ISTEA
ITALIAN SOCIETY OF SCIENCE TECHNOLOGY

BACK TO 4.0:

RETHINKING THE DIGITAL CONSTRUCTION INDUSTRY

A cura di

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MAGGIOLI EDITORE

ISBN 978-88-916-1807-8

Maggioli Editore è un marchio di Maggioli S.p.A.
Azienda con sistema qualità certificato ISO 9001:2008
47822 Santarcangelo di Romagna (RN) • Via del Carpino, 8
Tel. 0541/628111 • Fax 0541/622595

www.maggiolieditore.it
e-mail: clienti.editore@maggioli.it

Il catalogo completo è disponibile su www.maggioli.it area università

Finito di stampare nel mese di giugno 2016 nello stabilimento Maggioli S.p.A
Santarcangelo di Romagna (RN)

"5D BIM FOR CONSTRUCTION SITE SURVEYNG"

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Topic: Building Information Management, Models for design and construction

Abstract

The scope of work presented in this paper is to provide a BIM-based workflow supporting clients and contractors in construction site surveying. 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 allow 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 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 parameters have been identified to respond the needs of the on-field case study concerning the realization of a school complex in Cernusco sul Naviglio (Milan). Furthermore the field test proved efficiency and promptness to changes of the developed method in particular concerning scheduling optimization. By further inspections, this process is also supposed to become an instrument of dialog and comparison with the Health & Safety team, to verify work items clashes against health and safety on construction site.

1. Introduction

The construction process can deeply affect the final product quality, which is the most relevant feature of the expected outcome by the client.
Project Management is composed of different techniques intended to prevent quality drops, budget and deadline deviances since construction sites are widely concerned with schedule and budget overruns. In fact according to Standish Group survey report, 61% of the projects failed to meet success criteria; and in particular 74% faced schedule overruns (Standish, 2013). This usually leads to financial losses on both client's and firms' side, and undermines General Contractor's renown.
In addition, mismanaged speedup of works often means a threat to workers' safety. Host of problems can be avoided frequently monitoring the Key Performance Indicators –KPI– (Cheung et al., 2004).
This research aims to integrate Project Management with practical aspects for operational planning, encompassing also safety issues. The method hereinafter proposed deduces benefits from the Information Technology (IT) tools, especially from Building Information Modeling (BIM). The main intent is to develop a BIM use that would allow the Project and Construction Managers to face in advance possible contingencies and choose possible solutions analyzing consequences on time and cost.
Hence, the authors (i) investigated the research background to establish the actual level of integration between Project Control techniques and IT tools. The second step of the research consisted in (ii) the definition of a systematic and methodological approach directed to both project control and forecast planning, in order to enhance the efficiency of the construction performance carried out by General Contractors. At the end (iii), the method was validated through application on a case study.

2. Literary review

Project Performance Management (PPM) is a powerful instrument throughout the construction phase to take under control the efficiency of on-site productivity. World-wide academics, consultants and operators of the architecture, engineering, and construction (AEC) industry are developing various techniques, such as Critical Path Method, Earn Value Management (EVM), Construction Management, Location Based Management System (LBMS), Last Planner System, Lean and Agile Method, prioritizing somewhat different aims.
In addition to these issues, many authors suggest the thesis that a graphic visualization and management information system may incisively assist Project Managers in decision-making (Chou et al., 2010), (Kamat et al., 2000).
The very last introduction of BIM technology certainly guarantees an improvement of quality, reducing time and costs (Ciribini et al., 2013) 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 (AE UK 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 for 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 (Suermann, 2009).
While overall benefits concern the design phase with cost and time savings and communication improvement (Bryde et al., 2013), 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 (Haque et al., 2007).
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 (Haque et al., 2007) and Jrade and Lessard's intuition (Jrade et al., 2015). 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 (Trani et al., 2014).

3. Workflow

The proposed approach aims in particular 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 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. 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. Figure 1 shows the workflow of the two considered steps, described below.

