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A BIM-based construction supply chain framework for monitoring progress and coordination of site activities

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Abstract

In spite of the growing implementation of Computer-aided technologies and Building Information Modeling (BIM) in AEC industry, building activities in construction sites are ineffectively monitored even now. Current formats of reporting and communicating the construction progress (e.g., textual progress reports, progress lines, and photographs) may not properly and quickly communicate the construction progress. In the proposed research the capability to communicate progress information right away and to share an Interactive Building Model (IBModel) are identified as the key components for successful management of the site and the supply chain network. This is carried out establishing the involved actors (Owner, Site Director, Site Safety Coordinator, Construction Companies and Suppliers) and setting them several options for the information management and visualization within the BIM environment. The monitoring system comes from the integration of the building and construction site model bestowing the visualization of site conditions on a set of graphical parametric rules, such as: chromatic visualization of building components referred to objects' completion percentage; thematic views, automatically extracted and updated, representing the real site conditions; and so forth. The monitoring system, supported by the BIM-based visualization model and managed in a Cloud computing seems to be one of the right directions for improving safety condition on one hand and site productivity and control on the other one.

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1. Introduction

In recent years, with the increasing level of competition in the AEC Industry, several research efforts have focused on the application of information technology (IT) as a way to improve the integration process of Construction Supply Chain Management (CSCM) [1]. Visual representation of the process can provide an effective tool for monitoring resources and construction process in the CSCM. At the same time, Building Information Modeling (BIM) has played a pivotal role in reforming the information flows in the construction supply chain. Extensive worldwide efforts have been undertaken to enhance different aspects of BIM implementation in various domains, including how to improve a collaborative work on the construction site. In fact, BIM enables information creation and reuse throughout the project life cycle and for that reason it also facilitates collaboration and provides a database platform for site management during its progression. This platform, when coordinated, integrated, and preserved properly, can be effectively used to support various operations.

This study proposes to integrate BIM and CSCM within an on-going site monitoring system. It is based on the implementation of a BIM-based information management and control system within a cloud environment for monitoring the progress of construction operations through the analysis of data coming from the construction site and collected by means of construction apps and mobile devices directly by the main construction actors: General Contractor, Subcontractors, Suppliers, Site Safety Coordinator and Site Director.

The paper is structured as follows: Section 2 reviews three fields that are strictly connected with the proposed workflow, such as the integration of the supply chain management in the construction process, the use of construction apps on site and the relationship between BIM and traditional monitoring systems; Section 3 explains the methodology which are tested in case study widely illustrated in Section 4; finally, Section 5 discusses results and future developments.

2. Background

From the end of the 1980s, the construction industry has seen the launch of a number of supply chain management (SCM) initiatives which have been focused on four major roles of SCM in construction [2] depending on whether the focus is on the supply chain, the construction site, or both: (a) Improving the interface between site activities and supply chain which aims to reduce their costs and duration (b) Improving supply chain itself with the goal of reducing costs, especially those relating to logistics, lead-time and inventory (c) Transferring activities from the site to the supply chain, (d) Integration of site and supply chain.

In this regards, the use of information technology (IT) is suggested to achieve better logistics processes, indeed, various IT applications have been used in the literature as a way to improve the integration process of CSCM [3]. These applications have harnessed the capabilities of IT to facilitate the mapping of time and cost resources and also transportation analysis and optimization models to improve logistics performance [4]. In the recent year the use of IT-based tools comes in the direction of BIM which on one hand combines the design and visualization capabilities with the rich parametric object and attributes modeling and on the other hand provides the integration of digital building models with construction site by using integrated BIM platforms.

Concerning the integration of site and supply chain, traditionally project information is acquired during on-site inspections and data is recorded in paper-based documents to be shared with the supply chain [5]. On the other hand, Mobile devices are more and more used on site in order to acquire and process data [6] to improve information management and to increase operational efficiency [7]. Currently there are many construction applications available for activities such as quality control and construction management. However, the majority of the mobile applications being used by construction companies on site are not construction apps, but file sharing and weather ones [8]; that is the reason why new tools are emerging containing all these potentialities into a single platform. Some of these technologies can be effectively linked with BIM authoring platforms; anyway, the full potential of mobile technologies implemented within a BIM Environment can be achieved only when the information obtained on site is effectively shared among project participants, supporting the decision-making process [9]. Traditionally, project information and construction site photographs are acquired during on-site visits and inspections and data are recorded in paper-based documents to be shared with the office team [5]. Information technologies create opportunities for increased efficiency of information exchange, eliminating the need to manually copy data already

recorded on site [10]. Their application during the construction phase could be related to quality control and assurance records, as well as submittal requests, construction field activities and progress monitoring [5]. For instance, understanding the current status of a construction project, essential for a successful on-site management: to this end, mobile technologies could provide improved accessibility of project information to all the stakeholders involved in the construction phase by linking mobile devices with a share database [9], the Building Information Model.

