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Implementation of Building Information Modeling (BIM) in Modular Construction: Benefits and Challenges

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Modular Construction consists of one or more structure units fabricated in a manufacturing plant away from the jobsite. In the building industry, prefabricated modules are normally completed with trim work, electrical, mechanical and plumbing installed. Previous studies have proved that Modular Construction provided many advantages to the built environment, including the reduction of need for workforce, the reduction of onsite Green House Gas (GHG) emissions, and the improvement of construction schedule and product quality; however the extensive demand of pre-project planning and coordination among members of cross-interdisciplinary professionals have significantly impeded the application of this technique. With the recent development of Building Information Modeling (BIM), these challenges could be overcome through the BIM platform. Through case studies the benefits and challenges of implementing BIM in modular construction are clearly identified.

Keywords: Building Information Modeling, Coordination, Prefabrication, Building Systems.

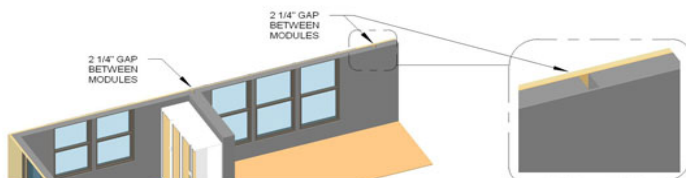
Introduction

Modular construction refers to factory-built building units completely assembled or fabricated in a manufacturing plant away from the jobsite, then transported and assembled on site (Pasquire, 2002). Modular building normally consists of multiple rooms with three-dimensional units, which are constructed and pre-assembled complete with trim work, mechanical, electrical and plumbing components installed (O'Brien, 2000). A large portion of construction research conducted in the United States and globally discusses that the use of modular construction provides many significant advantages, including: 1) the reduction of overall project schedules, 2) the improvement of product quality, 3) increased onsite safety performance, 4) a

reduction in the need for onsite skilled workers, and 5) a decrease in the negative environmental impact caused by construction operations (Gann, 1996; Hsieh, 1997; Edge, 2002; Gibb, 2001; Venables, 2004; Lu, 2007). However, the coordination and fabrication of the Mechanical, Electrical and Plumbing (MEP) systems in modular construction has always been one of the most challenging tasks encountered in the delivery process of modular constructions (Tatum, 2000; Korman, 2001; Lu, 2008).

The MEP coordination and fabrication process involves defining the locations for components of building systems, in where are often congested spaces, to avoid interferences and to comply with diverse design and operations criteria. There are three primary reasons contributing to the challenges of MEP fabrication in modular construction. First, the process is highly fragmented between design and construction firms. Second, the level of technology used in different coordination scenarios has historically varied significantly between engineers and construction contractors. Third, historically the process did not provide a model for use by specialty contractors plan prefabrication (Korman, 2001).

Using Building Information Modeling (BIM) to coordinate, document and fabricate MEP systems in modular constructions appears to be an effective approach to overcome these challenges. In 2009, Maine based Modular Construction Company KBS has successfully delivered their recently awarded modular project by integrating BIM technology into the design and construction process for the New Street Project, Cambridge, MA, as presented in Figure 1 (KBS, 2009).



(a) Architecture BIM Model to present modular wall details



(b) Installation prefabricated Roofs



(c) Prefabricated Wall Panels

Figure 1: BIM application in Modular Construction Projects (Tocci & KBS)

- *Visualization*: ability to create a 3D presentation of building modules geometry, location, space, contained systems in relation to each other
- *Modeling*: ability to generate a 3D rendering tool to present the final product and finishes to owners, designers and constructors
- *Code reviews*: allows for building officials and fire officials could use the 3D models with related data for code compliance reviews
- *Fabrication/ shop drawings*: facilitates for the generation of detailed shop drawings could be easily produced once the BIM model is completed
- *Communication*: facilitates simultaneously creation of construction documents, product imagery, rapid prototypes, exterior envelope, interior finishing, and MEP fixtures of building modules. Through this single information platform, BIM promote collaborations among the design team, consultant, constructors and the clients
- *Cost estimating*: provides for cost estimating, material quantifications, and pricing to be automatically generated and modified while changes are applied for each building module
- *Construction sequences*: provides a complete construction schedule for material ordering, fabrication, delivery and onsite installation of each building systems. With the integration of 3D rendering, 4 D (3D model + scheduling information) could be easily generated during the project design and construction phase
- *Conflict, interference and collision detection*: ability to determine building system interferences which can be visually presented. For instance, an air distribution duct for the HVAC system physically interfering with a concrete beam

