Integrated BIM/Lean Base Production Line Schedule Model for Modular Construction Manufacturing

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ABSTRACT

Building Information Modeling (BIM) and lean are two distinct concepts used in the construction industry which are independently applied to the construction process and provide profound impacts. Evidence shows potential gain if both BIM and lean are integrated. This research proposes an integrated model that applies both BIM and lean on a modular construction manufacturing (MCM) process and gains the benefits of both concepts. A computer tool for drafting the modular construction process called MCMPro was expanded to generate the building components’ schedule. The Value Stream Map (VSM) of the factory is generated based on the components’ schedule through a proposed Integrated Process Improvement (IPI) method using a set of mix lean principles to reduce waste over a broad range of factory activities. A simulation model using Simphony.NET 3.5 is developed to run the generated VSM and produces the results. The proposed methodology is validated by a case study, which is a modular building located in Edmonton, AB, and illustrates the effectiveness of the proposed methodology.

INTRODUCTION

Industrialization of the building construction process requires special methods of production technology and particular design criteria to support automated production operations that are focused on factory settings. Engineers must consider production plan and support the manufacturing requirements for design and drafting. Factory production provides opportunities for applying production efficiency
strategies extracted from lean thinking in the plant, including eliminating waste and helping building manufacturers deliver a wider variety of products which are more responsive to customers’ preferences in a shorter time and at a lower cost. To support the manufacturer’s needs for design and drafting considering lean thinking in construction, an integration of Building Information Model (BIM) with lean construction principals is required. The concept of incorporating lean and BIM is not new; Rischmoller et al. (2006) used Computer Advanced Visualization Tools (CAVT) to improve the value generation in design and construction processes. They used lean principles as the theoretical framework to evaluate the impact of CAVT in waste reduction, better customer value, and improving construction flow. Khanzode et al. (2006) introduced and applied the concepts of Virtual Design and Construction (VDC) to represent aspects of BIM in Lean Project Delivery Process (LPDS). They explained which specific VDC tools and methods can be applied to each phases in LPDS to achieve the objectives of a lean production system.

Sacks et al. (2009a) discussed the synergy between BIM and lean construction. They provided two examples to generate 3D visualizations of a construction process in order to facilitate process flow and reduce variability within the context of BIM software systems. In another attempt to integrate lean and BIM, Sacks et al. (2009b, 2010a) provided a conceptual framework for assessing the interconnections between lean and BIM and they identified 56 interactions through their developed matrix. The profound conceptual framework proved the benefits of using BIM in order to achieve the lean outcomes. In the same manner, Ningappa (2011) used three different analysis methods including literature review on BIM and Lean, existing data from a US general contractor, and interviewing BIM experts to determine how BIM helps to achieve a leaner construction. The result proved that BIM helps implement lean techniques mainly to reduce construction waste and save cost in overall reduction of change orders.

Sackes et al. (2010b) compiled a set of requirements based on the Last Planner System™, called KanBIM to implement a BIM-based lean production management system. The KanBIM concept provides visualization of the construction product as well as the production process which enables construction managers to focus on establishing production systems and continuous improvement. In other research, Alwisy (2010) developed an automated design system that produces design aspects needed for construction manufacturing and facilitates information communication. He developed an integrated computer tool for design and drafting for the modular construction manufacturing (MCM) process called MCMPro that generates sets of shop drawings. This research proposed an integrated model that applies both BIM and lean on the modular construction manufacturing (MCM) process and gains the benefits of both concepts. The MCMPro was expanded to generate the building components’ schedule. Then the Value Stream Map (VSM) of the factory was developed based on the components’ schedule through an Integrated Process Improvement (IPI) using a mix of lean principles to reduce waste over a broad range of factory activities. A simulation model was generated to explore the proposed VSM. In this research, advanced methods and techniques in productivity efficiency were integrated and a new methodology was created for manufacturing construction.
INTERACTION BETWEEN BIM & LEAN

BIM and Lean are two distinct concepts in the construction industry and each provides a fundamental impact on the construction process. Although the two areas are independent and are separately applicable to the construction process, profit can be maximized by integrating both BIM and lean concepts. In the following section, each concept is briefly introduced with emphasis on characteristics which highlight the interaction between lean and BIM.

