BIM AND LEAN INTERACTIONS FROM THE BIM CAPABILITY MATURITY MODEL PERSPECTIVE: A CASE STUDY

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ABSTRACT

Building Information Modeling (BIM) and Lean Thinking have been used separately as key approaches to overall construction projects' improvement. Their combination, given several scenarios, presents opportunities for improvement as well as challenges in implementation. However, the exploration of eventual interactions and relationships between BIM as a process and Lean Construction principles is recent in research. The objective of this paper is to identify BIM and Lean relationship aspects with a focus on the construction phase and from the perspective of the general contractor (GC). This paper is based on a case study where BIM is already heavily used by the GC and where the integration of Lean practices is recent. We explore areas of improvement and Lean contributions to BIM from two perspectives. First, from Sacks et al.'s (2010) Interaction Matrix perspective, we identify some existing interactions. Second, based on the Capability Maturity Model (CMM) of the National Building Information Modeling Standard (NBIMS), we measure the level of the project's BIM maturity and highlight areas of improvement for Lean. The main contribution of the paper is concerned with the exploration of the BIM maturity levels that are enhanced by Lean implementation.

KEYWORDS

Interaction between Lean and BIM, Capability Maturity Model, lean construction, case study

INTRODUCTION

Building Information Modeling (BIM) is an approach to design, construction and facility management that can make all project stakeholders be involved. The adoption of BIM as an activity that results in a "Building Information Model" is becoming a key approach to overall construction projects improvement. In fact, the core attribute of building information modeling that distinguishes it from previous design technologies is not three dimensional geometry modeling but information that is organized, defined and exchangeable (Smith and Tardif, 2009). BIM use in construction projects is, in that regard, related to technologies, business and organization. The objective of this paper is to identify the relationship between BIM

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as a process and Lean as management thinking. Our focus is BIM usage during the construction phase and from the general contractor's perspective that is described based on a case study. The first part is a literature review of BIM usage in the construction phase as well as evidences about Lean and BIM interactions. We then present our findings from the case study about the relationship between Lean and BIM.

METHODOLOGY

Our methodology includes the analysis of the integration of Lean practices through a case study where BIM is already implemented and used by the General Contractor. As a starting point, we focus on BIM and Lean interactions from the Sacks et al. (2010) Interaction Matrix perspective. Through this Matrix, we enumerate several areas of improvement observed in the case study. Then, based on the Capability Maturity Model (CMM) of the National Building Information Modeling Standard (NBIMS), we measure the level of BIM maturity.

SACKS ET AL. MATRIX

First, Sacks et al. (2009) discussed the potential contributions of BIM to visualization of the product and process aspects of construction projects in terms of lean construction principles. Then, they defined a bare matrix for the analysis of BIM functionalities (such as Visualization or Automated generation of drawings and documents) and Lean principles (such as reduce variability or increase flexibility). This matrix, without cell entries, served as a framework for the enumeration of BIM/Lean interactions emerging from research and practice. Sacks et al. (2010) presented 56 distinct interactions grouped in a matrix. We will use these findings from the interaction matrix to assess the relationship between BIM and Lean in the case study we conducted. This will be considered as a first perspective that will lead to a discussion on the case study results in comparison with our second assessment method based on the NBIMS CMM.

NBIMS CAPABILITY MATURITY MODEL (CMM)

The Capability Maturity Model (CMM) is a process improvement approach that aims in helping organizations to improve their performance. CMM can be used to guide process improvement across a project, a division, or an entire organization. Originally developed in 1986 by the Carnegie Mellon Software Engineering Institute (SEI – a federally funded research and development center), the CMM-based improvement Tools are used to identify an organization's process strengths and weaknesses and make process changes to turn weaknesses into strengths. The CMM concept has since been applied to several industries and areas of studies. Based on this model, the National Building Information Modeling Standard (NBIMS) developed a BIM-oriented CMM that has as a first objective the measurement of the « maturity » of a building information model and the processes to create it. Basically, the NBIMS CMM is a measurement tool of a BIM organization's maturity. It presents eleven categories of maturity (called also areas of interest) that are weighted according to importance and that can be scored from 1 to 10. Each score is a level of maturity for that specific area of interest. A global score is then calculated based on each

individual score for each of the eleven categories. This score and the level of maturity evaluated for each criterion translate the status of the BIM process capability and maturity within the company. For instance, Timeless / Response is an area of interest that measures the degree to which BIM information is sufficiently complete, up-to-date, and accessible to users throughout the life-cycle. The scale ranges from « Most responses are manually re-collected » to « Real time access and life feedback » (NBIMS CMM v1.8, 2007). This tool is seen to be a good step toward establishing BIM implementation Benchmarks (National Institute of Building Science, "National Building Information Modeling Standard, version 1, Part 1: Overview, Principles, and Methodologies", 2007).

