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A BIM-based Supply Chain Integration for Prefabrication and Modularization

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ABSTRACT
Prefabrication and modularization helps to reduce cost and schedule time for on-site activities. The use of Building Information Modeling (BIM) helps to improve collaboration and improve the construction process. The improved installation precision provided by BIM Model-Driven Prefabrication can decrease on-site labor time and increase productivity. Prefabrication, Modularization, and off-site construction transfers activities that would have been performed on site to earlier stages of the supply chain. The implementation of Just-In-Time (JIT) delivery transfers the costs and risks associated with inventory to the supplier. Construction Supply Chain Integration can help reduce cost and waste across the supply chain particularly for large and complex buildings. This paper presents a methodology that utilizes a BIM based construction supply chain integration to reduce cost and waste in the construction and offsite manufacturing processes. It utilizes the integration of BIM with the on-site schedule and the manufacturing or fabrication schedule of the different supply chain members. The methodology utilizes the onsite schedule, lead times of prefabricated elements or modules and the transportation logistics to help reduce cost across the supply chain. The information, material and cash flows as well as the transportation logistics is utilized in generating an optimized just-in-time delivery schedule for large and complex buildings. The optimized delivery schedule takes into account the variations in the on-site and off-site schedules to forecast delivery dates of precast elements or fabricated modules.

KEYWORDS
Supply chain integration, prefabrication, modular construction, Building Information Modelling (BIM), Just-In-Time (JIT)

INTRODUCTION
Prefabrication and modularization reduce total project cost by reducing the time for on-site construction operations and related activities. These onsite activities are reduced due to modularization because they are performed in a factory under more suitable environmental conditions, which enables tasks to be performed more efficiently. Mao et al. (2013) listed some of

the major barriers to offsite construction as high initial cost, fragmentation of the construction industry and high transportation costs.

Higher initial costs was also highlighted as one of the significant barriers to offsite construction by other researchers (Pan and Sidwell, 2011; and Nadim, and Goulding, 2010; Blismas and Wakefield; 2009 and Pan et al, 2008). Construction methods and engineering issues related to modular buildings become more complicated with increases in the number of stories (Ramaji et al. 2017). Building Information Modeling (BIM) is used in the design of prefabricated elements and modules, and helps facilitate collaboration among project stakeholders, which helps improve productivity. A McGraw-Hill Construction (2011) report showed improved quality, time and cost savings as some of the important reasons for using BIM Model-Driven Prefabrication. 3D models and the information obtained from them can be shared with different stakeholders in a project using an integrated platform. BIM encourages integration of the roles of all stakeholders on a project, which has the potential to bring about greater efficiency and harmony among players Azhar (2011). Nissilä et al. (2014) studied saving different status information (design, fabrication, transportation and site erections), into building information model to facilitates the tracking of schedule situation in using a cloud-based networked service. Babič et al (2010) described how BIM can be used to integrate design, manufacturing and construction processes, as a link between an enterprise resource planning (ERP) information system that supports manufacturing process and construction object related information, for project progress monitoring and material flow management. BIM deployment in the reinforcement supply chain can considerably enhance the performance of the reinforced concrete projects by providing richer and more accurate information (Aram et al., 2013).

The construction supply chain is fragmented because of the temporary nature of projects. Vrijhoef and Koskela (2000) showed that the construction supply chain has a lot of persistent waste and problems, most of which are derived from earlier stages of the construction supply chain because of their interdependency. Synchronization, which is accomplished by coordinating starting and ending times, is the only way to eliminate process delays (Shingo, 1988). Supply chain integration helps to improve coordination between supply partners through Information Sharing. Some limitations of modularity are related to product architecture, and will require increased supply chain integration to overcome the dimensional issues associated with transportation, and architectural issues associated with modular construction (Doran and Giannakis, 2011).

