A BIM-Based Simulation Model for Inventory Management in Panelized Construction

Samer Bu Hamdan[a], **Beda Barkokebas**[a], **Juan D. Manrique**[b], **Mohamed Al-Hussein**[a]

[a]Dept. of Civil and Environmental Engineering, University of Alberta, Edmonton, Canada
[b]Landmark Group of Builders, Edmonton, Canada
E-mail: buhamdan@ualberta.ca, barkokeb@ualberta.ca, juanm@landmarkgroup.ca, malhussein@ualberta.ca

ABSTRACT

Off-site construction is gaining more consideration from builders in North America, as it provides better quality products in less time and cost. Panelized construction is an increasingly popular off-site construction method in which panels are fabricated off site, then transported to the site for assembly. In this approach, panels are typically manufactured at a rate that exceeds that of on-site assembly of the panels, which necessitates inventory management of the fabricated panels awaiting transportation to the site for assembly. Effective inventory management is thus required in panelized construction to reduce costs. The randomness of the manufacturing and assembly process entails processing a large amount of information iteratively in order to select the proper production scenario to effectively manage the inventory. In this context, simulation provides an appropriate means of testing proposed scenarios in a timely manner. Simulation models require precise information, and building information modelling (BIM) provides a convenient and comprehensive means of data exchange among different environments. This paper thus presents a combination of discrete-event and continuous simulation that uses the information extracted from the BIM model to facilitate inventory management for panelized construction. This approach develops a schedule and ensures continuity and smoothness of the workflow.

Keywords -
Panelized construction, Inventory management, simulation, Building Information Modelling

1 Introduction

Material delivery in construction is an important process that warrants increased attention from project management teams due to it is significant influence on project delivery. Researchers have been aware of the importance of supply chain integration in construction, as it reduces 2.2% of the cost when proper information exchange can be facilitated (Gerard and Fisher, 2000). On the other hand, supply chain has its own associated waste, the cause of which typically lies in a different construction phase than that in which it is discovered. (Ruben and Koskela, 2000). Accordingly, supply chain components (production, procurement, and distribution) should not be managed separately from one another (Douglas and Griffin, 1996), but should instead be manage together in a complex and interrelational manner (Lee and Billington, 1992).

Implementation of BIM and other new trends in construction have garnered their share of attention as construction planners seek to improve the performance of material delivery to the site. An example of this effort is the integrated system developed by Irizarry and his colleagues, pairing BIM and GIS technologies to track and monitor the material and inventory in a construction project (Irizarry et al., 2013).

Similar to stick-built construction, just-in-time delivery is crucial in off-site construction. Profits can be increased by reducing the inventory size, and designing a workflow that ensures the continuity of the delivered products, and streamlines the supply chain between plant and site. Manufacturers can thus minimize delays or shutdowns of the plant due to poor coordination of work.

A large share of activities in off-site construction and particularly in panelized construction are carried out at the plant, where components are manufactured and then transported to the site for assembly. Since the two main phases of construction are separated geographically in this approach, a high level of coordination is required to avoid delays, which lead to budget and schedule overruns.

For any manufacturer, inventories help to balance the supply chain; however, they also introduce additional costs associated with the physical space needed to accommodate the inventory. This underscores the need for a systematic procedure to manage and control the process of inventory selection, which can be thought of as an integrated process that considers the overall construction process from manufacturing to assembly.

The challenge in the case of panelized construction is to control the major influencing factors—production, assembly, and inventory—by maximizing their utilization while minimizing their associated costs. For instance, choosing the appropriate production volume of manufacturing will minimize the inventory size.

However, determining the ideal timing and production rate for manufacturing is a difficult undertaking; it requires the assessment of large amount of input. In this regard, simulation is a powerful tool by which to analyze the planned work and define potential obstacles (AbouRizk, 2010). Simulation can effectively improve performance (Sacks et al., 2009), thus enabling assessment of mutable parameters in a timely manner, which can serve to reduce cost and provide reliable approximation of potential challenges and opportunities.

However, simulation is about processing information, which points to the importance of evaluating the source of information. As described by (Alwisy et al., 2012) building information modelling (BIM) provides a sufficient level of detail for simulating and optimizing manufacturing processes. Given this, BIM models are a convenient source of information for simulation effort, making accurate and sufficient data available to be processed when needed.