We have chosen to present this BIM maturity measurement tool of BIM maturity measurement for two reasons: (1) by defining the categories of maturity, this tool helps highlight areas of focus for any type of BIM evaluation effort; (2) the idea behind the tool, that is CMM in general, can be applied to the construction issues and also enhances multidisciplinary efforts for the construction industry. We will be using this tool for the case study in order to get an idea of which BIM maturity categories can be improved or enhanced by the implementation of Lean.

RESEARCH BACKGROUND

The case study company is a main contractor that is one of the nation leading companies in BIM integration to their work processes. The company has more than 10 years of BIM experience. Lean implementation however is recent on this specific case study. For this project specifically, a combination of Lean techniques and the company's BIM experience resulted in the delivery of $3 million in budgeted costs savings below the Owner's initial target at the beginning of the project and an additional projection of nearly $1 million in savings from BIM-enabled prefabrication alone by the end of the project. The characteristics of the project are then oriented to highlight the input of Lean to a highly BIM mature project.

CASE STUDY DESCRIPTION AND LEAN IMPLEMENTATION APPROACH

The project is a 555,000 square foot health facility with a 286-bed capacity located in Tennessee (Figure 1). People involved in the BIM execution plan for this project are, as for any BIM based project within this general contractor, the regional BIM manager, the project BIM manager, the project manager and superintendents.

Onsite activities that involved BIM for this project are: Structural Steel, Architectural Elements (Walls, Ceilings, Doors, etc.), Mechanical HVAC, Plumbing,

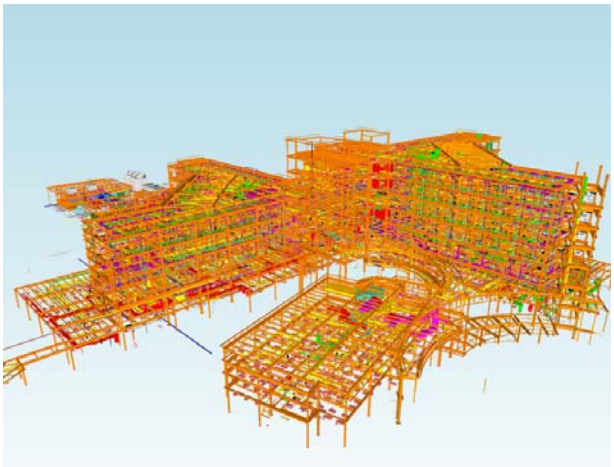

Figure 1: View of the information model of the project

Electrical, Fire Protection, and Pneumatic Tubing. Coordination and constructability issues are big challenges for this project. The lean construction implementation process started by utilizing a lean consultant from the Lean Construction Institute (LCI) to initially assist in developing a lean project approach for this project. The company proceeded then to a quick development of a project specific approach to lean and did not use the consultant past the first month of the project. Lean Construction practices that are used during this project are: Push/Pull Planning, Last Planner, Weekly Work Plans, Extensive Prefabrication, Offsite Prefab, Onsite Prefab, OAC Constraint Logs, and Just-in-Time Delivery of Materials. As we can notice, these different practices that can be considered as goals are also focused on the scheduling aspect of the project.

This case study is interesting by the fact that the company has already significant experience in BIM usage and has proceeded to a specific Lean implementation process on this project by initiating the implementation process by a Lean Consultant and carrying on a shaped implementation process developed by the company for its own needs. The combination of Lean and BIM is defined by a BIM engineer for this project: "By combining BIM and Lean practices you truly create a collaborative environment that can truly minimize waste, both tangible and intangible wastes, on a construction project". Our focus in the following paragraph is the enumeration of selected benefits resulting from this combination for this specific case.

BENEFITS OF BIM/LEAN PRACTICES IMPLEMENTATION

This section presents selected BIM and lean interactions within the case study:

1st perspective: Sacks et al. (2010) Interaction Matrix

- Matrix Cell 24: Model-based coordination between disciplines (including clash checking) is automated and so requires a fraction of the time needed for coordination using CAD overlays.