This paper presents a Building Information Modeling (BIM) based, construction supply chain integration model. The proposed model utilizes a 3D Model, which is used to generate a material quantity takeoff, and integrates an onsite schedule, an off-site fabrication schedule, a relational database, and different automated data acquisition technologies. The integration of the onsite schedule and off-site fabrication schedule, helps to generate an optimized delivery schedule, which takes into account the variations in the schedule, the cash flows, lead times, transportation logistics, and structural constraints. The optimized delivery schedule is generated to deliver prefabricated components or modules on a just-in-time basis, and help reduce costs across the supply chain.

BACKGROUND

Offsite construction is the process where a building is constructed off-site under controlled conditions, as different components, which are transported to the site, where they are assembled sequentially using a crane. The building is assembled in a shorter time than traditional construction with fewer requirements for tradesmen. Better work spaces gives room for a more coordinated use of machinery, which helps to reduce the time and cost of executing tasks. Prefabricated elements or modules are manufactured and transported to the jobsite according to their installation sequence. The assembled components of the building are non-volumetric, when they do not enclose usable space, or volumetric/modular, when they enclose usable space and are installed as either non-load bearing or load bearing modules. There are different types of modules and the building can be modular, panelized or hybrid. Lawson et al (2014) described different examples of hybrid or mixed modular and panel systems, where the modular units are used for the higher-value serviced areas, such as bathrooms and kitchens.

PROPOSED MODEL

The proposed model utilizes Building Information Modeling (BIM), barcoding, RFID and a scheduling software to acquire data, which is integrated in a centralized relational database. The developed model helps to collects data automatically from construction sites in near real time, which is used to forecast the delivery dates of prefabricated elements or modules. Figure 1. Shows the schematic depiction of the model.

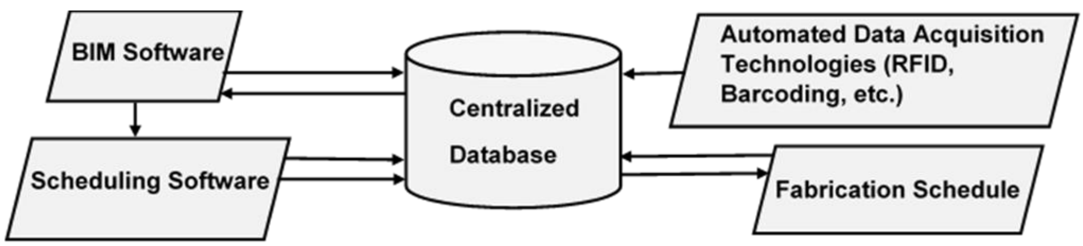

Figure 1. Schematic depiction of the model

The BIM software is used to create the building model. The BIM software is also used to generate the material quantity take-off, and visualize the 3D model of the project. The 3D BIM model is integrated with the project schedule, which enables it to schedule the installation of building elements, and report as-build progress in 4D. The information from the BIM software and the scheduling software is stored in the centralized relational database. Data acquired from the jobsite using automated data acquisition technologies such as RFID and barcoding, is also stored in the relational database. Relevant information from the fabrication schedule is obtained from the suppliers or manufacturers and stored in the database. The objective of the model is to integrate BIM with an on-site schedule, which is updated with automatically acquired data form the jobsite, to facilitate the synchronization of the on-site schedule with the fabrication schedule. The synchronization takes into account the lead times of the building elements and the transportation logistics. The flowchart for the proposed model is shown in figure 2 below.