Today, there are many examples of BIM software. NavisWorks™ is a software program that interprets all of the other software programs used by various specialty contractors and design engineers. NavisWorks™ is to software what the Rosetta Stone was to interpreting languages. This software has the potential to unlock and or interpret the other 2-D CAD drawings. This program only identifies the clashes and the individual specialty contractors need to revisit their own software programs and revise them in order to resubmit. NavisWorks™ will then reanalyze the new shop drawings and hopefully there are fewer or no clashes. Obviously, when there are multiple specialty contractors involved in a project, the challenge is to create an environment whereby everyone has worked out the details successfully.

There are many 3-D graphical representation software programs available for architects and engineers to model their project in BIM platform as well. Graphisoft's ArchiCAD™ allows one to draw in 3-D or import a 2-D drawing and create a 3-D model. This program allows you to toggle back and forth from 2-D to 3-D with the click of a mouse. AutoDesk™ is a 2-D drafting program coupled with Revit™ creating the 3-D model.

MEP Coordination in Modular Construction prior to BIM technology

Without the use of BIM system MEP coordination, prefabrication phase in modular construction begins after the design and preliminary routing of all building systems (mechanical, plumbing, electrical, etc.) is complete. The design is considered complete when engineers have sized all components (e.g., HVAC duct, pipe, conduits), completed the engineering calculations, and produced the diagrammatic drawings. Representatives from each of the specialty contractors (primarily HVAC wet and dry, plumbing, electrical, and fire protection) meet to discuss their particular designs and drawings, which indicate the proposed routing for each system to follow to service each required location. Most specialty contractors refer to these contract drawings as schematic design drawings. The engineers' stamp that the engineer provides only insures that the design of the systems will work functionally. It does not ensure that the system will actually fit within building.

In this scenario, the design consultant remains the engineer of record (EOR) and retains liability for the system functionality; however, these drawings are not detailed enough to either fabricate components or construct the systems. The required size of components, such as conductor wire, duct dimensions, and pipe diameter are called out on the drawings, but no scaling of the components is shown in the drawings. It is the specialty contractor's responsibility to build the particular building system from these design documents. This requires that the contractor produce shop drawings, also known as fabrication drawings. The shop drawings include the detailed information required by the specialty contractor to fabricate and install a particular building system.

During coordination meetings, the participating specialty contractors compare preliminary routing for their systems to identify and resolve conflicts. The MEP trades use a sequential comparison overlay process to compare their design drawings until they resolve all interferences. This often requires preparing section views for highly congested areas to identify interferences. The preliminary shop drawings that each specialty contractor brings to the meeting indicate the path preferred for each branch of the system to reach the required locations and perform essential functions. Architectural, structural, and diagrammatic drawings constrain this routing. Within these constraints, specialty contractors route systems based on the lowest cost; however, they generally do not consider the other systems. They also decide which specialty contractor(s) will revise their design and submit requests for information regarding problems that require an engineering resolution. The product of this process is a set of coordinated shop drawings that the specialty contractors submit to the design engineer for approval that the system functionality has not been compromised.

Using BIM for MEP Coordination in Modular Construction

Historically, there has been a wide variation in the level of technology used in the MEP coordination process. At the low-tech end of the spectrum, specialty contractors drafted plan-views on translucent media and prepare section-views when necessary. At the other extreme, progressive contractors have used 3D CAD to improve the process. With the recent development of BIM, the process has gravitated toward the use of

BIM software.

