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Using Building Information Modeling to Achieve Lean Principles by Improving Efficiency of Work Teams

Xun Zhang, Salman Azhar
McWhorter School of Building Science, Auburn University, Alabama, USA
xzz0032@auburn.edu, sza0001@aubun.edu

Abid Nadeem
Department of Civil Engineering, Nazarbayev University, Astana, Kazakhstan
abid.andeem@nu.edu.kz

Abstract

Both of Building Information Modeling (BIM) and Lean construction have significant impacts on construction industry. It is widely accepted that BIM can be used as a tool to help reduce project cost, shorten project duration by optimizing the construction sequence, improving the coordination of project teams, providing communication platform for different disciplines and so on. A further exploration can be made to find whether BIM can be used as a tool to help project team to achieve the Lean Principles. In this research, a hypothesis was developed to validate if BIM can be used as a tool to achieve the principles of Lean construction by improving the construction productivity of a project. Several metrics were investigated to measure the contributions of BIM towards project productivity. By analyzing a case study, this paper explores the connection between BIM and Lean construction, the contribution of BIM in the development of coordination and collaboration of work teams, project quality, and reduction of waste and cost.

Keywords

Building Information Modeling, Construction Management, Lean Construction

1. Introduction

Over the past 40 years, although several new and advanced technologies have been applied to construction projects, the efficiency of the industry has remained quite low (Koushki, 2005). The main reason for this appears to be the inability of new technologies to effectively reduce the cost of design and construction while, at the same time, improving the management of the construction process (Teicholz, 2004). One approach for improving the situation is using Lean construction philosophy (Aziz and Hafez, 2013). Lean construction philosophy refers to the application and adaptation of the underlying concepts and principles of the Toyota Production System (TPS) to construction. Like in the TPS, the focus in Lean construction is on eliminating waste; cutting costs, improving team productivity and creating positive project outcomes. (Sacks et al., 2009a).

The productivity of the USA construction industry has been declining since 1964 (Teicholz, 2013). In a project, construction productivity could be affected by many different factors. One of most important factors is the lack of coordination of subcontractors with work activities (Mincks and Johnston, 2011). Poor coordination and collaboration will cause construction errors requiring costly and time consuming re-work. These errors are treated as a kind of waste by Lean thinking and should be eliminated during project construction. In order to achieve this objective, Lean construction techniques require careful coordination and collaboration between the general contractor and subcontractors to ensure that work can be performed when the appropriate resources are available on site (Eastman et al, 2009). In this case, Building Information Modeling (BIM) is a possible tool to avoid the errors created by poor coordination and collaboration. At the same time, BIM may also help to achieve the principles of Lean construction as an expansion of the capabilities of 3D CAD (Computer Aided Design). The BIM model initially can be used to aid in the description of the design complexity; then used to assist in the description of construction sequence, leading to the reduction of coordination problems during construction.

2. Research Aim, Objectives and Scope

As a response to the construction problems previously discussed, the main aim of this research is to investigate if BIM can be used as a tool to achieve the principles of Lean construction philosophy by improving the productivity of work teams. The research sought to achieve the following objectives:

1. To map the interactions of BIM and Lean construction philosophy.
2. To investigate the improvement of work team's productivity in a BIM-Lean project.
3. To find the contribution of BIM in achieving the principles of Lean construction.
4. To explore the functions of BIM in assisting Lean techniques.

The scope of this research was limited to the construction companies and BIM-Lean projects in the southeast of the US.

3. Literature Review

3.1 Lean Thinking Principles and Applications

Koskela (2002) described Lean construction as a way to design production systems to minimize waste of materials, time and effort in order to generate the maximum possible amount of value. Earlier, Koskela (1992) listed the following heuristic principles of Lean thinking: 1) Reduce the share of non-value adding activities; 2) Increase output value through systematic consideration on customer requirements; 3) Reduce variability: reduce uncertainty, increase predictability; 4) Reduce cycle time; 5) Simplify by minimizing the number of steps, parts and linkages; 6) Increase output flexibility; 7) Increase process transparency; 8) Focus control on the complete process; 9) Build continuous improvement into the process; 10) Balance flow improvement with conversion improvement; 11) Benchmarking.