This paper proposes a framework to control and manage inventory in panelized construction, based on simulation integrated with BIM. What follows is a discussion of the model development, followed by a description of the case study and implementation framework. Research limitations and direction for future research are also outlined.

2 Research Methodology

This research aims to enhance the performance of inventory management in panelized construction by improving the inventory size selection practice and production patterns with a view for the overall construction process. This involves analysis of the panelized construction process in order to determine weaknesses and potential improvement. Building on these findings, further exploration is conducted in order to select the best approach to overcome the identified challenges. A framework is designed for information processing and exchange to serve the purpose of improving inventory planning and management in panelized construction. Further improvements are made to the framework to generalize its application.

2.1 Analysis of Current Practice in Panelized Construction

Panelized construction accelerates the construction process while improving quality. However, unlike with conventional construction methods, components are manufactured off site and then shipped to the site. The production rate of the panels fluctuates because such factors as crew size variation. This fluctuation causes irregularity in the procurement process, which influences the on-site assembly process, causing delays in delivery of the completed building. Moreover, the on-site assembly requires continuous procurement of the panels to reduce cost and enhance the learning curve. To overcome these challenges, maintaining a large inventory and beginning panel production long enough before the construction starts would seem a reasonable option.

However, this is not an economical solution given the considerable associated facility costs to accommodate the larger inventory and potentially frequent factory shutdowns. Accordingly, the underlying objective of this research is to achieve continuous production, smaller inventory, and continuous on-site assembly. This can be achieved by developing a framework that tracks the performance of the inventory and allows testing of different scenarios to determine the best alternative.

2.2 Development of Preliminary Framework

Considering the randomness of the panel production process, simulation is a suitable option for performing probabilistic analysis of the problem. The accurate results sought require accurate input data about the building, and BIM can be leveraged to deliver the needed data. This research thus combines BIM and simulation to build an information model that facilitates inventory management and planning. The proposed model, as Figure 2 shows, is built on a Central Simulation Engine (CSE) that performs all simulation operations. The CSE simulates activities that influence inventory usage, beginning with the manufacturing process and advancing to construction operations, assembly, and movement of materials.

Simulation, it should be noted, is highly dependent on data, its accuracy, type, size, and availability. These are major factors affecting the performance and reliability of simulation. Data source selection is thus an important issue influencing performance of the comprehensive model. Growing interest in BIM within the construction industry is justified, since this technology makes large amounts of information available to share and exchange at different levels of detail and with multiple parties. BIM serves as the data repository for the proposed model of this research, serving the different BIM modules in different direction. The results of the CSE are further analyzed in order to determine the optimal production pattern.

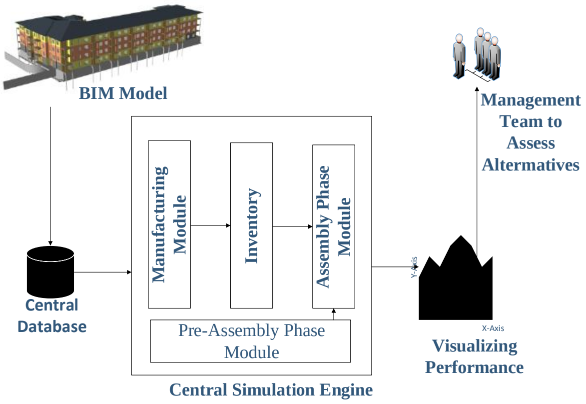

Figure 1. Proposed framework

The following sections describe in greater detail the components of the model.

2.2.1 Central Simulation Engine (CSE)

The CSE consists of four sub-modules, each responsible for processing a different construction phase. The sub-modules interact internally with one another, and externally with the other components of the model. Moreover, the sub-modules can work interactively or independently based on the pattern or scenario being tested by the team. This allows the user to explore a variety of alternatives to find the optimum pattern. This engine uses Simphony.NET 4.0 Build 4.0.0.144 as the simulation environment.