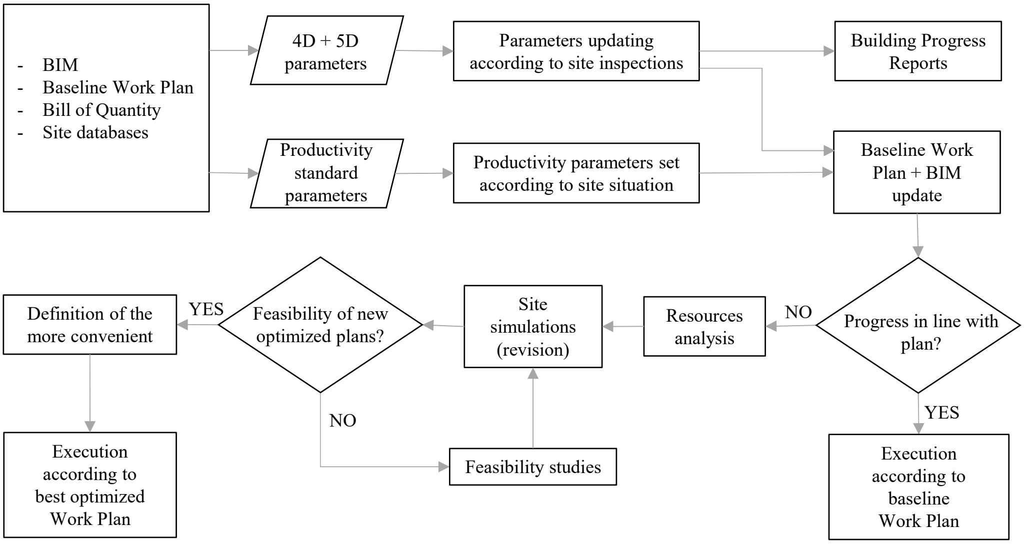

Fig. 1 Workflow of the proposed method.

3.1 Monitoring and Building Progress Reports

This section utility is to let the client and Project Managers to supervise the progress of the works during the construction phase and redact Building Progress Reports (Trani et al., 2013). 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 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. Then, 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 control times and costs of the completed works verifying the progress of the Work Plan highlighting any delays or advances. The more frequent site inspections are (e.g., monthly or weekly), the more in-depth forecast (see paragraph 3.2) solutions will be.
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.

Tab. 1 5D parameters.

Element	Information
Technical element (e.g. pillar)	- 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

3.2 Forecast

The second phase consists in the model implementation with additional parameters in order to provide a forward planning. Among those, the definition of a specific parameter to extract the work duration according to available resources is of primary importance. For this reason a set of "productivity parameters" has been used for the development of this phase. As the duration depends on the task degree of mechanization, we use a machinery database in which are collected information about standard productivity, health and safety and operational information (e.g. dimensions, weight, capacity, etc.) (Trani et al., 2015). Every construction firm is able to customize the machinery database according to its own inventory, adding related costs, and other useful information (e.g. maintenance service dates, etc.). The machinery databases are linked to machinery family types inside the BIM model. Philtering the view for a specific time window, the user identifies the technical elements to be realized with the machinery, and transposes information about productivity (e.g. m^3/h) from the machinery family type into the building component; then, the task duration is automatically drawn out. In addition to productive parameters some corrective coefficients were added in the model representing site-specific constraints and criticalities (e.g. distance between stocking area and working place), in order to obtain a more likely duration. Actual production rates are applied to the remaining quantities of work; a quantity take-off allows to inspect the weekly productivity. Next, by retrieving the costs from the model, the Work Plan is updated and forecast production is evaluated against the target schedule.

Several work sequences are usually adoptable to continue works, and Site Managers are required to define the best one.

Tab. 2 Productivity parameters.

Element	Information
Machinery (e.g. crane)	- Standard productivity per hour - Damage events
Products (e.g. rebar)	- Technical sheet - Requirement for storage area - Dimensions - Handling - Supply date
Storage area	- Dimensions - Characteristics (UV protection, water protection, aeration, accessibility)

Hence, it is necessary to evaluate also constraints and analyze which locations are available for work. An IT management of products and storage areas helps in recognizing other probable constraints, such as space availability, aerial restriction, interferences with other activities and so on, that could drive the final choice. The representation of products and stored materials contains information about supply and laying date, besides all information about the product life-cycle (procurement, stockpiling, handling, provision and laying) (Trani et al., 2014). This also entails an improvement in planning supplying and disposal of materials. Stocking areas may change along with changes of the construction site layout, so the availability to host the quantity of necessary materials needs to be checked on during all the construction phase. Concerning safety analysis the databases contains also an identification of possible damage events for a standard construction site, whereas BIM model helps in pinpointing specific risks for each activities due to the specific context and in fixing interferences between multiple tasks. All these evaluations are useful to plan weekly works because they optimize time and cost evaluations, considering also safety issues.
All these considerations need to be also compared with the precedent progress reports in order to evaluate, according to what is already done, the availability of resources for the further optimization. Rendering through BIM model helps in evaluating the state of being contemporary and proximity of activities, and lets the user reorganize the Work Plan taking into account available resources and interferences on the construction site. Each work feasibility is tested through the BIM model observation, complying costs and worker's safety, then the most profitable one is chosen.