Based on these principles and several case studies, Engineers Australia (2012) listed the recommended practices used for the application of Lean construction methods: 1) Eliminating Waste: a) waste walks b) value stream mapping; 2) Target Value Design; 3) Building information modeling (BIM); 4) Last Planner system; 5) Pull Planning; 6) Information Center Meetings; 7) Five step plan (5S) and Visual Management; 8) Standardized work; 9) Continuous Improvement (CI) 10) Built in quality and error proofing; 11) Just in time (JIT); 12) Prefabrication.

3.2 The Interaction of BIM and Lean Construction

Building Information Modeling (BIM) was seen as an emerging approach that will help the construction industry in achieving Lean construction principles by eliminating waste; cutting costs, improving team productivity and creating positive project outcomes (Gerber et al., 2010). The report of McGraw Hill Construction 2012 showed the business value of BIM: 1) 52% reduced document errors and omissions; 2)

51% Market New Business; 3) 48% Reduced Rework; 4) 46% Offer New Services; 5) 39% Reduced Cycle time of Specific Workflows; 6) 23% Staff Recruitment and Retention. Sacks et al. (2010a) identified 56 interactions via using a matrix that juxtaposes BIM functionalities with prescriptive Lean construction principles. Oskouie et al. (2012) extended the matrix of the interaction of BIM and Lean construction. They introduced new BIM functionalities added to those identified by Sacks et al. (2010): (1) Support the Make Ready Process; (2) Facilitating Real-Time Construction Tracking and Reporting; (3) Support Augmented Reality.

Gerber et al. (2010) conducted three case studies from practice through the BIM based objectives and outcomes. They mapped these outcome to the taxonomy of the interaction matrix described by Sacks et al. (2010a). They present the hypothesis that BIM in fact will become increasingly essential and an inextricably linked component to a Lean construction process, especially within the context of abundant geometric and semantic project information,. The hypothesis is validated through the project documentation and practice testimonial in the form of time-savings, waste reduction, and enhanced collaboration. Building Information Modeling provides a powerful platform for visualizing workflow in control systems that also enable pull flow and deeper collaboration between teams on and off site (Sacks et al., 2010b). Their case study found that BIM and schedule integration are essential to improving upstream flow variability through visualizing construction methods and processes (Sacks et al., 2010a). Interaction; optimization through 4D scheduling for improving efficiency and safety can help identify bottlenecks and improve flow, and interaction; visualization of proposed schedules and visualization of ongoing processes to verify and validate process information (Sacks et al., 2010a). The use of BIM and the synchronizing with scheduling software solutions and experts to reduce the waste caused by poor coordination, and to maximize value for the entire project constituency by ensuring look-ahead collaboration (Gerber et al., 2010).

In conclusion, construction projects suffer from waste that is manifested in waiting time for crews, rework, unnecessary movement and handling of materials, unused inventories of workspaces and materials (Sacks *et al.*, 2007). Adopting a methodology based on a BIM-Lean approach will lead workers to manage the everyday processes with greater reliability and less variability, reducing operation downtimes in public facilities of intense use (Clemente and Cachadinha, 2013).

4. Research Methodology

This research aimed to analyze the outcome of BIM and Lean practices in project productivity. The methodology has been to explore the relation of BIM and Lean thinking, the contribution of BIM in achieving Lean principles. Based on the results of existing research, a framework (Figure 1) has been developed to validate the Hypothesis that *BIM can be used as a tool to achieve Lean principles by developing project productivity*.