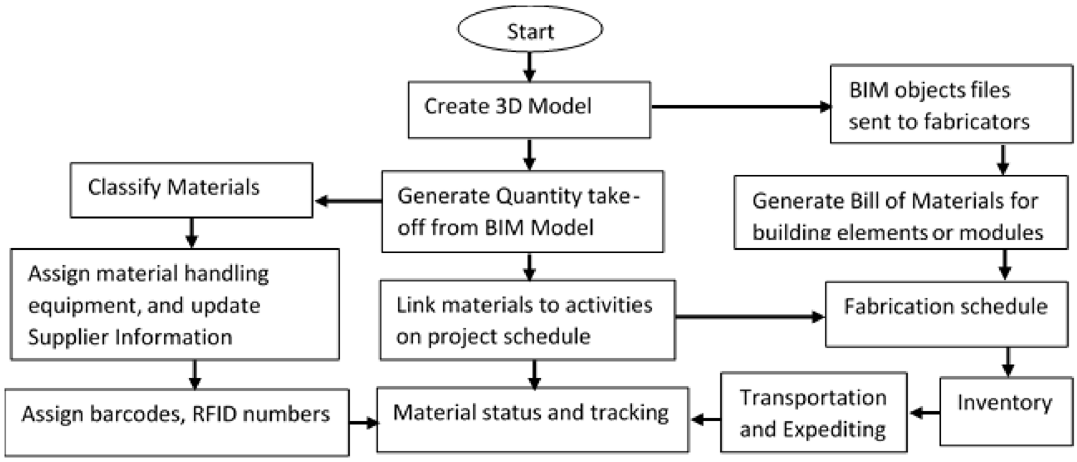

Figure 2. Flowchart of the proposed model

BIM Modeling and Material classification

The first step involves creating the 3D BIM model for the project. Early multidisciplinary collaboration is recommended early in the design stage. The material quantity take-off is generated from the BIM model. The materials or building elements are classified as bulk, standard off-the-shelf materials or prefabricated or specialized equipment. The materials or building elements are linked to activities in the project schedule. The materials or building elements are assigned material handling equipment, which will be used during their delivery or installation. The materials or building elements are categorized by their supplier or manufacturer, and additional information such as their lead times are included. The materials or building elements are subsequently assigned barcodes of RFID ID's. These barcodes and RFID numbers will be used to track the materials and building element when they arrive on the jobsite.

Material status and tracking

When the building elements or modules arrive at the jobsite their arrival is recorded in the centralized relational database using a barcode scanner or RFID reader. Prefabricated building modules are usually installed when they arrive at the jobsite because of storage space limitations. The prefabricated elements or modules are installed directly from the truck bed or are first unloaded. Their location is tracked using RFID and zone detection. Razavi and Moselhi (2012) developed a zone detection approach which uses K-Nearest Neighbor classification method to assign a zone to a tagged item. Prefabricated elements or modules are scanned after installation using either RFID or barcodes, and their status is set to "installed".

Prefabrication and Modularization

After materials are classified the information for prefabrication or modular manufacture is shared with the suppliers or manufacturers. The bill of materials for the building elements or modules are generated. The building elements or modules are scheduled for fabrication. The centralized database is updated with the fabrication or manufacturing progress of the individual building elements or modules. The relevant information can either transmitted for the update or updated remotely. After fabrication the building elements or modules are held in inventory until they are transported to the jobsite for installation. They are assigned barcodes or tagged with RFID tags.

Transportation logistics

The transportation of the prefabricated elements or modules can be done by any of the four major modes of transportation, which are road, railway, air, water (inland and maritime). They can use the owner's transport, the contractor's transport, the supplier's transport or third party logistics providers. The transport mode and the responsible party for the transportation of all prefabricated elements or modules is recorded in the database. This is to ensure that delivery dates are shared with them in advance, so they can make appropriate plans and apply for any required permits. Special travel permits are required for in various provinces in Canada and states in the US for non-divisible oversize and/or overweight loads which exceeds the limits set out in the relevant regulations. There are restrictions on routes and time of day, as well as safety and escort requirements. GPS can be used to track the transportation and delivery of prefabricated elements or modules. Ergen et al (2007) demonstrated the basic feasibility of an automated system that integrates RFID and GPS technologies for tracking precast pieces in a storage yard.