4. Case study

The proposed method has been tested on a real case study. It consists of a new construction site for a school complex in Cernusco sul Naviglio (Milan).

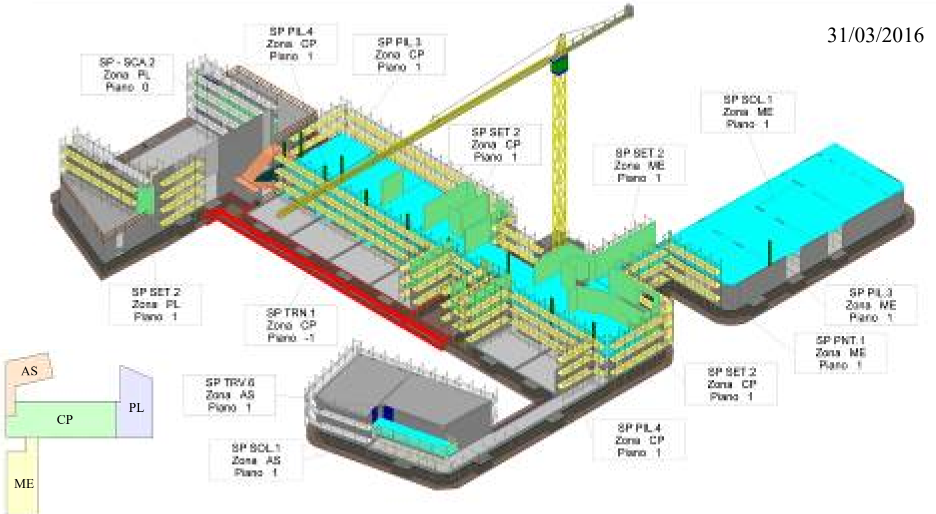

Fig. 2 Identification of functional-spatial areas and realized items in the BIM model.

The monitoring process for the production of BPR started at the beginning of the construction phase and is updated weekly to see works progress. The updating consists in site inspections for evaluate advancements and compiling in the model the parameters values related to realized items. Such a procedure permits to view the single monthly advancements and automatically takeoff from the model the quantities of the realized work. The graphic in Figure 3 summarizes the work progress by showing the comparison between the percentages of last month with the percentages of all previous work for each identified work category.

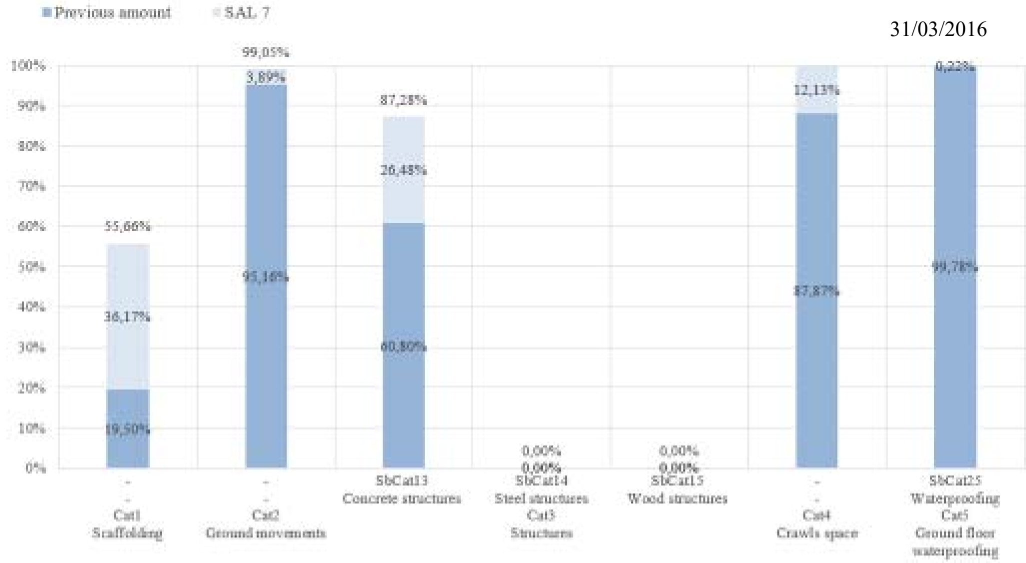

Fig. 3 Monthly work progress.

