Towards a concept of operation using BIM technologies to improve productivity in construction projects

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Abstract: The main objective of this paper is to evaluate the potential role of approaches that integrates the BIM and productivity measurement tools to increase the productivity in construction. A concept of operation will be proposed in the context of a pilot project that is designed to be used in future projects that use a new constructive system which is developed by industrial partners; this system offers a controlled and protected building environment. The research methodology is structured into four steps. 1) Benchmarking the firm's current situation through direct observations, surveys and interviews to identify issues and challenges related to the use of technologies, the current process, and the organizational structure of the project. 2) Defining the desired situation based on the project's stakeholders' expectations. 3) Using Focus Groups to determine and sort the requirements for an instrumentation of the new Construction Process. 4) Determining the instrumentation to be installed to support the new operation modes that are to be used by industrial partners. This instrumentation is supported by BIM, Productivity and ICT tools, and will be validated through site tests and interviews with project's stakeholders. Preliminary results showed a problem of coordination and communication in the project, and identified resistance factors to technology adoption, specifically BIM implementation. The paper also highlights several wastes that have been found during pilot project analysis, and that have been correlated to the wastes found from literature.

Keywords: BIM, productivity, ICT, construction wastes

1 Introduction

The construction industry is a major component of the economy of many countries including Canada. However, construction continues to lag behind other industries, such as manufacturing, in terms of adopting information technologies (IT), which have brought major productivity improvements to other industries. The construction industry seems to follow changes from a distance. IT has been used as a support tool rather than a driver in the design and construction process. Furthermore, both IT and process have been treated as separate entities without any apparent links (Cooper et al. 2004).

This research belongs to a large ongoing research project that was initiated in fall 2010, and aimed at better understanding how information technologies have the potential to transform a construction project, in terms of processes and interactions between stakeholders. Research findings of previous phases highlighted that technologies and tools related to building information modeling (BIM) are the most promising in terms of improving the productivity of the construction industry (Forgues et al. 2011). Interviews were conducted with Canadian early adopters of IT and BIM (clients, design professionals and contractors), first to discover possible gaps between existing practices and the literature, second to identify directions of emerging practices in the Canadian industry, third to assess discrepancies in the level of BIM adoption between the Canadian and American industries, and finally to articulate pilot projects that may help to address these gaps.

An experimental program has been developed to study BIM adoption within the industry. Three pilot projects have been identified to cover different angles of BIM for improving productivity in construction. The goal of these pilot projects is to optimize practices within a small or medium enterprise (SME): Two were conducted in Quebec, and one in British Columbia. For each pilot project, the research team has accompanied the participating company in integrating the new BIM methodology; monitored and collected data on its appropriation to understand the process and derive the best practices. This paper presents preliminary results of one of these pilot projects, conducted in Quebec, which is based on a new Building Construction System that could offer a controlled and protected build environment.

2 BIM, Lean and productivity

Various reports have outlined the lack of productivity as a major issue of the construction industry (Forbes 2011, Khanzode 2010, Suermann 2009). Two different initiatives, aimed to solve this issue are creating fundamental change in the planning and delivery of construction projects. The first is a transformative information technology –Building Information Modeling (BIM) Building Information Modeling– and the second is a conceptual approach to project and construction management – Lean Construction.

Building Information Modeling (BIM) is about integrated technologies and sets of processes to produce, communicate, and analyze building models containing coordinated, consistent, computable information about a building project. The core principle of BIM is to create a shared, multi-disciplinary virtual model of a building that contains precise geometry and relevant data needed to support the design, fabrication, construction, and operational activities needed to build and manage the facility. The parametric information in the intelligent digital model can be used for a variety of purposes, including design decision-making, production of high-quality construction documents, simulation of building performance, cost estimating, construction planning, and even space management.