2.2.1.1 Manufacturing of Module

Similar to with other manufacturing processes, row materials go through a production line where they are assembled to form panels. The production line consists of many stations, where a greater number of stations makes modelling the production line increasingly complex. Therefore, an abstract representation is used to build the simulation model of the production line, where stations with similar work are combined into one station. From a technical perspective, this can reduce the processing effort while delivering the same result in respect to the time. This facilitates debugging, as there are fewer simulation components for the user to follow up with less, which enhances the accuracy of the resulting data. Figure 2 shows the abstraction of the production line used in the model.

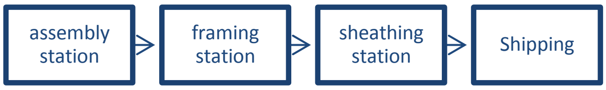

Figure 2. Abstraction of production phase

In this process, it is assumed that the panels are shipped to an external inventory, which will be managed. However, different scenarios may apply.

Since this paper is interested in identifying a production pattern that achieves good workflow throughout the entire construction process, optimization of the production line is not considered. This abstraction of the production line is intended to simulate panel prefabrication, with panels divided into three main categories: bearing, non-bearing, and mechanical. Panels in each category vary in size and internal components, which imposes different production rates for each category. Additionally, crew size is not constant, which affects productivities throughout the production process. Those two issues are considered in the sub-module so the user can test endless scenarios before making decision.

2.2.1.2 Pre-Assembly Simulation

Site preparation and parkade construction are major phases in many multi-family and commercial projects, and the on-site assembly process cannot commence before this phase ends, as it is not possible to start framing without having the structural slab of the basement complete (based on the construction method followed in Canada). However, these modules can be turned on/off as one unit or as individual components to match the requirements of the case being analyzed. Similar to the manufacturing module, this module uses a simplified presentation of the physical process carried out to construct the structural slab, for the same reasons described above. Figure 3 illustrates these activities.

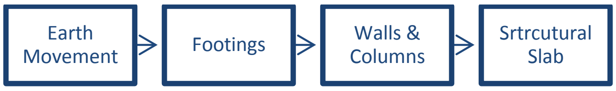

Figure 3. Activities simulated in pre-construction phase

In this sub-module, earth moving is simulated using discrete-event simulation. Activities involving concrete work are modelled as continuous processes. This simulation technique captures more accurately the actual behaviour of the modelled elements, and allows the user to watch the progress and thus affords greater flexibility with regard to interaction with other sub-modules within the CSE.

Simulation in this sub-module can start before and continue concurrently with the manufacturing process. However, the assembly phase cannot start before this phase ends; this is a built-in constraint that cannot be changed by the user, as any change would contradict with the logical sequence of work.

2.2.1.3 Assembly Phase

Discrete-event simulation is used to represent the assembly process, where panels are assembled together to construct the building. By the end of this phase, the structure of the building is ready and activities independent of manufacturing can begin. Cranes are important components in this phase. Therefore, any simulation must consider crane modelling as it may dramatically affect the end results. In this module, discrete-event simulation is used for all activities, as with the manufacturing module. However, unlike with the manufacturing module, continuous simulation can be a good alternative to model the crane behaviour within the module. Figure 4 shows the simulation model representation of this phase.

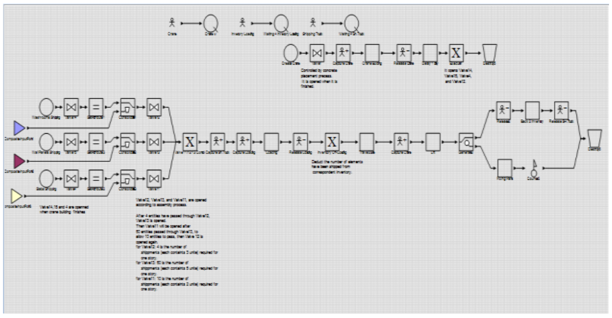

Figure 4. Simulation model of assembly phase

2.2.1.4 Inventory

The inventory module uses continuous simulation to track the behaviour of the inventory used during construction. It is the simplest module in the CSE, simulating the movement of panels in and out of the inventory. It is responsible to generate the performance reports and send them to the analysis unit, where they are analyzed and a decision can be made.