Schedule Integration and synchronization

Offsite construction allows the building envelope to be completed quickly, giving room for other trades to work safely inside the building. The prefabricated building elements or modules take a shorter time to erect and assemble than it takes to manufacture them. Additional work that are performed after the panels or modules are assembled include: MEP installation, drywall installation, interior and exterior finishes, etc. A case study of the construction of the first prototype of a Deep-Performance Dwelling in Montreal, a sustainable house being constructed by TeamMTL, showed an example for how BIM was used ensure a tight fit between panels. The two story, urban single-family home consisted of 71 panels, which were manufactured over about a two month period. The panels took 6 days to install. Various works were performed inside and outside the building after the panel assembly was completed. Figure 3 below shows a picture of the deep performance dwelling under construction.

Figure 3. Panelized Deep Performance Dwelling under construction

The integration of the on-site schedule with the fabrication or manufacturing schedule involves synchronizing the start or end times of activities on the jobsite, with the start or end times of the off-site fabrication or manufacture of building elements or modules. The onsite schedule will be updated manually or in near real time using automated data acquisition technologies. A centralized relational database is used to exchange information between the different supply chain members. A forecast of the required delivery date of each prefabricated element or module is shared with its supplier or manufacturer. The forecasted date takes into account the lead times as well as the transportation duration to determine the required delivery date or time on the jobsite. The forecasted date is updated with changes to the project schedule or lead times. The prefabricated elements or modules are ordered when the predecessor activities corresponding to its delivery date, less its lead time and transportation time, are started or completed. This will help ensure that they are ordered and delivered on a Just-In-Time basis. Sharing the forecasted delivery date will make the fabricators or manufacturer aware of the date, which will give them sufficient time to plan and schedule the fabrication or manufacturing. This will also highlight the need to accelerate the fabrication or manufacturing schedule if required, or highlight the need to expedite if the fabrication or manufacturing progress is also shared and delays are forecasted. This approach aims to reduce inventory across the supply chain without affecting the total duration of the onsite schedule, and assumes that there is no shortage of labour.

Inventory optimization

The Modular/offsite supply chains is comprised of the flow of prefabricated elements and modules from the supplier or manufacturer to the jobsite, and the flow of information and money from the buyer to the supplier or manufacturer. The supply chain also comprises the suppliers of the manufacturer. The difference between the Modular/offsite supply chain and the traditional supply chain is shown in figure 4 below.

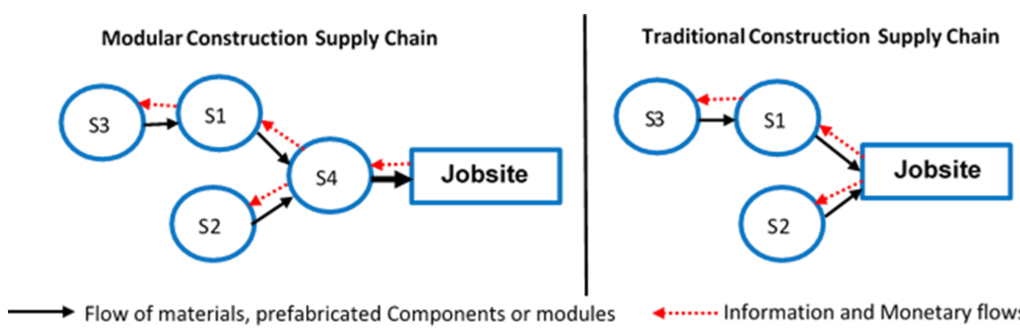

Figure 4. Modular and Traditional Construction Supply Chains

In the traditional supply chain there are 3 suppliers S1 to S3 with S3 supplying materials to S1. In the Modular supply chain, you have the same suppliers, but with S1 and S2 delivering the materials to the module manufacturer who subsequently delivers the finished module to the jobsite. Inventory is optimized across the supply chain by delivering the prefabricated elements or modules in smaller batches as they are manufactured, and taking into consideration both the onsite and offsite schedules. The total cost of the panels or modules comprises of the cost of the materials, plus other additional costs absorbed by the supplier, and other related costs absorbed by the owner or contractor.