The comparison of the obtained results with the baseline of the Work Plan shows directly the possible delays compared to expected times.

Starting from this point some simulations with the proposed method have been carried on in order to develop a detailed production Work Plan for the weeks immediately following the site inspections. In particular, simulations aim to optimize, according to the real site situation, the subsequent works. Speaking about the completion of wooden structures, for instance, they are to be completed in three different work areas, involving thus more work teams of the same subcontractor. In order to reduce time for the following works different scenarios has been modeled and analyzed.

With the BIM support, it is possible to visualize the alternatives and their related parameters of cost, time and safety. The baseline simulation presented refers to the contractual Work Plan that serves as a visualized time-control model to appraise cost and time gains. In the first alternative, two teams are working in two different areas simultaneously. To not reduce productivity rate the firm hires a truck-mounted crane. By matching the truck-mounted crane information contained in the machinery database and those related to the package of materials is evident that the load capacity of the selected machinery is compatible.

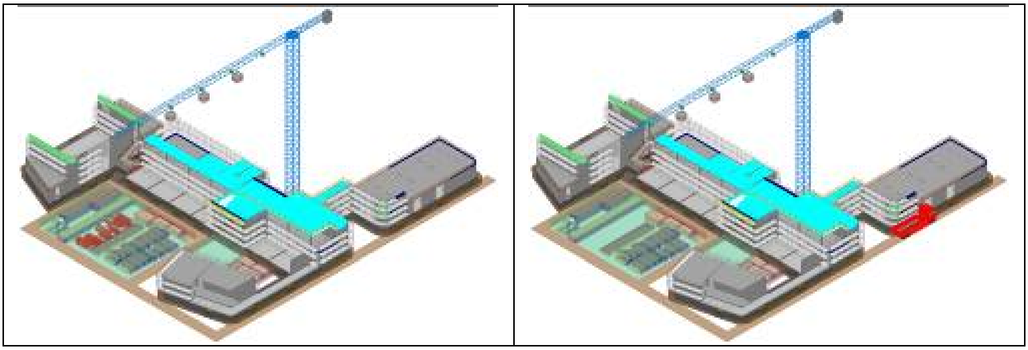

Fig. 4 Simulation of baseline plan and possible alternatives.

The material is laid directly on the supply date and the time required for stocking is cut out. The BIM visualization guarantees the feasibility of the solution; many possible scenarios are feasible without noticing safety; in the quantity take-off, costs and durations for every likely solution are comparable as well.

Work package	Work Program ID	Zone	Floor	Daily productivity	Area	Supply duration	Task duration	Contemporary task duration	Total material cost	Machinery cost
				[m²/h]	[m²]	[h]	[h]	[h]	[€]	[€]
1	75	PL	2	150	300 m²	3	16	0	€33198.67	€1189.72
1: 1					300 m²	3	16	0	€33198.67	€1189.72
2	81	CP	0	120	104 m²	1	7	0	€11487.91	€115.10
2	95	ME	1	120	242 m²	0	0	16	€13157.28	€1288.13
2: 22					346 m²	1	7	16	€24645.19	€1403.23
3	89	CP	1	150	296 m²	3	17	0	€32812.08	€323.71
3: 3					296 m²	3	17	0	€32812.08	€323.71
4	92	CP	1	120	386 m²	5	27	0	€15819.82	€378.04
4: 26					386 m²	5	27	0	€15819.82	€378.04
6	97	PL	0	120	203 m²	3	14	0	€24287.14	€250.67
6: 1					203 m²	3	14	0	€24287.14	€250.67
7	100	CP	2	150	311 m²	3	18	0	€34492.96	€349.13
7: 2					311 m²	3	18	0	€34492.96	€349.13
8	102	ME	2	150	252 m²	3	16	0	€27924.84	€304.39
8: 1					252 m²	3	16	0	€27924.84	€304.39
Totale generale					2094 m²	22	114	16	€193180.71	€4198.89

Fig. 5 Quantity take-off of first scenario.