2.2.2 BIM Model

As previously mentioned, the BIM model serves as the repository of information for the entire model. Entity creation depends on the information provided by the model pertaining to types of walls and their dimensional properties. The BIM model also provides information related to non-panelized elements of the building. This includes, but is not limited to, concrete elements and earthwork quantities. Figure 5 shows the interaction between the BIM model and the modules.

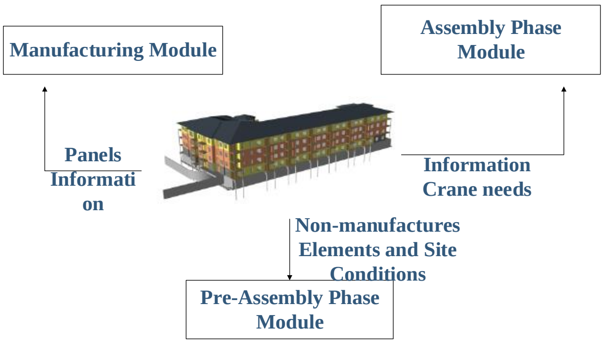

Figure 5. Information exchange between BIM model and simulation modules

However, the interaction between the BIM model and the other modules is two-way. In other words, the results of the performance analysis can be used to influence the design process of the manufactured elements. This process continues back and forth to optimize the manufacturing process in terms of panels' size. However, since the optimization process is not in the scope of this paper, it will not be discussed in detail here.

As is well known, BIM software supports exporting of information to different formats. However, this is limited by the file type the simulation platform can support. In this model information is exported to the CSE using the “csv” file format. Table 1 shows the information each simulation module requires.

Table 1. Information exported to each module

Simulation Module	Information imported from the BIM model
Manufacturing Module	Panel Type
	Panel Dimensions
	Number of pieces needed of each type
Pre-Assembly Phase Module	Site work (excavation, backfilling)
	Footings (number and size)
	Concrete wall (total length and size)
	Columns (number and size)
	Grade beams (number and size)
	Slab on grade
	Structural slab
Assembly Phase Module	Storey height
	Building dimensions

2.2.3 Performance Analysis Report

Performance information is visually presented to the planning team so they can plan or manipulate their plan, and even test the performance of their initial plans. There are many ways to present the information needed for decision making, depending on the preferences of the decision maker. Performance graphs are among the most commonly used format of visualized material. Tabular representation of the data is supported as well. However, it is important to mention that the analysis process has not yet been fully automated, as it is believed that human reasoning is more suitable in such cases.

3 Case Study

To test the framework, the construction of a 4-storey condominium building is assessed using the framework. Nine scenarios are simulated, each with the production process beginning at a different point. Starting points are as follows:

1. Simultaneous with the start of earth moving
2. When 25% of earth moving is complete
3. When 50% of earth moving is complete
4. When 75% of earth moving is complete
5. When 100% of earth moving is complete
6. When 25% of concrete placement is complete
7. When 50% of concrete placement is complete
8. When 75% of concrete placement is complete
9. When 100% of concrete placement is complete

These starting points are suggested as examples, but other scenarios could be chosen as well. Throughout the simulation, the performance of the construction process is tracked by monitoring the fulfilment of inventory. Figure 6 and Figure 7 show the inventory fulfilment changes for Scenario 5 and Scenario 7, respectively. It is apparent that size of inventory is smaller when the production starts later, but it is also obvious that the assembly process performs less productively in this case.

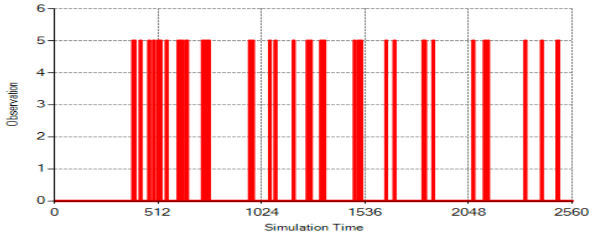

Figure 6. Inventory fulfilment when production starts at 25% concrete placement

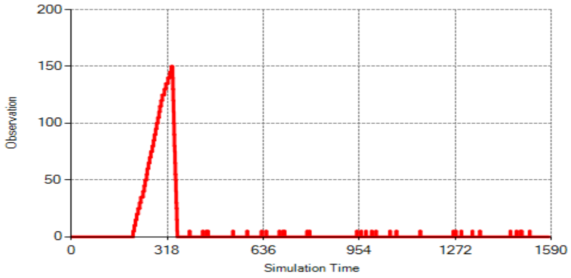

Figure 7. Inventory fulfilment when production starts at 75% concrete placement

Although it is possible to compare the alternatives graphically, the tabular form provides a more convenient means of summarizing the results. Table 2 presents a summary of model runs for different scenarios.