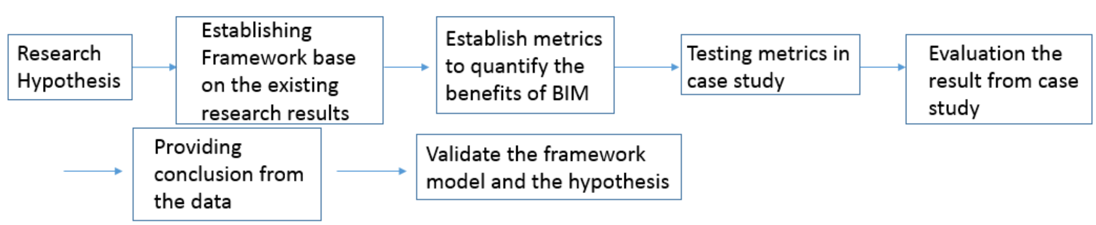

Figure 1: Framework Development of this Research

Some metrics were established to measure the benefits of BIM in achieving Lean principles. 1) Hours of Rework: Rework causes cost overrun and project delay. However, as BIM reduces the amount of hours required for rework, the product cost, cycle time and duration will all be reduced as well; 2) Physical Conflicts: Clashes are discovered in the models and corrected before construction begins. Discovering these errors early on allows for a higher level of coordination between different contractors, and significantly reduces conflicts occurring in the field, saving time and money; 3) RFIs: RFIs are used to clarify unresolved issues on a project. The visualization of the project that BIM offers allows the contractor to work with a higher degree of clarity and allows for better coordination and communication between all work teams on a project. In this workflow, the number of RFIs required to finish a project are much lower than normal; 4) Change Orders: Better coordination and communication of work teams will significantly reduce the amount of Change Orders needed; 5) Prefabrication: BIM allows a higher use of prefabricated structural elements to provide a more efficient and safer construction phase. 6) Cost Saving: This metric compares the estimated cost to actual cost. 7) Schedule Compliance: This metric compares the estimated schedule to actual schedule completion.

Then, a case study was conducted to test the metrics established as well as the main contribution of BIM and Lean practices in the improvement of project productivity. The related qualitative and quantitative data were collected by interviews with construction professionals, project documents and observation from a BIM-Lean based project involved in the case study. After evaluating the results from the case study, research conclusion was provided to validate framework model and the hypothesis.

5. Results and Main Findings

The main part of the case study research was about a hospital located in Georgia, US. Several Lean practices were applied in this project like Just In Time (JIT) Delivery, Last Planner System, prefabrication and so on. The main contributions of BIM support team in the application of these practices were to improve the coordination of MEP systems, to allow more prefabrication, to develop construction safety, to reduce inventory, and to avoid construction clashes and time-consuming re-work.

5.1 The Application of Lean Practices on the Case Project

Just In Time Delivery is one of the main applications of Lean Material management which requires the material be delivered in the right part, at the right time, and in the right place. The aim of this application is to minimize the on-site storage area as well as reduce the project inventory cost. In this project, construction teams tried to bring the materials on site when it was ready to be consumed on the project and kept minimum amount of materials on site throughout the duration of the project. In many situations, the teams allowed the storage of materials a maximum one week. In this process, BIM was used as a tool to provide project teams the information of materials. For example, based on the information and construction sequence, project teams looked-ahead to identify the exact number of doors and frames which were needed to be installed in a certain construction phase. In this way, they did not need any redundant materials on site, which met the requirement of JIT delivery.

The Last Planner System produces maximized value to the owner by eliminating waste caused by unpredictable work flow which may be caused by bad weather, change orders etc. In this project, work teams developed a 6 month construction sequence and involved each subcontractor to determine which role they would play in the sequence. Then they started working it backwards, to determine the construction sequence from the end to the start. After every 3 months, the teams repeated this process and planned the next 6 month sequence. The traditional scheduling methods separate groups from one another, causing a lack of communication and teamwork. This is one of the main reasons for low work efficiency. Instead, using the Last Planner System construction groups determined the sequence and shared their responsibilities together. Through the researched project, this system proved to encourage the communication between different work teams. Compared with the conventional way, the Last Planner System made the project sequence more flexible and predictable. As a visual tool, the BIM model was used firstly by construction groups when they made construction plans. The model provided illustrating support to the system. Every work team highlighted their construction activities with the help of the model. In fact, the BIM model played as a reference in the system.

5.2 The Applications and Main Contributions of BIM

As one of the main functions of BIM, the MEP system coordination process in this project had a high quality and brought a lot of benefits to construction teams. During the coordination process, the BIM group tried to minimize the clashes in this project. Usually, they coordinated a half of a floor about 15,000 to 20,000 square feet in one time. They started with several thousand clashes as a total among the systems. After days' coordination, the clashes came down to few hundreds. There was a remarkable reduction in the construction clashes with the help of Navisworks clash detection. As they continued the coordination, the BIM group became more confident and more comfortable. Trust among the teammates developed so they did much better at coordinating the things in the tightened time frame. The high degree with confidence allowed the high efficiency and comfort of installation crews.