3. Methodology

The study aims to develop a collaborative CSCM Environment in order to achieve common development goals between actors, to share the same site progress information and to adopt the same approach to inform the supply chain on site in order to improve cooperation opportunities [2].

A Building Information Model (BIM), managed by authoring rules, parametric filtering rules and visualization settings, will be used to reach the goals listed below:

- Sharing the BIM, including site layout and safety plans, across the construction supply chain schema in order to make it robust when facing uncertainty;
- Updating and synchronizing the Building Information Model with data coming from different users and applications in order to effectively visualize updates according to construction processes and site changes;
- Synchronize the BIM with supply chain schema in terms of site users and construction operators by using BIM authoring rules;
- Manage the order information propagation informing the construction supply chain, in terms of direct suppliers and subcontractors;
- Visualize and manage the common usage of site organization in terms of main work spaces, site spaces and equipment (e.g. if a supplier need a crane to install components he can display its availability before entering in site, without coming in conflict with other users preventing delays and congestion using a truck mounted crane).

The integration between the on-going site monitoring system and the Building Information Model, which represents what the authors called the Interactive Building Model (IBModel), is structured in the following three work-steps.

3.1. Modelling assumption

The Building Information Model is structured in three main objects' categories:



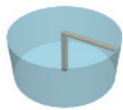
- *OB_1) Building elements*: components of the design solutions that, according to monitoring aims, should be scheduled in construction activities. The optimal solution should be a 1:1 ratio have to be established between activities and simulated building objects; anyway, the granulometry of the BIM in terms of Level Of Detail (LOD) specifications should be assessed in the planning phase of the monitoring system, in a round table with the client, in order to define how many actors in the chain seem to be able to impact site and activities performance;
- *OB_2) Site facilities and work-spaces*: according to the arrangement of the site layout, the available site facilities across each construction stage should be given as models inputs. With regard to workspaces, the general process to identify their evolution pattern would be as follow: (a) identification of the construction activity that is required to build an individual construction object according to the Information model's granulometry identified in step 1; (b) determine the workspaces needed at all stages in the life cycle for the construction activity;
- *OB_3) Equipment*: in order to manage the use on site of equipment, their workspace are simulated both for static (e.g. scaffoldings) and dynamic ones (e.g. crane).

3.2. Parametric filtering rules

The Interactive Building Model (IBModel), which is the core of the proposed monitoring system, works through a list of parametric filtering rules which effect its synchronization and vitalization.

For each Objects' categories, listed in 3.1, their (1) monitoring parameters and (2) data set and filtering rules have been defined and linked to the objects visualization by using the (3) display patterns, which govern how the IBModel transfer the on-going monitoring to the users (Table 1).

Table 1. Objects' categories and parametric filtering rules

| Object Category | Monitoring Parameters | Filtering rules | Display pattern | |
|--|---|------------------|--|---|
| Building Elements (e.g.)  | Constructed by Sub-contractor or Supplier | Name assignment | Type of Colour = X_n | |
| | Construction Percentage Progress PP | To start | Number assignment (%) $PP = 0$ | Colour Transparency = PP |
| | | In construction | Number assignment (%) $1 \leq PP \leq 99$ | Colour Transparency = PP Dashed line edge |
| | | Ended | Number assignment (%) $PP = 100$ | Type of Colour = X_n Opaque Colour = X_n |
| | Construction Progress Standby | Text assignment | Type of Colour Red Colour | |
| Site facilities Workspaces (e.g.)  | Used by Sub-contractor or Supplier | If one | Type of Colour = X_n | |
| | | If more than one | Tag | |
| | | If Available | Continuous line edge | |
| | | If Not Available | Dashed line edge | |
| Equipment (e.g.)  | Used by Sub-contractor or Supplier | If one | Type of Colour = X_n | |
| | | If more than one | Tag | |
| | | If Available | Continuous line edge | |
| | | If Not Available | Dashed line edge | |

3.3. Responsibility assignment matrix

After the Building Information Model is structured according to the logics in step 3.2, the BIM Monitoring Environment should be manage in terms of data monitoring and authoring tools. This is carried out using the *Responsibility Assignment Matrix* (RACI Matrix) which describes the participation by various roles in completing tasks or deliverables for the monitoring system. Four monitoring actions are covered: 'Add Information', 'Permission to view', 'Edit Information' and 'No action'.