Research (Cannistrato 2009, Khanzode 2010, Kunz and Fischer 2012) shows that the use of BIM during the construction processes was responsible for major reduction of request for information and change orders – which translated into gains in productivity. However, BIM is a disruptive technology, which means that the effective use of BIM requires reconfiguring and integrating work between specialties around the BIM enabled tools. Its biggest impact is on traditional project and construction management practices. BIM being a shared and integrated platform, it is quite difficult to divide work around activities and tasks. It is more question here of planning and managing workflows and data flows.

Lean construction refers to the application and adaptation of the underlying concepts and principles of the Toyota Production System to construction. Both focus on reduction of waste, increase of value to the customer, and continuous improvement. A core concept of Lean is the management of flow. Lean construction is therefore considered as a sound approach to manage the various uses of BIM.

3 Research scope and goals

The current structure of project supply that is used by the work providers in Canada, and especially in Quebec (lowest bidder, construction sites control by unions, etc.) limits the achievement of a successful pilot project. The selected SME developed a new construction system that could shake up current practices. In order to optimize production, and to build a solid base for the implementation of this new construction system in future projects, the SME lunched a six-story multi-residential project on the South Shore of Montreal. This project has also been selected to be a pilot project for the present study. The construction phase has been started on June 2012, traditional methods of construction were applied, and to be delivered by the end of February 2013.

Two levels of objectives were recognized: A) At the SME level: (1) Identifying the waste in conventional systems, and identifying the potential tools to be used in the future to reduce the waste in construction. (2) Demonstrating the productivity gains that the new system could bring to the construction. B) At the research level, the objectives were (1) to understand the challenges facing the implementation of a factory-like approach in a construction project, (2) to experiment BIM related technologies to facilitate the evolution of existing practices for a better control of the production process – these with the aim of developing a concept of operation for the next pilot project.

4 Research Methodology

In order to develop a concept of operation, and to set up the framework for methods using BIM and Lean for future projects, an experimentation program has been designed. The assumption was that the integration of promising technologies and processes, such as combining BIM and performance measurement within the new construction system, could optimize the construction process. The experimentation program was established in four steps. This paper focuses on the first three steps, presents their preliminary findings, and sets up the important elements to propose the concept of operation.

- **Step 1. Benchmarking the project's current situation:** This step aims to identify issues and challenges related to the current practices concerning the use of technology, the adopted process, and the organizational structure of the project. Interviews have been conducted at the end of June 2012 with project stakeholders (client/system developer, project manager, general contractor, structural engineer), and were then combined with field observations to identify the problems that were faced during the construction phase, and to collect performance measurement that can be used to create value stream mapping to identify the project wastes. The analysis of collected data also helped the development of the current organization chart, the modeling of information flows, and workflow.
- **Step 2. Defining the desired solution based on project stakeholders' expectations**: Interviews and observation analysis also allowed the definition of the action plan that can meet project stakeholders' expectations, short and long terms goals, and strategy.
- **Step 3. Determining and sorting requirements of the new information and communication technology (NICT) of the new Construction Process:** this step is mainly based on results issued from a focus group that has been taken place with the main key players of the project. The focus group aims to share experiences to define the requirements of the technologies to be tested in the construction field, and to validate the findings of the analysis of step 1 and 2.
- **Step 4. Proposing the instrumentation and the concept of operations** that will support the New Construction Process. BIM and ICT tools, selected according to the focus group results, will be experienced to identify advantages and limitations of each technology. The evaluation of the selected technologies will be based on an evaluation list, interviews, and filed observations. Feed-back from users and observation interpretation could set the requirements of the new instrumentation, and help the identification of the concept of operations to be used in the future projects.

5 Benchmarking the project's current situation

The analysis of the current situation contains two levels of evaluation: *Project team level*. Which includes the evaluation of the current work practices of the firms that are involved in the project; and *field level*, which includes the identification of waste sources in construction site.

5.1 Evaluation of the current situation from project team level

The problems analysis was related to changes in existing practices from three dimensions: Technology, Process, and Organization (Staub-French and Khanzode, 2007). The current situation result analysis is presented according to these three topics.