$$\text{Total Cost of Prefabricated Element or Module} = \text{Purchase Cost} + \text{Ordering Cost} + \text{Tranportation Cost} + \text{Holding Cost} \quad (1)$$

JIT implementation helps to reduce inventory, which leads to a reduction in the holding cost, and subsequently the total cost. However, transferring the costs up the supply chain to the supplier or manufacturer increases the supplier's/manufacturer's holding cost, which leads to an increase in the purchase cost. The manufacturer or supplier can reduce their holding cost by using a JIT approach, and transferring the buyer, who stores them on site or in a warehouse. Neither of these approaches reduces the supply chain's total cost.
The integrated supply chain will improve visibility, and reduces the response time across the supply chain. Supply chain integration helps to reduce the total cost of the supply chain by enabling information to be shared, which helps the supplier or manufacturer in the implementation of JIT, and in achieving optimum inventory levels. This is achievable if the prefabricated elements or modules can be delivered and installed in batches, and this does not lead to an increase in the crane cost or a mobile crane is used. There also has to be onsite activities of a considerable duration to be performed, and the tradespeople should be able to work safely in the usable spaces before the installation of all the modules or panels are complete. This approach does not increase the total project duration. Non-load bearing prefabricated elements such as non-load bearing wall panels are manufactured in consideration of the on-site schedule, and are installed progressively as they are manufactured and delivered to the jobsite. Repetitive units will progress from one level to another. Load bearing prefabricated elements or modules will take additional constraints into consideration such as the structural constraints of the building and the installation sequence.

For the case study above the delivery can be done in two batches, with the first batch having 36 panels and the second batch having 35 panels. Making an assumption that it takes half a day to manufacture each panel. The difference in inventory held by the manufacturer over time between the two scenarios is shown on the graph in figure 5 below.

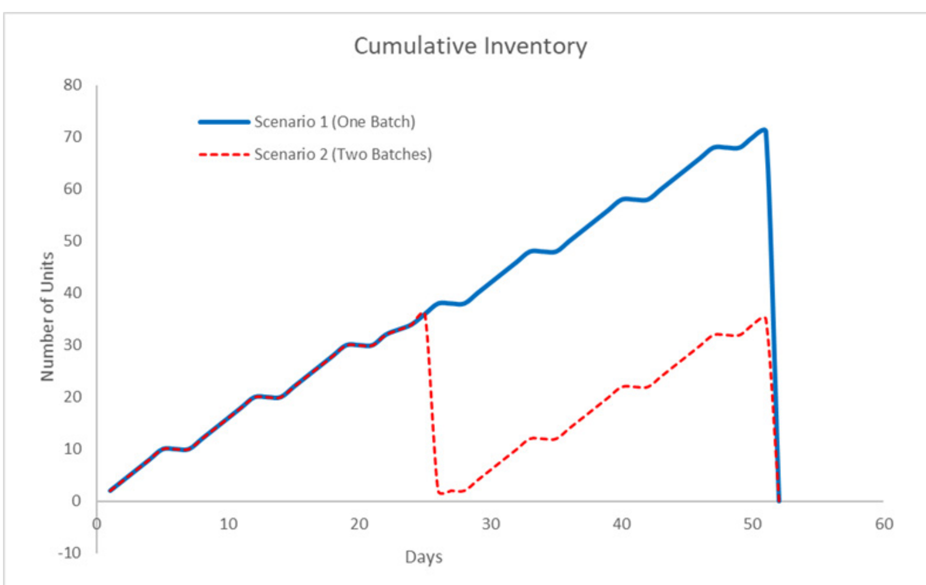

Figure 5. Cumulative inventory for two scenarios

The total cumulative inventory days for all the panels in scenario one is 1,966, while the total cumulative inventory days for all the panels in scenario two is 978, which gives a difference of

988 inventory days, a reduction of 50.25%. Reducing the inventory days would lead to cost reductions when the associated costs of holding inventory, such as storage costs and financing costs are taken into consideration.