Work package	Work Program ID	Zone	Floor	Daily productivity	Area	Supply duration	Task duration	Contemporary task duration	Total material cost	Machinery cost
				[m²/h]	[m²]	[h]	[h]	[h]	[€]	[€]
1	75	PL	2	150	300 m²	3	16	0	€33198.67	€1189.72
1	95	ME	1	120	242 m²	0	0	16	€13157.28	€1232.09
1: 15					542 m²	3	16	16	€46355.95	€2421.81
2	81	CP	0	120	104 m²	1	7	0	€11487.91	€115.10
2	102	ME	2	150	252 m²	0	0	13	€27924.84	€1026.68
2: 9					356 m²	1	7	13	€39412.78	€1141.78
3	89	CP	1	150	296 m²	3	17	0	€32812.08	€323.71
3: 3					296 m²	3	17	0	€32812.08	€323.71
4	92	CP	1	120	386 m²	5	27	0	€15819.82	€378.04
4: 26					386 m²	5	27	0	€15819.82	€378.04
6	97	PL	0	120	203 m²	3	14	0	€24287.14	€250.67
6: 1					203 m²	3	14	0	€24287.14	€250.67
7	100	CP	2	150	311 m²	3	18	0	€34492.96	€349.13
7: 2					311 m²	3	18	0	€34492.96	€349.13
Totale generale					2094 m²	19	98	30	€193180.71	€4865.15

Fig. 6 Quantity take-off of second scenario.

Figures 5 and 6 show the economic impact of compressing duration with different machineries and work teams. The authors have gradually augmented the number of contemporary tasks, guarantying construction logical priorities and safety.
For this reason we exclude the possibilities of combining tasks in areas CP and PL (see Figure 2) and mounting walls and roofs in the same functional-spatial location.
In the first scenario two activities of laying walls in area CP and ME are matched in work package 2 with a reduction of one day. With regard to the monthly budget and the days delayed, we prefer to investigate shorter scenario. We finally choose as best solution the second scenario, in which the mounted-truck crane works in ME without clashing with the crane which works in PL and CP, gaining two days more.

5. Conclusions

The method implies an upgrade in usual Project Control benefits: after monitoring, control guarantees that future site performance will be in line with planned standards of cost and time. Nonetheless, the comparison between different alternatives for the next tasks through a BIM visualization guarantees that the chosen solution is the best among the analysed ones. This method greatly supports the operative site design. The result complies with as many KPI as voluntarily established and introduced in the Information and Communication Technology (ICT) model. Hence, the measures of the performance can be increased with parameters related to the specific site layout (i.e. availability of the stocking area, health and safety risks).
The identification of a person in charge for this role suits the fundamentals of Last Planner System, and further studies may have interesting repercussions conciliating other Project Management techniques. For instance, BIM management of stocking areas and workstations core of LBMS, whose forecast production is based on actual production rates and contingences, rather than those planned (Seppänen et al., 2014).
Depending on General Contractor financial availability, the information flow can also be optimized exploiting IT tools like QR-code, pen-based computers, RFID, multimedia, up to creating an actual Management Information System (MIS) (Chou et al., 2010). During construction, site-operatives can easily access to design information on-site, and Project Managers are also aided in capturing work progress data (Trani et al., 2014), (Haque et al., 2007), (Davies et al., 2013).
The forecast procedure implemented in BIM model currently lacks of automation. Developments to compute accurately safety devices costs and refine the automation of the procedure are still desirable to make the process faster. Despite this, it is proved to be a flexible method that can be manipulated to reflect the intrinsic peculiarities of each and every construction site. The final decision remains a Construction Manager's task, based on his personal skills and experience.
We believe this study's main contribute is having achieved a sole multi-functional instrument that construction firms can adopt to coordinate and control sites operations in every respect, conciliating productivity and safety. The procedure exploits BIM not only during the design phase, but also during the execution phase, as a proper

instrument for construction management, and is projected toward integrated and interoperable design with a continuous flow of information from design to execution. Handling with this system can also be a way to collaborate with Health & Safety team and Work Managers.

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