Technology

Communication tools between project stakeholders are telephone, weekly meetings, and emails. Plans are exchanged electronically in PDF or DWG format, either by email or via a FTP server. Different stakeholders are still using 2D Autocad drawings. The 3D model that contains the architecture, structure and mechanics has never been created. Plans are submitted on construction site in hard copy. The interviewed stakeholders have never used the BIM, and the impact of using BIM on their practices is not yet clear at all. Their maturity level of technology is very low since the use of technology does not reach the visualization level (3D).

Three attitudes concerning BIM implementation have been observed during interviews. They depend on the role of actors: 1) Levels of motivation are variables for client and project manager; 2) Hesitation / Resistance to change for the structural engineer: using a new technology needs time to get a good level of experience. 3) Resistance to change for the contractor: no added value in using BIM. On the other hand, three factors preventing the introduction of new technologies have been identified: 1) *Human factor:* a gap of level of knowledge on ICT between the client and the various project stakeholders; 2) *Time factor:* lack of time for implementation; 3) *Financial factor:* the initial investment is too costly (software, computers, training) especially for SMEs in the construction sector.

Organization

To better understand the delivery process and the contractual relationship between the stakeholders, an organisational chart has been represented basing on the collected data from the interviews (Figure 1). An iterative approach has been used to better represent the organization chart that has never been defined by the project stakeholders. Several issues related to the organizational structure and context of the project have been identified. The perception of roles was ambiguous; the client outsourced the project management to two firms without well defining the limits of responsibilities, like who made decisions or provided work instructions. That had impacts on the construction site works, where delays have been noticed because of incomplete plans, a lack of information due to a coordination problem.

Figure 1 Organizational Chart of the project

Processes

The design process did not follow a traditional sequence, which has created some problems in the coordination between professionals. The structural engineer was hired at the first to design the structure of the project, taking into account the particularities of the construction system. The architect then had to adapt the concept to the constraints proposed by the structure. The mechanical engineer has been involved once the architectural part has been defined. To better understand the information exchange between project stakeholders, how they collaborate and share information, and to identify gaps in the workflow, a representation of information flow (Figure 2:) has been established basing on collected data. Figure 2: highlights the difficulty of representing information flow in understandable logic structure. The lack of a common strategy for information management is reflected in the information redundancy, which is related to the fact that the project has many "*leaders*".

Decisions are taken and transmitted via two main channels: site meeting and email communications. Problems identified in regards to the site meeting are: 1) Meetings were regular, but not continuous; 2) Meeting minutes were not tracked after meetings; 3) Meetings attendances were irregular. Problems identified in regards to the e-mails communication are: 1) Tracking problems; 2) Information has not been sent to all the concerned actors; 3) Delays in replying to emails; 4) Problems in information interpretation; 5) Lack of responsibility after sending emails. Finally, two sources of delays in the construction site works have been identified: 1) Decisions issues: The client takes a long time to respond to comments from site, and 2) Plans issues: plan are not complete, and there is a delay in sending them to site.

