs of a contractor. Both the studies aim indeed to the progressive quantity takeoff of the realized works and in the automation in produce reports useful for the client to check the contractors works, and useful for the contractors to simply match with its subcontractors. In any case the proposed approach satisfied the needs of the users concerning visualization capacities, simplicity of use and processing speed. However, such approach did not serve only the cost progress analysis. Such a BIM support permitted also to visualize the 4D advancement related to the 4D contract work

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plan, to visualize and evaluate delays compared to the design plan. Some simulations were made in this sense to use the parameters related to delay to re-plan the future works to avoid the same delays. This plan is made by modelling different construction alternatives for future works and visualize their related parameters of cost, time and safety. Thanks to the match of the parameters of the alternatives, based on the past parameters it is possible to choose the best solution in terms of times and costs. Only some simulations were made about this topic, but the first results are comfortable and put to continue to the research about construction options optimization.

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