Finally, Fig.1. shows the architecture of the developed system.

4. Methodology computation and case study

A preliminary implementation of the BIM and CSCM integration is described. The proposed methodology was tested simulating the workflow with experimental purposes, in collaboration with a medium-sized construction company. The case study is a four-floor building containing offices and laboratories. The supporting structure is a combination of precast elements, assembled in place, and cast-in-place reinforced concrete ones. Full-height precast columns contain shelves for supporting precast beams and for positioning overhead travelling cranes. The stair, the elevator core and the structural walls are in cast-in-place reinforced concrete. Exterior panels are reinforced concrete prefabricated elements.

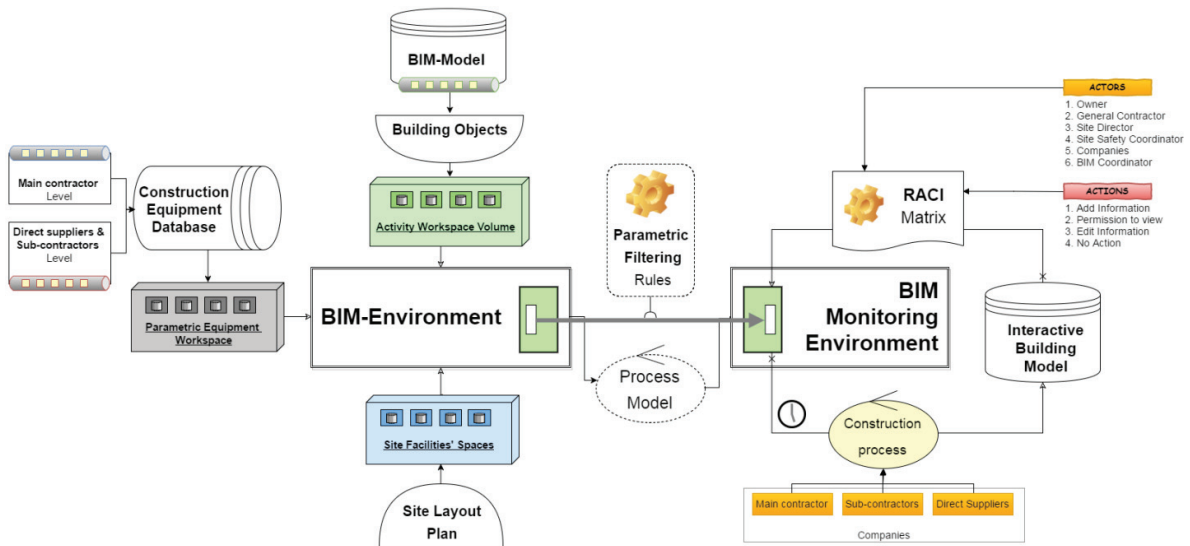


Fig. 1. Process Map

4.1. A BIM Environment and Information Workflow

In order to test the implementation of the proposed methodology, a BIM Environment was defined [10]. It consists in a BIM authoring platform and two construction apps connected to each other with a closed-BIM approach, based on the Autodesk BIM 360 cloud potentialities. Closed-BIM means that only native formats of a single software house were used [11]. Part of the proposed iterative BIM-to-Field BIM workflow (Fig. 1) was tested; synchronizing Revit to BIM 360 Glue and BIM 360 Field. Glue and Field are BIM management and construction management products that combine desktop and mobile technologies with cloud-based collaboration [12]; these tools were used in order to enrich the BIM informative content with the monitoring information according to Table 1. The data flow was managed by using native formats (.dwf and .nwc), testing different interoperability scenarios. The process is structured in four steps (Fig. 2): for each of them the *Responsibility assignment matrix* was defined in terms of users, roles, permissions to view, add and edit information. The proposed workflow is an iterative process, starting from the design phase in the BIM authoring platform, where geometric and non-geometric information related to the construction phase is embedded in the Building Information Model, including the construction site layout one. Other properties, such as monitoring parameters listed in Table 1, will be later included in Field BIM tools in order to monitor the construction phase and to support the supply chain management; these attributes will be finally synchronized, updating the informative content of the Building Information Model with data coming from the construction site and creating a coherent and shared database. In the BIM authoring platform, parametric filtering rules are set in order to create thematic views automatically updatable for data visualization and communication. These views are customized according to the users involved in the process and having access to the Building Information Model.