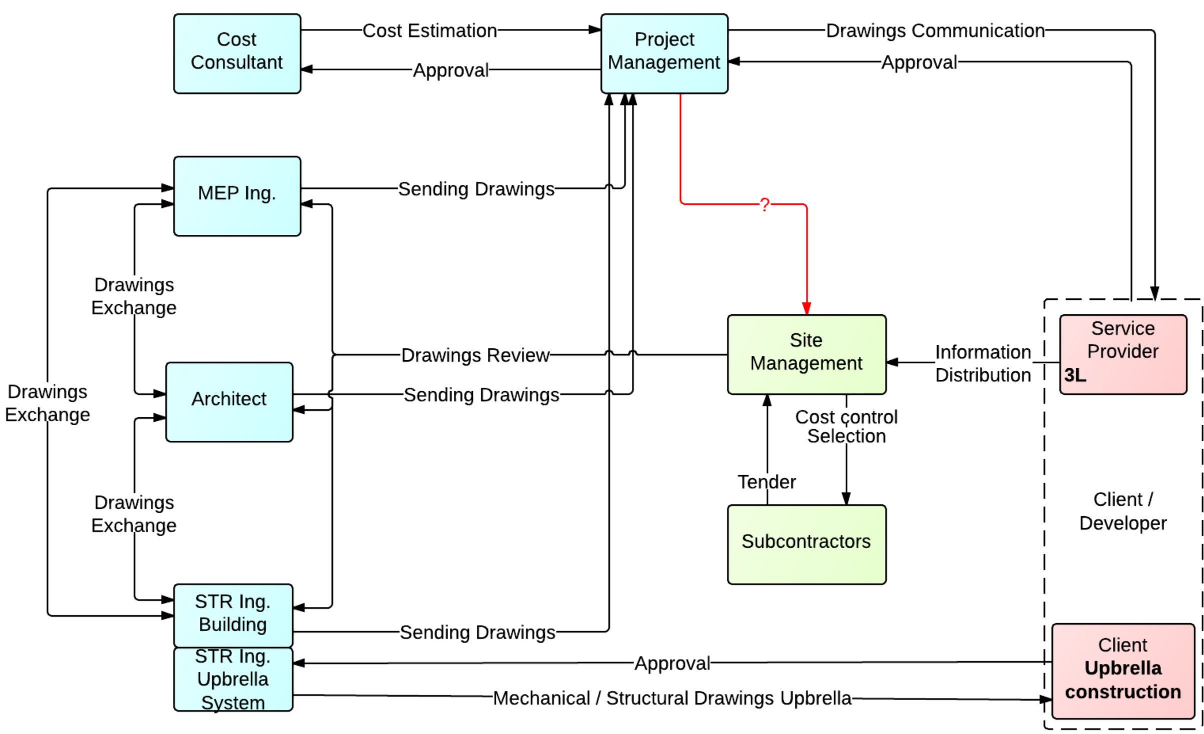

Figure 2: Information Flows Chart

6 Evaluation of the current situation from field level

A member of the research team has carried out the site observation and productivity measurement throughout the construction period. The objective is to document the construction work, and to identify current practices and problems during site work, such as the sources of waste in construction field.

The identification of waste sources allows maximizing the benefits and minimizing the losses associated with traditional practices of project management. The site observations allowed identifying a list of wastes on field; this list has been also compared to the client's observations to highlight the most important problems in construction field. Table 1 presents site observations, sorted and classified into three main categories: Requirements definition, Human factors, and Information transfer. This list has been used later to prepare the focus group session (see section 7)

Table 1: Wastes sources in construction site

Category	Wasteful
Requirements definition	• Lack of requirements definition for each module associated with a co-contractor; • Fuzzy definition of the tasks of each one; • Fuzzy Organizational links between stakeholders and concerning decision-making processes; • Rework; • Lot of wasted time in the management; • Fluctuation of production; • Over-production and under-production of some teams; • Standby Time: a lot of spaces are not used by workers; • Bad coordination of orders for materials; • False starts of some activities; • Lack of definition of the decision boundaries; • Poor equipment to perform the work; • Disparity in the efficiency of the used machinery; • Inconsistency between building systems; • Lack of systematic construction processes.
Human factors	• Lack of motivation among workers; • Poor working method (lack of qualification of workers); • Working in silos; • Urgent decisions must wait the weekly meeting; • Long delays approval of shop drawings; • Deadlines for agreement with the subcontractors; • Centralized decision-making; • No final decisions; • Lack of decision monitoring;
Information transfer	• Delays of plans production; • Incomplete plans; • Problems of interpretation; • Non-compliance plans following a change request; • Redundancy in the information exchange.