There are many locations in buildings that repeatedly cause coordination problems. These include building corridors, points of entry and exit, openings in shear walls, and vertical utility chases. Reserving space for access is more easily accomplished using BIM models. However, often times resolving interferences most frequently entails determining which building system has priority. In these cases priority is typically determined by evaluating the functionality of each system. In the event of interferences or clashes, the newly proposed route must be evaluated to determine if the new route changes the systems' functionality. If it is determined that the new route affects the functionality of the system performance, it is given priority over another system.

The need for MEP coordination grows out of the lack of detailed design provided for fabrication and installation of building systems, and exists regard-less of the project delivery process used. The current conditions in the design and construction industry drive current practice for MEP coordination. The use of BIM technology has created an opportunity to improve the current process by changing the way design engineers and construction contractors interact with each other during the coordination process. BIM offers parties involved in MEP coordination to take the opportunity to align goals and define requirements during the construction of the model. In addition, when historically MEP design consultants have not considered constructability issues and made assumptions about constructability or ignore the issue totally, the use of BIM allows a mechanism for dialogue between specialty contractors who install the system and design engineers who design the system.

Benefits and Challenges of BIM Implementation: Case Studies

The following case studies document the implementation of BIM in two different types of commercial projects. Specific examples of using BIM facilitating MEP coordination in Modular Construction are discussed as well. The project and owners name are anonymous for confidentiality purpose. The construction manager was Rogers Builders, headquartered at Charlotte, NC. The company has over 350 associates and nationally ranked among Top 100 CM-at-Risk firm by Engineering News Record (ENR) and Top 10 Healthcare General Contractors by Modern Healthcare for the last 10 Consecutive years. The company has implemented BIM system for every project they have built since 2007, with no premium cost to the owner side. Rogers Builders maintain that the cost for development and maintenance of BIM model with in-house resources is controlled at 0.1% of total project cost.

Case Study 1: Healthcare Expansion Project, Charlotte, North Carolina, USA

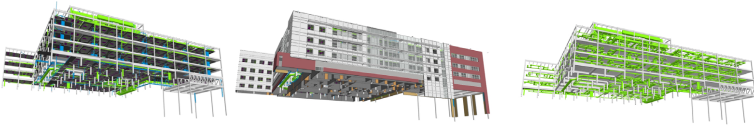
Project Scope: \$44Million, 110,000 SF healthcare expansion project

Modular Construction: prefabricated concrete panels are used for floor slab

Delivery Methods: CM @ Risk

Contract Type: Cost Plus with Guaranteed Maximum Price

Design Assistant: No Design Involvement
 BIM Implementation Cost: \$44000
 BIM Implementation Saving: \$220,000
 BIM Platform: Naviswork™



(a) Structural BIM Model (b) Architecture BIM Model (c) MEP BIM Model

Figure 3 BIM Models in Healthcare Expansion Project
 (Courtesy of: Rogers Builders, Charlotte, NC, USA)

For this project, the BIM model produced architecture, structural systems and MEP systems. It was developed to provide a dynamic platform for inter-disciplinary collaborations as presented in Figure 3. Through the entire project management phase, Roger Builders used the BIM models for cost engineering, subcontractor buyout, MEP coordination and clash detection. The specific benefits have been identified by using BIM model in this project includes:

- Clearly defined subcontractor's work scope
- Automatic quantity extraction of structural steel and major MEP systems
- Facilitate shop drawing of structural steel and MEP systems
- 560 clash conflicts between MEP systems and the structural systems were identified prior to the fabrication of the MEP and structural systems

Case Study 2: High School Project, Gastonia, North Carolina, US

Project Scope: \$38 Million, 220,000 SF High School Project
 Modular Construction: Prefabricated classroom with rough-in MEP installation
 Delivery Methods: Design- Build
 Contract Type: Cost Plus with Guaranteed Maximum Price
 Design Assistant: Extensive Design Involvement
 BIM Implementation Cost: \$38000
 BIM Implementation Saving: N/A
 BIM Platform: Naviswork™

A comprehensive BIM model with overlapped architecture, structural, MEP model has been created by Rogers Builders BIM specialists at the design phase of the project, as presented in Figure 4. The BIM model was used extensively for design coordination, subcontractor work scope clarifications, cost engineering, MEP coordination and project sequencing.