4.2. Setting the Interactive Building Model (IBModel)

The first step of the proposed workflow concerns the creation of the Building Information Model in Autodesk Revit. Non-geometric properties were added for monitoring the construction phase, with a focus on construction progress and CSCM supported by an improved visualization and collaboration between project stakeholders and BIM users [13]. The actors involved in the construction phase were defined: owner, site director, site safety coordinator and construction companies (general contractor, subcontractors and suppliers). Each user was identified

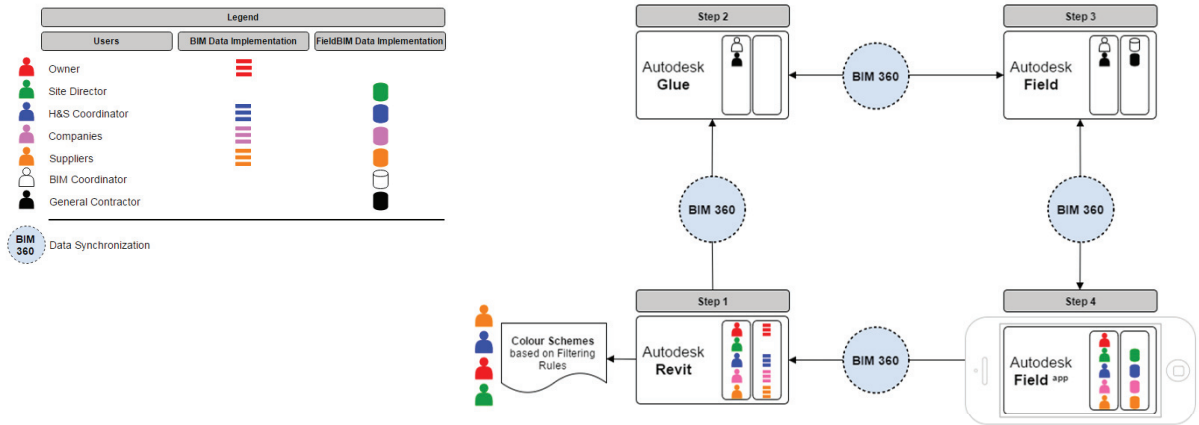


Fig. 2. Information management workflow between the design phase and the construction management one. Users, roles and their permissions to add, view and edit information are defined.

with a color that was also used in setting thematic views and color schemes to be updated with data coming from the construction site. Actors have different permissions to visualize, edit and add information within the model, filling BIM objects’ attributes related to building elements, site facilities, workspaces and equipment. Examples of these attributes are identity data and spaces/equipment availability to the construction companies working on site. For instance, contractors could manage information about their subcontractors, suppliers and connected workers. The Site Safety Coordinator could define which working area can be used by contractors and suppliers in different construction phases and they could use this information to optimize their schedule. Moreover, identity data of construction companies and suppliers could be useful for the Site Director. At this point, the proposed approach shows its benefits by means of an Interactive Building Model (IBModel) visualization.

Once the BIM template had been organized, the model was exported to Autodesk BIM 360 Glue via the add-in for the cloud environment, BIM 360. In Glue different models can be merged and coordinated in order to create and analyze the federated Building Information Model. In this case, Glue was used as a necessary intermediate step for exporting the Building Information Model from Revit to the construction app Autodesk BIM 360 Field, where it can be managed with Field properties such as construction progress information. In this phase, the BIM coordinator and the General Contractor should be involved. The former should visualize and coordinate disciplinary Building Information Models, as well as oversee the information management workflow; the latter should manage the process according to construction procedures, defining stakeholders and responsibilities on site (Fig. 3) and mapping BIM objects properties following construction management and quality control criteria. Default construction properties in

| | Owner | Site Director | H&S Coordinator | Companies | BIM Coordinator | General Contractor |
|---------------------------------|-------|---------------|-----------------|---------------|--------------------|--------------------|
| BIM Field Users | Owner | Inspector | Inspector | Subcontractor | Architect/Engineer | Contractor |
| Issues | Q | Q + | Q + | Q + | Q | Q |
| QA/QC | ⊘ | Q + | Q + | Q + | Q + | Q + |
| Safety | ⊘ | Q + | Q + | Q | Q + | Q + |
| Daily Updates | | ✓ | ✓ | ✓ | ✓ | ✓ |
| Equipment | ⊘ | Q + | Q + | Q | Q + | Q + |
| Run Reports | | ✓ | ✓ | ✓ | ✓ | ✓ |
| Enforce role filters in Reports | | | | | | |
| Library | ⊘ | Q | Q | ⊘ | Q | Q |
| Assign Tasks | ✓ | ✓ | ✓ | | ✓ | ✓ |