For this project, a major BIM use concerns clash detection. It is true that this process, when BIM based, can reduce significantly the time cycle of clash detection and consequently enhance one of Lean principles that is Reduction of Time cycles. However, as mentioned by BIM managers for this project, BIM success requires skilled individuals to input and export the needed information. Developing the building's design and the carrying out construction still requires a high degree of experience and expertise to successfully complete complicated projects, BIM simply assists in this process hopefully making it more efficient and saving the owner money. Hence, it is not evident that BIM usage reduces time cycle but the interaction, as defined by Sacks et al. (2010), between "Collaboration in design and construction" as a BIM functionality and "Reduce cycle times" as a Lean principle depends on the level of skill of the people involved in BIM manipulation and execution. For the case study, the company has an 8 week BIM course for newly hired personnel as well as an advanced course for experienced BIM users. These courses cover every aspect from laser scanning and model development to model turnover and closeout of the project. Being aware of the importance of skilled people in the achievement of BIM's successful usage, the BIM engineer insists on the fact that BIM still has a supporting function.

- Matrix Cell 25: All three functions serve to reduce cycle time during construction itself because they result in optimized operational schedules, with fewer conflicts.

Within this company and especially for this project, there is a proprietary system that allows BIM engineers to analyze the projects' schedule, work in place, and required manpower to assure that the project is being staffed correctly and billings are correct. Avoiding conflicts is in general a key factor for maintaining the schedule. The BIM functionality presented to achieve this goal is the rapid generation and evaluation of multiple construction plan alternatives (Sacks et al. 2010). Skilled BIM engineers in addition to experienced constructability experts and a good knowledge of the project's aspects are requirements towards the achievement of time cycle reduction as a lean principle. It is important to mention that Lean practices based on the push/pull process help detect conflicts earlier and prevent the company from scheduling conflicts and time loss. In fact, for this project, the work flow process was based on BIM modeling: 6 month push/pull sessions, 6 week push/pull sessions, Weekly Work plan submittals and commitment/task scoring of promises met. In this case, we can recognize a two-way interaction between Lean and BIM because each one is boosting the other by providing an enhancing function.

- Matrix Cell 5: Virtual prototyping and simulation due to the intelligence built in the model; objects enable automated checking against design and building regulations, which in turn make verification and validation of the design more efficient.

Visualization of form as a BIM functionality enhances Lean principles such as "reduction of variability", "verification and validation" or "decision by consensus" (Sacks et al. 2010). For this project, we can notice some aspects of the important role of the visualization as a BIM function: (1) the general contractor typically has an iRoom onsite (Figures 2 and 3) which consists of multiple smart boards as well as plasma screen monitors and project laptops or computers.

Figure 2: Last Planner® on the project construction site

Figure 3: BIM iRoom

In the field superintendents are carrying iPADs and or Tablet PC's loaded with the latest BIM model for up-to the minute coordination models, drawings, as-builts, etc. This level of visualization is high because it is close to the actual and most updated model version and is available to different levels of the hierarchy especially for on-site workers. The process of leaning the work is easier with this high level of communication and involvement already acquired. (2) For this project, a constraint

log was used in all Owner, Architect, and Contractor meetings to track the level of commitment of the three parties. These commitments were scored and communicated to the team throughout the project. The Lean principle that is "Decide by consensus" was one of the key factors for the project's success that was enhanced by the visualization option provided by BIM during the project phases. Throughout the case study, we highlight the importance of the skill level of BIM users to achieve reduction of time cycles as much as the importance of the existing BIM-based framework for leaning processes.

2nd Perspective: NBIMS CMM

© NIBS 2007	The Interactive BIM Capability Maturity Model			
	Area of Interest	Weighted Importance	Choose your perceived maturity level	Credit
	Data Richness	84%	Limited Knowledge Management	7.6
	Life-cycle Views	84%	Supports External Efforts	8.4
	Change Management	90%	Limited Control	4.5
	Roles or Disciplines	90%	Operations & Sustainment Supported	7.2
	Business Process	91%	All BP Collect & Maintain Info	7.3
	Timeliness/ Response	91%	Limited Real Time Access From BIM	7.3
	Delivery Method	92%	Web Enabled Services - Secure	7.4
	Graphical Information	93%	nD - Time & Cost	9.3
	Spatial Capability	94%	Integrated into a complete GIS	8.5
	Information Accuracy	95%	Full Ground Truth - Int And Ext	5.7
	Interoperability/ IFC Support	96%	All Info Uses IFC's For Interoperability	9.6
	National Institute of BUILDING SCIENCES Facilities Information Council National BIM Standard		Credit Sum	82.6
			Maturity Level	Gold