The phrase lean is used in lean production because everything is used less compared to mass production (Koskela, 2000). Lean Production was developed by Toyota led by Engineer Ohno to demonstrate waste reduction in Toyota production system (TPS) (Ohno, 1988). The criterion to define waste in lean production is performance from the customer point of view (Howell, 1999). According to Womack and Jones (1996), lean principals are defined in five steps Specify value as perceived by the customer for each specific product; Identify the value stream; Make the value flow without interruption through the value stream; Let the customer pull the value from the value stream; Strive and pursue perfection. The lean production concept was adopted in the construction industry in 1992 through Koskela’s seminal report (Koskela, 1992). The focus for lean construction, same as that for TPS, is on reducing waste, increasing the value for the customer, and continuous improvement (Sacks et al., 2009b). Lean production methods focus on the value stream in which value, as defined by the customer, is continually added to a product. BIM is expected to provide the foundation for some of the results that lean construction is expected to deliver. Based on the definition in the BIM Handbook, BIM provides requirements for new capabilities in construction and supports creation of an integrated design and construction process that increases quality, and reduces the cost and duration of a project (Eastman et al., 2008). BIM is applicable to all of the project stages and helps reduce waste from the design conceptual stage to the construction operation (Arayici et al., 2011). There are some benefits of using BIM particularly in applying lean to the construction process. The procedure of generating shop drawings is simpler for any building type once the model is generated completely. First a model is created in BIM, and then the schedule for building components, material ordering, fabrication, and the delivery process are developed (Azhar et.al, 2008).

MODULAR BUILDING CONSTRUCTION

One type of building construction technology is modular building where the modules are manufactured in the factory under controlled conditions and transported to be erected on site. The use of manufacturing construction is directly influenced by the customer’s requirements. Such construction technology can increase the effectiveness of advanced technologies such as BIM and Lean construction. The modular construction manufacturing (MCM) process consists of three main stages: panel prefabrication, production line in the factory, and on-site modules installation. The production line is divided into a number of stations, where all activities including framing, door and window, electrical, mechanical, and finishing can be done.
PROPOSED METHODOLOGY

The objective of this research is integrating BIM and lean for a modular construction process. For this purpose, the integrated computer tool for the design and drafting of the modular construction manufacturing (MCM) process, MCMPro, generates sets of shop drawings was expanded to generate building components’ schedule and accommodate the proposed methodology requirements (See Alwisy thesis, 2010). Then the Value Stream Map (VSM) of the factory is developed based on the components’ schedule through a proposed method called Integrated Process Improvement (IPI) using lean principles to reduce waste over the factory activities.

The proposed drafting and design system, MCMPro, provides a complete set of shop drawings needed for modular construction manufacturing using AutoCAD Visual Basic for Applications 2009. This tool utilizes a Scenario Based Analysis (SBA) in order to automatically generate the required set of shop drawings. SBA interprets the inputs, criteria, and standards into a set of rules and incorporates it into the tool core BIM [Figure 1]. Architectural components are represented through the 2D layout of the project and must yield to city bylaws. Structural requirements are specified with building codes are used to define the components for each wall, door, window, beam, and column. Modular concept provides a set of rules needed for dividing the layout into units and specifies allowable module dimensions based on road regulations, acceptable dividing elements, and rules related to slab thickness adjustment for each unit.

Figure 1. The Scenario Based Analysis (SBA) process
The framing method uses framing best practice to specify different types of wall connections, framing elements, and openings. These requirements are included in the parametric algorithm and pass through three main stages: generating the Building Information Model; creating the Modular Construction Manufacturing BIM; producing detailed shop drawings. The upgraded model based on the construction manufacturing concepts, creates a set of detailed construction drawings, take-off lists of materials, and building components’ schedule.

After developing a fully-detailed set of shop drawings, Lean construction concepts can be utilized to optimize the work flow in the production line based on the amount of work needed to be performed in each station. For this purpose, a project components’ scheduling for the production line stage is developed as input to create a Value Stream Map (VSM) through a proposed Integrated Process Improvement (IPI) method. The VSM is a core lean tool; it is a pencil and paper technique that graphically depicts the flow of materials and information as value is added in the production process. Most importantly, it helps identify opportunities for improvements and operations that consume resources without adding value. In this stage the VSM is created manually through an IPI method, though the model is under development to create the VSM automatically.

The goals of the proposed IPI method include the following: increase productivity, reduce or eliminate waste, standardize building processes, reduce delays, eliminate bottlenecks and unnecessary material handling, raise skill levels, reduce inventories, address defects and problems, and optimize space usage. The proposed method is presented in Figure 2. The input for the IPI is the building components’ schedule including wall, slab, door, window, beam, column, and MEP system. A set of criteria need to be considered such as factory space limitation, available human resources, factory working hours, and customer demand scheduling. In the main process, the building components’ schedule is analyzed and the VSM for the factory is created which is currently generated manually and shows the product family, information and material flow, work cell, inventory space, daily customer demand, supplier and shipping schedule, and production volume. Then a simulation model using Simphony.NET 3.5© runs the generated VSM to produce results such as takt time, lead time, processing time, amount of work in process, buffer stuck, bottleneck, on time delivery percentage, and rework or defect rate. If the result from the simulation model is not satisfying, then VSM is required to be revised and the simulation model is updated with the new inputs and runs again until an optimized result is produced as the output of the IPI method.