Users

Actions

Q Permission to view

+ Add Information

✎ Edit Information

⊘ No Action

Fig. 3. RACI Matrix established for the case study. Users and Actions have been defined as well as permissions to view, add and edit information

■ Contractor A $1 \leq PP \leq 99$

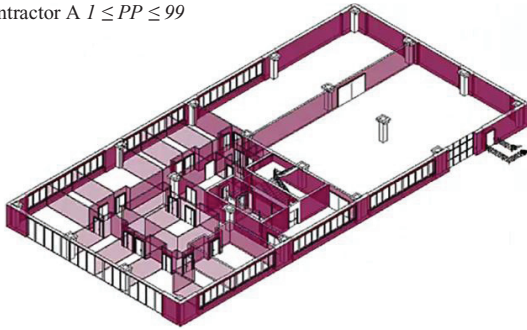


Fig. 4. Model view for the visualization of the construction progress related to a specific contractor (construction percentage progress PP between 1% and 99%)

■ Contractor A $1 \leq PP \leq 99$

■ Contractor B $1 \leq PP \leq 99$

■ Site Director $PP = 100$

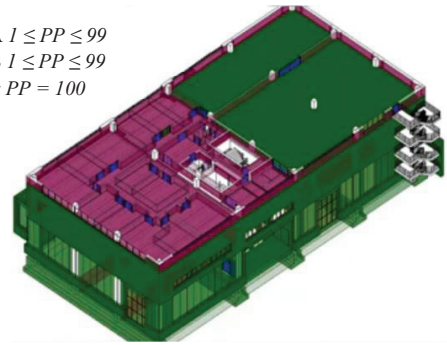


Fig. 5. Model view to be used by the site director to validate the conclusion of construction activities and by the supply chain to monitor the construction progress

BIM 360 Field are *location, status, install date, purchase date, purchase order*, to name a few. Other custom properties were created assuming some possible IBModel uses: the WBS code and the “Construction Percentage Progress” were added for monitoring the construction phase. Moreover, checklists of quality control (QC) and safety management were digitalized.

The third step consists in synchronizing the Building Information Model with the Field BIM app on mobile devices to be used directly on site. Team members can update the construction properties and fill the Quality Control and safety management checklists monitoring on-site activities. For example, the “Construction Percentage Progress” can be monitored and the relative parameter filled to be later synchronized with the model in Revit, where this data will be visualized and analyzed by the Site Director and the supply chain. The former will have to validate the construction progress; the latter could use this data in order to organize the material procurement and the building components’ production. In case of critical issues, they can be registered in digitalized checklists. Comments and images can be attached and a notification sent to whom it may concern in order to ask for the issue to be resolved.

Finally, Field properties are synchronized to the Revit model shared with Glue and integrated with Field [12]. The informative content of the Building Information Model is updated at the construction phase, including information about construction progresses and detected issues. In order to effectively visualize the information coming from the construction site, thematic views were set by means of parametric filtering rules. For example, multiple levels of transparency represent the progress of construction activities according to the rules described in the methodology Table 1. The thematic view related to a contractor’s activities was set with the color defined at the beginning for this contractor (Fig. 4) with different percentages of transparency representing different levels of construction progresses. In the proposed system, the contractor can define a “Construction Percentage Progress” between 1% and 99% in order to visualize the building object with the related color at different levels of transparency. Site Director has to validate the conclusion of the construction activity and the 100% of the construction progress. A filtering rule was set so the BIM object changes color if the related activities are 100% completed (Fig. 5). Any changing values for these parameters is synchronized and views are automatically updated depending on the filtering rules set.

5. Results and discussion

Preliminary results of an IBModel based on the Autodesk BIM 360 workflow have been described. The main aim was an improved information exchange during the construction phase, implementing construction apps and mobile devices into a BIM-to-Field BIM Environment. Anyway, a smoother and open workflow would be needed in order to effectively acquire and process data integrating BIM and CSCM. A customized BIM aware application should be developed to better support this integration and an improved collaboration between all the stakeholders involved.

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