Figure 4: NBIMS CMM for the case study project

As explained below, the NBIMS CMM is a measurement tool of a BIM organization's maturity. We went through the eleven criteria or areas of interest during an interview with one of the company's BIM mangers. Depending on the project's size and scope, a BIM Manager is responsible for all aspects of the BIM model from preconstruction to closeout. Managing the preconstruction BIM models, BIM quantity take-offs, coordination models, design models, subcontractors' models, 4D Schedule/Model development and 3D logistics plans are standard procedures. During construction the BIM Manager is responsible for subcontractor coordination and clash detection, updating the 4D Schedule, coordination of the various logistics' plans, updating the as-built BIM models and linking the closeout documents to the BIM model if desired by the owner. Based on one of the company's BIM managers' description of the eleven criteria of interest, we consider that the assessment of the BIM maturity level for the regional office responsible for this project is accurate enough to help us identify areas of improvement that are realized by lean processes. Results of the NBIMS CMM for the company's Construction are shown in figure 4: the total score is equal to 82.6. The lowest score for the Gold maturity level is 80. This shows at a first overview that the company is already showing skilled usage of almost BIM functionalities. Table 1 presents details of the maturity levels of each area of interest and the potential lean contributions to the improvement of each one.

RESEARCH FINDINGS

This case study helps address these findings:

- A major BIM use concerns clash detection. It is true that this process, when BIM based, can reduce significantly the time cycle of clash detection and enhance then one of Lean principles that is Reduction of Time Cycles (Sacks et al. 2010).

However, a high degree of experience and expertise in BIM to successfully complete complicated projects is required. Experience and skills are then found to be a key factor to the success of this interaction.

- Having formal processes applied towards managing changes occurring within the company serves several goals including continuous improvement and variability reduction (Sacks et al. 2010). A limited level of maturity in change management is then subject to improvement by Lean techniques implementation such as Percent Project Complete (PPC) for feedback and cause analysis.
- Interoperability issues can be countered by a company's ability to use all file types (with the acquisition of mainly all software licenses). However, as far as Standardization as a lean principle is concerned, moving toward using a standard file type (IFC) is to be considered a long term goal for the company. The benefits related to standardization range from stopping any parallel work and starting from zero to avoiding same mistakes in previous projects are all around increasing predictability and efficiency (Nekoufar 2011)
- From the case study analysis, considering the BIM level of maturity of a project is seen to be an important input towards decision making related to potential Lean practices implementation. Indeed, with a variety of Lean practices addressing different lean principles, selecting and prioritizing their implementation can be a challenging decision making it a task that the BIM Maturity assessment tool can contribute to.
- We believe that there is a potential in creating an assessment tool combining Lean principles and BIM functionalities that can be used prior to lean implementation in new projects. This tool can help focus lean implementation to areas that can most benefit from lean practices. For example, if the company has a poor level of maturity in Timeliness/response BIM criterion, it would be very difficult to achieve the most potential of the implementation of lean practices that are heavily dependent of the availability of information on time. Information needed for new scheduled meetings can then be assessed based on the capability of the company.

CONCLUSIONS

We listed in the paper some benefits of BIM and Lean combination based on some interactions points presented in the cells of Sacks et al. (2010) interaction matrix. Even though BIM is considered to be a supporting tool, different conceptually from Lean techniques which are managerial processes, mutual interactions are two-way interactions. Also, the BIM level of maturity for each addressed area of interest has an effect on how useful and successful lean processes are implemented and used. Stakeholder skills and level of expertise are also critical to optimize the use of BIM functionalities serving lean principles. The results of the analysis are not absolute and can be inappropriate for certain cases. However, they are very likely to open up a discussion about the selection process of Lean techniques to a project, based on its BIM level of maturity. This can result in the elaboration of a lean/BIM combined assessment tool that will benefit lean consultants and companies to refine their choices in implementing lean practices and shape them to the company capabilities.

