Opportunities for Advancement of Modular Construction Projects using Building Implementation Modeling (BIM)

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Modular construction projects consist of one or more structural units fabricated in a manufacturing plant away from the jobsite. In the construction industry, prefabricated modules are normally completed with rough-in mechanical, electrical, and plumbing components installed. Prior research has proven that modular construction projects provide many advantages to the built environment, which include reduced workforce, reduced production of onsite Green House Gas (GHG) emissions, reduced construction schedules, and increased quality. Extensive demand of pre-project planning and coordination among members of cross-interdisciplinary professionals has been significantly impeded the application of this technique. With the recent development of Building Information Modeling (BIM), these challenges are able to be overcome through the use of BIM technology. Through several case studies performed for this research, this paper details the benefits and challenges of implementing BIM for modular construction projects.

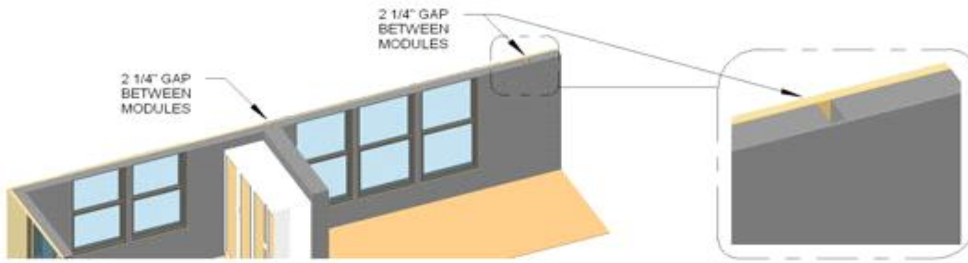
Keywords: Building Information Modeling, Coordination, Prefabrication, Building Systems.

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).

The coordination and fabrication of the Mechanical, Electrical and Plumbing (MEP) systems in modular construction has always being one of the most challenging tasks encountered in the delivery process (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

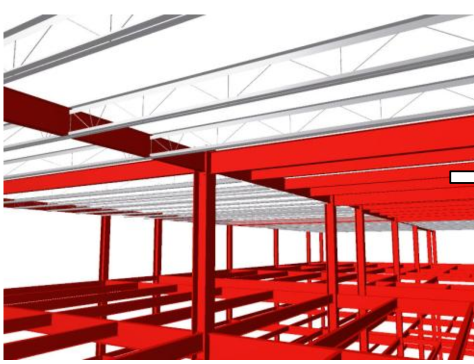
(b) Installation prefabricated Roofs

(c) Prefabricated Wall Panels

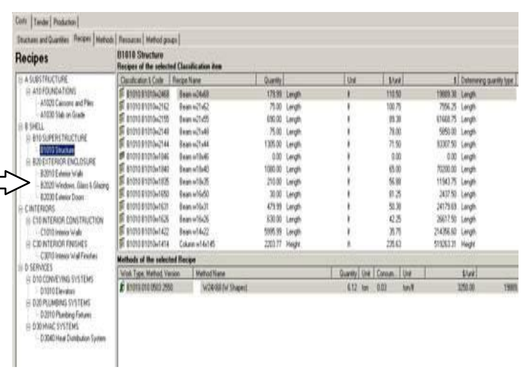
Figure 1 - BIM application in Modular Construction Projects (Tocci & KBS)

Building Information Modeling Technology and Current Applications

BIM is commonly defined as the process of creating an intelligent and computable three-dimensional (3D) data set and sharing the data among the various types of professionals within the design and construction team. With BIM technology, an accurate virtual model of a building is constructed with precise geometry and relevant data needed to support the procurement, fabrication, on-site installation activities, as presented in Figure 2 (Eastman et al, 2008).



(a) Structural Steel BIM Model



(b) Automatic Quantity Takeoff from BIM Model

Figure 2 - BIM Model Applications in Cost Engineering
(Courtesy of: Holder Construction Co, Atlanta, Georgia, USA)

The use of BIM technology allows for the creation of intelligent contextual semantic digital models in terms of building elements and systems, such as spaces, walls, beams, columns and MEP systems, whereas 3D CAD technology is limited to generating drawings in graphical entities in terms of lines, arcs and circles. In addition, BIM technology allows for a creation of a model that contains information related to the building physical, functional and procurement information. For instance, the BIM model would contain data about the geometry, location, its supplier, operation and maintenance schedule, flow rates, and clearance requirements for an air-handling unit (CRC Construction Innovation, 2007).

Using BIM technology allows designers, engineers, and construction contractors to visualize the entire scope of a building project in three dimensions. Therefore, BIM technology is not only defined by simply creating a 3-D data set for internal analysis. When most professionals refer to a 3-D model today, they are only referring to a digital 3-D data set that contains geographical representations of objects placed in relation to each other. BIM technology is also known as the process of using a 3-D model and associated data set to improve collaboration among project participants. Using this collaborative approach, designers and builders can plan, in precise detail, the location and clearances required for a complete and successful project.

The implementation of BIM systems in modular construction normally involves in the following process:

- *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 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. 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.

Coordination using BIM technology for Modular Construction Projects

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 (Korman 2001).