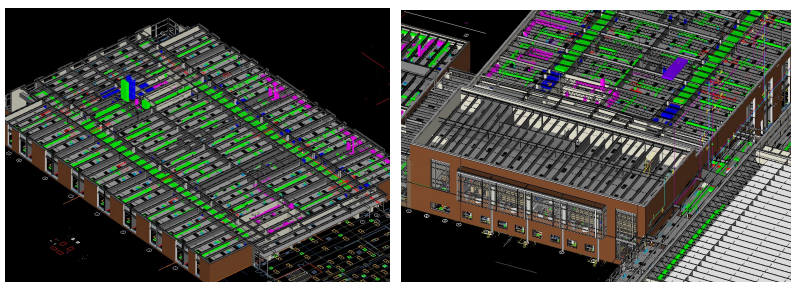
(a) 1st Floor BIM Model(b) 2nd Floor BIM Model

Figure 4 High School B Project BIM Model
(Courtesy of: Rogers Builders, Charlotte, NC, USA)

All MEP coordination was conducted through the BIM platform. It is very beneficial to have fully integrated architecture, structural systems, and MEP systems in single 3D file, which reduces change for human error and provides a visual check for interferences for clash detections. By using the BIM model for this project, 258 conflicts were identified and eliminated during the design phase, as presented in Figure 5 and Figure 6. Each classroom module was accurately manufactured offsite with rough-in plumbing pipes and electrical conduits installed. The finishing MEP and furnishing process began after the installation of each classroom module.

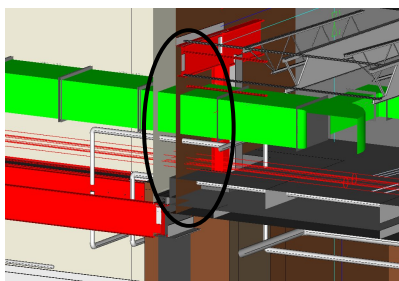


Figure 5 Ductwork Conflicts Structural Steels



Figure 6 Ductwork conflicts with Bar Joists

(Picture Courtesy: Rogers Builders, Charlotte, NC, USA)

Through these case studies, the researchers identified that the most effective use of BIM models was for design coordination, walk-through animation and clash detections. This was more so for modular construction project which requires extensive design coordination especially for MEP systems.

The greatest challenge of using BIM in construction project is the implementation process itself, regardless of the software capabilities. Development of accurate BIM model requires extensive resources and in-depth knowledge of construction methods and process. Most small or medium firm could not afford the special team and man-

hours to aligning BIM, as Rogers Builders employs several in-house BIM specialists to develop, maintain and operate BIM models for each project. A dual system of AutoCAD™ and BIM system functioning at same project is another major challenge of BIM implementation. Construction managers normally need to spend tremendous time and man hours to educate major subcontractors, materials suppliers and even some architecture firms to integrate BIM systems into their work platform.

Other than finance and organizational issues, the project team has experienced legal challenges as well. The use of BIM technology encourages multi-disciplinary collaboration, which contrasts to defining responsibility to each party and then assigning liability issues among the parties. In addition, using BIM models instead of traditional contract documents raises questions on insurance coverage and confidentiality exposure. Ownership and control of the model, use and distribution of the model, and intellectual property rights are some of the issues that need to be addressed while BIM implementation being adopted in construction industry.

Conclusion

The current construction delivery model does not support modular construction techniques due to extensive project planning and MEP coordination involved, even though modular building technologies offer tremendous advantages to the construction industry. With the increased integration of BIM in construction project, incorporating modular building technologies into project becomes more effective and desirable because the entire planning, design, shop drawings development, manufacturing and construction process could be streamlined. Physical conflicts between the structure, mechanical, electrical and plumbing systems can be easily identified early in the design process and resolution is expedited and the building trades are not restricted to only relying on paper plans and written specifications. Further research is suggested to focus on the organizational and legal issues evolved with implementing BIM models in construction projects.

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