SUMMARY AND CONCLUDING REMARKS

This paper presents a methodology that utilizes BIM based construction supply chain integration to reduce cost and waste in the onsite construction and offsite manufacturing processes. The model utilizes a BIM generated material quantity takeoff, and integrates an onsite schedule, an off-site fabrication schedule, a relational database, and different automated data acquisition technologies, to help reduce costs across the supply chain. Prefabrication and modularizations saves costs by reducing onsite activities, but have a high initial cost. However, exchanging more accurate and timely information helps to generate an optimized delivery schedule, which helps reduce inventory and its associated costs.

REFERENCES

Aram, S., Eastman, C., & Sacks, R. (2013). Requirements for BIM platforms in the concrete reinforcement supply chain. Automation in Construction, 35, 1-17.

Azhar, S. (2011). Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry. Leadership and management in engineering, 11(3), 241-252.

Babič, N. Č., Podbreznik, P., & Rebolj, D. (2010). Integrating resource production and construction using BIM. Automation in Construction, 19(5), 539-543.

Blismas, N., & Wakefield, R. (2009). Drivers, constraints and the future of offsite manufacture in Australia. Construction innovation, 9(1), 72-83.

Doran, D., & Giannakis, M. (2011). An examination of a modular supply chain: a construction sector perspective. Supply Chain Management: An International Journal, 16(4), 260-270.

Eastman, C. M., Jeong, Y. S., Sacks, R., & Kaner, I. (2009). Exchange model and exchange object concepts for implementation of national BIM standards. Journal of Computing in Civil Engineering, 24(1), 25-34.

Lawson, M., Ogden, R., & Goodier, C. (2014). Design in modular construction. CRC Press. Boca Raton, FL.

McGraw-Hill Construction. (2011). “Prefabrication and modularization: increasing productivity in the construction industry.” Smart Market Report, McGraw-Hill Construction, New York, NY, USA.

Mao, C., Shen, Q., Pan, W., & Ye, K. (2013). Major barriers to off-site construction: The developer’s perspective in China. Journal of Management in Engineering, 31(3), 04014043.

Nadim, W., & Goulding, J. S. (2010). Offsite production in the UK: the way forward? A UK construction industry perspective. Construction innovation, 10(2), 181-202.

Nissilä, J., Heikkilä, R., Romo, I., Malaska, M., & Aho, T. (2014, January). BIM based Schedule Control for Precast Concrete Supply Chain. In ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction (Vol. 31, p. 1). Vilnius Gediminas Technical University, Department of Construction Economics & Property.

Pan, W., Gibb, A. G., & Dainty, A. R. (2008). Leading UK housebuilders' utilization of offsite construction methods. Building Research & Information, 36(1), 56-67.

Pan, W., & Sidwell, R. (2011). Demystifying the cost barriers to offsite construction in the UK. Construction Management and Economics, 29(11), 1081-1099.

Ramaji, I. J., Memari, A. M., & Messner, J. I. (2017). Product-Oriented Information Delivery Framework for Multistory Modular Building Projects. Journal of Computing in Civil Engineering, 31(4), 04017001.

Razavi, S. N., & Moselhi, O. (2012). GPS-less indoor construction location sensing. Automation in Construction, 28, 128-136.

Ergen, E., Akinci, B., & Sacks, R. (2007). Tracking and locating components in a precast storage yard utilizing radio frequency identification technology and GPS. Automation in Construction, 16(3), 354-367.

Shingo, S. (1988). Non-stock production: the Shingo system of continuous improvement. CRC Press.

Vrijhoef, R., & Koskela, L. (2000). The four roles of supply chain management in construction. European journal of purchasing & supply management, 6(3), 169-178.