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 (Tatum 2000).

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 (Korman 2001).

Advancement Opportunities, Benefits and Challenges in Modular Construction

The following case studies document the implementation of BIM technology on two different types of commercial projects. Specific examples of using BIM technology which facilitated the MEP coordination process are discussed as well. The project and owners name are anonymous for confidentiality purpose. The construction manager was Rogers Builders, headquartered at Charlotte, NC, which 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 began implementing BIM technology on every project they have constructed since 2007. 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

The project scope for first case study included the expansion of a healthcare facility in Charlotte, North Carolina. The constructed improvements were valued at $44Million, which covered the construction of 110,000 SF of healthcare space. The construction is considered a modular construction project as concrete panels were prefabricated for the floor slab. The project delivery method was construction manager at risk with a cost plus with guaranteed maximum price contract. There was no design involvement on the part of the general contractor. The BIM implementation cost totaled $44,000. Savings from the BIM implementation are estimated at $220,000. The BIM Platform used was Naviswork™.

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

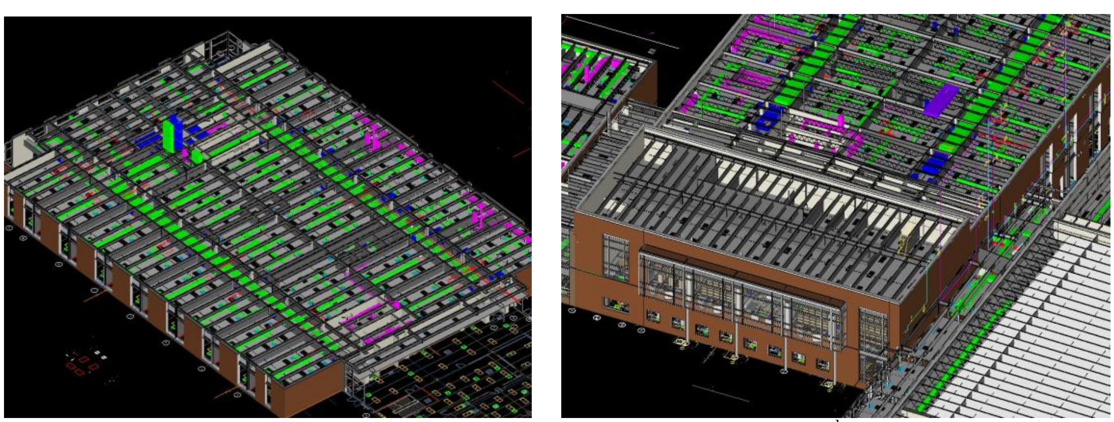
Figure 3 - BIM Models in Healthcare Expansion Project
(Courtesy of: Rogers Builders, Charlotte, NC, USA)

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

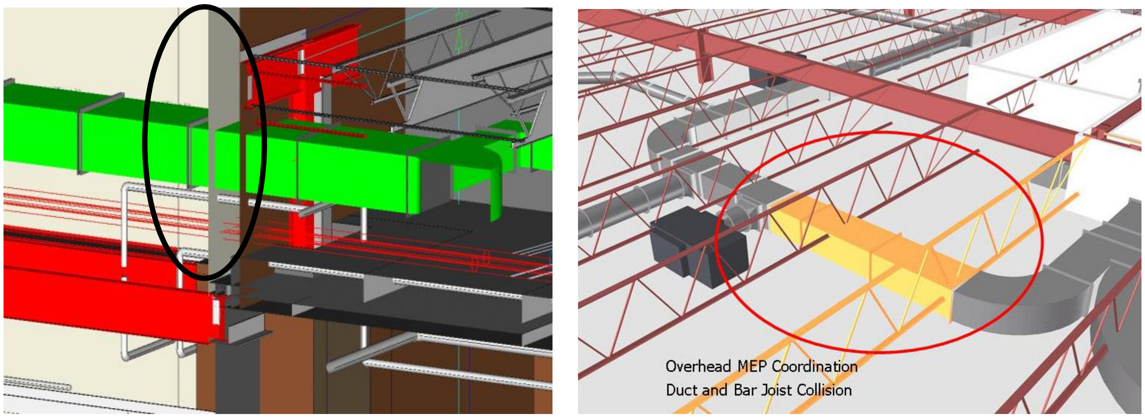
The project scope for the second case study included $38 Million of constructed improvements which totaled 220,000 SF High School Project. The construction project was considered a modular construction project due to the fact that the classroom were prefabricated and included rough-in MEP installations. The project delivery methods was Design-Build. The contract type was cost plus with a guaranteed maximum price. The general contactor was extensively involved with the design development stage. The BIM implementation cost totaled $38,000; unfortunately the savings were not calculated. The BIM platform was 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 Project BIM Model
(Courtesy of: Rogers Builders, Charlotte, NC, USA)

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.



(a) Ductwork Conflicts Structural Steels

(b) Ductwork conflicts with Bar Joists

Figure 5 - High School Project BIM Model Clash Detection
(Courtesy of: Rogers Builders, Charlotte, NC, USA)

Findings and Conclusions

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.

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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