Table 2. Summarized results of the scenarios

Scenario	Inventory Size	Total Project Duration (Hours)
1	332	1,433.130
2	259	1,504.389
3	226	1,532.860
4	164	1,582.660
5	114	1,632.460
6	10	1,738.131
7	10	1,850.730
8	10	1,851.859
9	10	1,852.987

4 Limitations and Future Research

The model presented in this paper is a generic one which supports the importation of different types of buildings as long as they have been modelled properly in the BIM environment. It also supports different visualization techniques to assist the management team in choosing the best production pattern and the optimal inventory size to avoid financial losses. Moreover, since the system integrates all construction phases it is possible to plan the project in such a way as to minimize overproduction, which can lead to factory shutdowns, or underproduction, which can lead to on-site assembly delays. However, this system lacks the Graphic User Interface (GUI), which makes it less user-friendly to those who are not familiar with the simulation platform used to build the CSE. Moreover, distribution functions used for the probabilistic simulation are fed manually to the modules. As mentioned above, the BIM model needs to be modelled according to certain standards that the CSE can recognize, which limits the framework in terms of its ability to generically support all BIM models. The model lacks some intelligence in it inference engine; further research will be directed toward developing this aspect and improving element recognition so the model can import information from the BIM model regardless of the modelling standards used to prepare it. Additionally, a more user-friendly GUI will be added to facilitate interaction with the user.

5 Conclusion

As more builders consider panelized construction for their projects, the need for an integrated management process is growing rapidly. Any integrated method should consider the interactions among the different construction phases from manufacturing to assembly. Among the different stations in the panelized construction, inventories have a major role as they ensure the balance of the construction process by helping with the mitigation of assembly delays. However, efforts are still required to reduce inventory costs. In this regard, this research has suggested a framework that integrates BIM techniques with simulation to provide an inventory planning and management tool. This tool can be utilized to reduce inventory size and cost, as well as to improve the performance of the supply chain in panelized construction.

References

[1] **AbouRizk S.** Role of simulation in construction engineering and management. *Journal of Construction Engineering and Management,* 136(10): 1140-1153, 2010.

[2] **Alwisy, A., M. Al-Hussein, and S. H. Al-Jibouri.** "BIM approach for automated drafting and design for modular construction manufacturing." *Computing in civil engineering (2012)* (2012): 221-228.

[3] **Banks J., Carson J.S., Nelson B.L., and Nicol D.M.** *Discrete-Event System Simulation*, 5th Ed. Prentice Hall, 2009.

[4] **Cachon, Gérard P., and Marshall** Fisher. "Supply chain inventory management and the value of shared information." *Management science* 46, no. 8 (2000): 1032-1048.

[5] **Irizarry, Javier, Ebrahim P. Karan, and Farzad Jalaei.** "Integrating BIM and GIS to improve the visual monitoring of construction supply chain management."*Automation in Construction* 31 (2013): 241-254.

[6] **Lee, Hau L., and Corey Billington.** "Managing supply chain inventory: pitfalls and opportunities." *Sloan management review* 33, no. 3 (1992).

[7] **Thomas, Douglas J., and Paul M. Griffin.** "Coordinated supply chain management." *European journal of operational research* 94, no. 1 (1996): 1-15.

[8] **Sacks R., Treckmann M., and Rozenfeld O.** Visualization of work flow to support lean construction. *Journal of Construction Engineering and Management*, 135(12): 1307-1315, 2009.

[9] **Slack N., Chambers S., and Johnston R.** *Operations Management*, 6th Ed. Pearson Education Limited, Harlow, UK, 2010.

[10] **Vrijhoef, Ruben, and Lauri Koskela.** "The four roles of supply chain management in construction." *European journal of purchasing & supply management* 6, no. 3 (2000): 169-178.