The problem of conventional sites is represented by the "Making-do" concept, which includes eight wasteful (Koskela 2004). A lack of information, resources and materials to work on the floor leads to work on another floor. This problem has an impact on the productivity: waste of time, resources, etc. According to studies, the effective work on site is approximately 40 to 55% (Choy & Ruwanpura 2005 Ballard & Howell 1998).

Because of the high variability in the way work was conducted, a value stream approach was adopted to measure productivity. According to Forbes (2011), a value stream is all the value added actions and non-value added actions currently, which are required to create a product from raw materials and decision management. Value stream mapping (VSM) focuses on information management and transformation tasks. The VSM process generates a current-state map, a future-state map, and an implementation plan. The main production processes are represented by distinguishing between value-adding and non-value-adding activities. Rother (2009) explains that the VSM helps to see the wastes and the sources of wastes. The analysis of the construction process of the second level has highlighted a too high lead-time. The Value Creating Time (VCT) has been measured to 195 hours while the Lead Time (L/T) was equal to 462 hours (the average duration of work was defined to 7 hours a day). Accordingly, the productivity criteria (the ratio between the VCT and the L/T) are equal to 42%. A lack of coordination between actors could be the cause of the non-continued construction flow. This poor result shows the need to improve the construction project management.

7 Defining the desired situation

To define the desired situation, and propose scenarios for improving the productivity of construction projects using the new construction system, some essential factors to improve future construction projects were identified, that can be applied in general projects and in specific case, related to future projects that will apply the new system proposed by the industrial partner. In other words, defining intentions that should take into consideration the particularity of the proposed system.

The interviews allowed highlighting several problems in construction projects, which helps in determining areas for future improvement to decrease of wastes in construction projects and to improve performance. These include 1) Better definition of needs and requirements; 2) Earlier study of budget impact on the project; 3) Improve coordination between disciplines; 3) Improve communication between project actors; 4) Reduce misunderstanding (on plans and e-mails); 5) Improve transmitting of information; 6) Create multidisciplinary standards of communication; 6) Reduce the “no change” attitude based on traditional habit.

The intentions of the client are to identify the tools as a solution to reduce mistakes and cost linked to non-quality in the project. The selection of the tool should be based on whether it could offer to the project, as well as, on the recourses needed for implementation. The tool should be easy to implement, can offer a return on the investment, accessible, etc.

The client has already in mind a strategy for implementation. In short term, he is looking to implement visualisation tools (3D), and a tool of centralization of information. In long term, he is looking to explore 4D and 5D tools and a 3D scanned model. The client's strategy is to gradually increase the maturity of using technology throughout the supply chain. His intentions to achieve these goals are by: 1) Imposing technology at professional levels by internally preparing the 3D model to 40% according to the developed construction system criteria, then invite the external stakeholders to continue working on, and completing, the same 3D model. 2) Convincing contractors by showing them the advantages of the proposed tool.

8 Defining the new information and communication technology (NICT)

The functional analysis of business processes around the project allowed to identify the problems in current practices, and figuring out the sources of waste. In order to validate and evaluate the findings, complete some missing information, and share experiences that could help in defining the new solution to improve productivity; a focus group with the key project actors has been used. Six participants attended the focus group that was held in the construction site on the early November 2012: the architect, the contractor, the client, the foreman, and his two assistants. As mentioned earlier, the list of observed wastes helped in the preparation of the focus group session. Four topics have been identified to initiate the discussion between participants: 1) productivity; 2) exchange of information; 3) rework; and 4) perspectives regarding the new construction system. For each topic, the observed problems were noted in directly during the meeting, and then participants were asked to rank them anonymously by priority to identify the main barriers to be addressed in future projects. Table 2 **Error! Reference source not found.** shows factors that have been judged by the stakeholders during the focus group session, as important to be taken into consideration.