In this project, BIM made a significant contribution in the application of prefabrication which is an efficient way to develop the project productivity. This project had two priorities in the electrical part. Priority A was the high bay racks, which was the biggest distribution of racks and most of them were prefabricated. This part was finished in high quality within a relatively short time. Priority B was the low conduit. Less than half of them were prefabricated. Without the help of the BIM model, too much on-site fabrication caused a lot of problems. Another thing that the project teams did to increase the project productivity was setting the hangers for major systems. The project teams used the information provided by BIM to locate the position of hangers. Then, they went out to the field and used Trimble total station devices to lay those points out on the metal deck above. After that, they drilled in and dropped in the blue banger screw posts before the pouring of slabs so that they could just go back with threaded rod. Traditional methods of layout and installation of slab inserts for overhead supports took a 3 man crew 9 hours on a single bay to complete. But in robotic layout, 2 men completed the same work in 3 hours. Thus they had four times increase in productivity by reducing man hours necessary to put in hangers. Besides, in this way, nobody will be standing on the sixteen feet up off ground and using a hammer drill to go into concrete, which is a tremendous development for construction safety.

Onsite job box was used in this project. This device was used to distribute the construction documents set. Project manager teams transferred these documents into various files and used the hyperlink set to upload the construction documents to the master folder in the cloud drop-box. Every work team could access to the documents by using the onsite job box on their laptops or iPads. There were two main advantages of the application of onsite job box. 1) This project had about 4000 sheet sets and always needed to be updated. If the project teams printed out all of the sheets, that would increase project cost and paper waste. While by using the job box and BIM model, the project teams updated the information without any paper cost. In this way, BIM helped to reduce the cost of project; 2) the updating speed of an internet-based information platform is much faster than that of a paper-based information platform. Work teams got the most up-to-date information with the help of BIM.

5.3 Main Findings from the Case Project Data

The metrics developed in the framework were used to analyze the outcome of BIM and Lean techniques in this project. Based on the collected data, the main findings of the case study were summarized as the following: 1) BIM and Lean practices help to reduce the cycle time of RFIs. In a traditional way, to get the response back of RFIs usually would be taken 2 weeks. However, the project teams did it in 3 days with help of the model. Because they showed the problems in an actual area and defined RFIs with much clearer terms the meaning of the questions. They turned around a RFIs at 3-4 days with a clear understanding in a minimum time; 2) BIM allowed more prefabrication for Lean practice. The BIM-based MEP coordination process allowed more prefabrication in this project. There were about 50%

prefabrication used in priority A of electrical part, 75-80% prefabrication used in the HVAC system and 40-50% prefabrication used in the Plumbing system. The robotic layout made the hanger installation speed 4 times faster than that of a traditional way. In this process, workers did not need to climb up ladders, which made the construction process much safer; 3) BIM reduced construction clashes significantly. The project team has reduced the number of clashes in a half floor area from thousands to few hundreds. This process reduced time-consuming re-work and gave work teams confidence; 4) BIM helped to achieve Lean principles by reducing waste. The job box reduced the hard documents used on site, which saved the project cost and reduced paper waste. Also, the on-site model accelerated the information exchanging speed.

6. Conclusions

This research illustrated the main applications of BIM and Lean practices in an actual project. BIM helped to establish a communication platform for work teams, improved the quality of coordination, developed productivity of work efficiency and made the project safer. It is known fact that Lean is the process which focuses on maximizing productivity as well as minimizing waste. The research results showed that BIM not only helped in clash detection, but also helped in the development of value adding work-flow through work team coordination and communication. The hypothesis about whether *BIM can be used as a tool to achieve the principles of Lean construction by improving the construction productivity of a project* was supported by the results of this research. In the case study, the BIM coordination gave work teams a high confidence. As we know, the morale of work teams is a very important impact factor of the project productivity. The further research can focus on: 1) The impact of BIM on work teams morale. It can be analyzed that BIM can be used to develop construction productivity of workforce; 2) Development of the interaction of BIM with Lean techniques.

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