CASE STUDY

The Compassion House Foundation was established in 1998 with the vision to build a facility supporting women with breast cancer from Northern Alberta during diagnosis, treatment and the early stages of recovery. In early 2001, the Key to Compassion Capital Campaign was launched. With the generous support of the Edmonton community, and donors across the province, the facility was under
construction by September of that year. The existing Compassion House is a 2-storey building and a basement [Compassion House, 2008]. The new project is an extension for the existing Compassion House. The architectural design for the building had the capability for modular construction. Therefore the layout was divided into modules except corridors and basement.

Generating BIM Output

The first step is to create a database to store the 2D layout analysis input and output. For the purpose of generating the BIM, the developed tool MCMPro includes a predefined set of knowledge-based rules that accommodate for the expertise needed to read a 2D CAD properly. This set of rules is used to transform the lines in the 2D layout into a BIM that includes the project’s different components that are represented by these lines. The input data is 2D CAD and the architectural requirements. The architectural requirements provide data related to the 2D and 3D architectural design. This data is used to provide a 3D visualization for the BIM. Structural design and wood-framing requirements are applied on the modular construction manufacturing BIM to provide the detailed shop drawings needed for manufacturing of the module’s wall, floor, and ceiling. The framing process starts by utilizing walls, openings, and connections. After analyzing the framing data, two
groups of data tables are stored: detailed data tables that contain data related to each component and layout data tables that display the take-off list of materials. This data is used to provide the detailed shop drawing needed to frame modules’ walls, floors, and ceiling. Figure 3 shows the generated shop drawings and material take-off table.

![Figure 3. Generated shop drawings and material take-off table](image)

**Integrated Process Improvement**

Generated building components’ schedule by MCMPro provides the required data to create the factory future state value stream map. The modules of the project were proposed to be fabricated in Igloo Prebuilt Homes’ factory. The current state value stream map of the factory based on the current process is first created, and then analyzed to make necessary changes for improvement in flow, and a new state map is created by the research team. Figure 4(a) presents the VSM of the factory. Work cells, work flow, and required man-hours for each cell were defined based on the lean principals and project schedule. All activities and their sequences in each cell were clarified and triangular or beta distributions for the process time of each activity were defined. In the next step, a simulation model using Simphony.Net3.5© along with Palisade @Risk© was developed to simulate the production process based on that depicted in the future state value stream map. Figure 4(b) shows a snapshot of the developed simulation model. The model is capable of producing results for takt time, lead time, processing time, amount of work in process, buffer stuck, bottleneck, on time delivery percentage, and rework or defect rate. A satisfying simulation run demonstrates an attempt to eliminate muda or waste from the system including delay, transportation, correction and rework, over-processing, inventory, over-production,
and process flow disconnection. In this paper the result for processing time is considered to be discussed. The result from the simulation model in very first runs was not satisfying so the sequence of activities, material flow, and required manpower in some working cells were changed and the VSM was revised. The simulation model also was updated with the new inputs and preceded again until a satisfying result was produced. The result for the processing time of one module to be fabricated in the factory is presented in Table 1. The result shows that one module can be fabricated between 2610 to 2752 working minutes (43.5 to 45.8 working hours) within 90% level of confidence. The probability density function (PDF) and cumulative density function (CDF) of the result is displayed in Figure 5. With 95% level of confident, each module can be built in less than 45.8 working hours (5.7 days) that shows 11 days improvement compared to current process time in the factory which is 17 days before applying lean on the manufacturing process.

![Table 1. Simulation result for processing time of one module](image)

**CONCLUSION**

Uncontrolled conditions and work sites limitations have negative effects on the cost, schedule, and the project quality. Modular manufacturing is a solution for those challenges with new requirements in automating the design and drafting for more effective construction. BIM provides the opportunity for automating the design.
and drafting process. Factory production provides opportunities for applying lean principals in the plant. To support the manufacturing needs for drafting considering lean thinking in construction, an integration of BIM with lean is required. In this paper an integrated BIM/lean model for production line schedule of modular construction Manufacturing was proposed. For this purpose the integrated computer tool for drafting in the MCM process called MCMPro was expanded to generate building components’ schedule. The VSM is developed based on the components’ schedule through a proposed method called Integrated Process Improvement (IPI) using lean principles to reduce waste over the factory activities. A simulation model was developed to produce the result of generated VSM. The results proved the effectiveness of proposed model in reducing waste, time, and resource usage.

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REFERENCES