Table 2: Important factors issued from focus group

Topics	Identified Factors
Factors that influence the productivity	1. Clarity of the information to the worker 2. Quality of worker's experience 3. Tools and equipment
Problems in information exchange	1. Many "Leader" 2. Delay in decision 3. Coordination between field and offices 4. Availability of information at the workstation (on site)
Reason of Rework	1. Misinterpretation and misreading 2. Changes in client requirements during the construction work 3. Initiatives that do not comply with the plans
Construction System advantages	1. Weather protection 2. Funding 3. Systematization of the realization of floors
Barriers of using the Construction System	1. Changing habits 2. System integration 3. Early involvement in the project

A questionnaire has been completed at the end of the session, to determine the primary problem to be solved in priority, and to have a feedback on the activity. Results issued from the discussion, as well as from the questionnaire, showed a correlation with the analysis in step 1 and 2. In other word, the poor communication is the main problem in this project.

Requirements for the tools

The choice of the tool to be tested on field was based on several requirements. 1) The need of a system that centralizes information becomes a priority to insure better communication and coordination. 2) The tool must be simple, easy to use on the field, and accessible. 3) The tool should take into consideration the existing data of the project, for example, how to use the 2D plans in PDF format. 4) The tool should consider the current status the project that will be delivered soon, in the current project case; it should support tracking deficiencies during the project delivery period.

The use of the tablet on the field was identified as the tool that meets the most the project requirements, and to be tested on field. The tablet has many advantages, but mainly the mobility and performance. In addition to test the use of tablets on field, different software will be tested too that can offer a centralized environment for users, improve communication, collaboration, tracking and efficiency.

9 Limitations and Lessons Learned

Several difficulties appeared during the development of research. The lack of collaboration of certain professionals was a problem, especially for interviews planning. On the other hand, having a single observer on construction site, and the large amount of information to be collected complicated the task of observing and measuring performance. A preliminary analysis showed that the main problem in the project practices is the lack of coordination and communication among the project team; the use of technology is not one of their priority, they prefer keep working with traditional ways. This current context of the project showed the constraints of using BIM tools: it should be introduced at an early stage, which could involve a change in current practices, tools, and working methods. The industrial partner is aware of the benefits of using new devices, implementing the BIM and using production control methods and approaches in construction project. He is looking to modify construction practices by proposing his new construction system. Several factors have slowed the research process; these problems particularly affect construction practices in the context of the multi-residential projects on Quebec:

- Resistance to change: project work is carried out in a traditional context; drawings are not well detailed, the work is not organized, and there is a lack of coordination;
- The low capitalization in multi-residential projects makes the exploration of new techniques and technologies hardly affordable.
- Lack of collaboration between professionals as well as a lack of respect for production deadlines for project documentation.

Despite theses constraints, the project seems to be a relevant example for exploring innovative practices in construction; it illustrates the current situation in its context (*in situ*) to introduce new technologies. The main lessons learned were:

- For successful implementation of BIM in a project setting, a client/owner should establish a business strategy, hire a BIM coordinator and prepare a BIM Project Execution Plan prior to launching a project;
- Production control methods and approaches should be documented in a Concept of Operations and be included in the contractual documents for any given project.

10 Conclusion

This paper has presented the preliminary results of an on-going research project aimed at studying the adoption and implementation of BIM tools within a construction project. The paper described a brief analysis of the current situation and set up a first image of the project organization, workflow, and value stream mapping. Findings highlighted the main problem in the practices around the pilot project, which is the lack of communication, and coordination, that have impacts on the quality of work on the field. The implementation of BIM has not been reached because of the current practices of multi-residential project. Professionals and construction managers showed no interest in using BIM. However, several interesting observations were made that will support the integration of BIM in construction. The client showed the intention to launch another project to benefit from the full implementation of BIM.

Results of the focus group have identified technological tools to be tested on construction site. A test of using TIC is on-going, and is looking for evaluating the use of tablets on field. The test is based on evaluation list, observations, and interviews. The results of the test will allow to set standards and will help in the definition of a conception of operation that uses the information technology to improve productivity. Finally, a new value stream mapping will be proposed that takes into account the operation of firms around the new construction system proposed by the client.

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