Table 1: Case study BIM maturity assessment and perceived lean improvements (Part 1)

Area of interest	Level n°	Perceived level of maturity	Detail (NBIMS CMM,2007)	Area of improvement	Relationship to Lean		Explanation	Reference
					Involved lean principle	Lean construction practice		
Data Richness	9	Limited Knowledge Management	Limited Knowledge Management implies that KM strategies are in place and authorative information is beginning	Having a robust data-rich environment, with virtually all authorative information loaded and linked together	Select an appropriate production control approach	5s Process	Because of the increasing number of people involved in BIM information, there is a need to manage the knowledge acquisition and ensure consistency between plans, specification, models and other supportive documents	Weygant, 2011
Life-cycle Views	10	Supports External Efforts	External information is linked into the model and analysis can be performed on the entire ecosystem of the facility throughout its life	Improving analysis capacities and then decision making effectiveness during the lifecycle	Increase flexibility	Master Schedule	Use and reuse of design models to set up analysis models such as energy, acoustics, wind, thermal, etc. reduce setup time and make it possible to run more varied and more detailed analyses	Sacks et al. 2010
Change Management	5	Limited Control	Business processes are in place and the organization has begun implementing change management procedures	Achieving an environment in which business processes are routinely supported by integrated change management processes that includes root cause analysis and feedback loops to assess the effectiveness of the change	Standardize Ensure comprehensive requirements capture	PPC for feedback & cause analysis	Having formal processes to changes occurring within the company serves several goals including continuous improvement and variability reduction	Sacks et al. 2010
Roles or Disciplines	8	Operations & Sustainment Supported	People's jobs in planning, design, construction, and operations and sustainment are fully supported through BIM in that they do not have to go to other products to accomplish their jobs	Making all facility-related jobs both internal and external to the organization rely solely on the BIM to accomplish their jobs	Cultivate an extended network of partners	Daily Huddle Meetings (in an i-room)	Integration of different companies' logistic and other information systems makes working relationships that extend beyond individual projects worthwhile and desirable	Sacks et al. 2010
Business Process	8	All BP Collect & Maintain Info	All business processes are designed to collect information as they are performed and all are capable of maintaining information in the BIM	Making all business processes designed to collect and maintain data in real time	Reduce cycle time	5s Process Fail Safe for Quality & Safety	Real time data collection and maintenance is an optimum operation that helps reduce the time for any other risk depending on updated data	

Table 1: Case study BIM maturity assessment and perceived lean improvements (Part 2)

Area of interest	Level n°	Perceived level of maturity	Detail (NBIMS CMM,2007)	Area of improvement	Relationship to Lean		Explanation	Reference
					Involved lean principle	Lean construction practice		
Timeliness/ Response	8	Limited Real Time Access From BIM	Information stored in a BIM is available real time and although not from a live feed. Processes are in place to maintain its accuracy	Making information continually updated and available from live feeds to sensor. Responses to questions are immediate, accurate and relational.	Verify and validate	Fail Safe for Quality & Safety	Early detection of actual or potential schedule delay in field construction activities entails project managers to design, implement, and maintain a systematic approach for construction progress monitoring to promptly identify, process and communicate discrepancies between actual and as-planned performances	Golparvar-Far et al. 2009
Delivery Method	8	Web Enabled Services - Secure	The BIM is web-enabled environment and is considered secure. It is not an SOA	Making BIM a net centric Web environment and served up as a service in a service-oriented architecture with role-based CAC enabled to enter and access information	Design the production system for flow and value	-	Sharing models among all participants of a project team enhances communication at the design phase even without producing drawings, helping ensure that the requirements are understood and transmitted throughout the team and on to builders and suppliers.	Sacks et al. 2010
Graphical Information	10	nD - Time & Cost	The drawings stored in the BIM are intelligent and object-based and include time and cost information	Enhancing graphical information that is object-based, parametrically intelligent and that includes information related to time and cost	Use visual management	Increased Visualization	BIM provides the ability to evaluate the impact of design changes on construction in a visual manner that is not possible with traditional 2D drawings. This goes coherently with lean emphasis on visual management	Eastman et al. 2008
Spatial Capability	9	Integrated into a complete GIS	Information from the BIM is partially recognized by the GIS environment and some metadata is available	Making information from the BIM fully recognized by the GIS environment, including full metadata interaction	Institute continuous improvement	-	With the increasing complexity of projects, such an improvement is for sure beneficial to better control the complexity issues.	-
Information Accuracy	6	Full Ground Truth - Int And Ext	All internal and external spaces are identified electronically	Calculating all spaces automatically and using metrics to ensure information availability and accuracy	Reduce variability	-	Automated quantity takeoff which is linked to the BIM model is more accurate as there are less chances of human error; hence, it improves f ow by reducing variability.	Eastman et al. 2008

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