Innovation and Improvements of Mechanical Electrical and Plumbing Systems for Modular Construction using Building Information Modeling

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ABSTRACT

Modular construction is defined as structure units fabricated in a manufacturing plant away from the jobsite. In the building industry, prefabricated modules are normally completed with mechanical, electrical, and plumbing (MEP) installed. Prior to the use of Building Information Modeling (BIM) software technology, the coordination of MEP systems had created major challenges for complex buildings and industrial plants and limited the potential for pre-fabrication in modular construction projects. The prefabrication coordination process has historically involved representatives from each all trades working together to locate equipment and route connecting elements for each system. The use of BIM software technology has facilitated the prefabrication coordination process and has increased the potential for prefabrication on multiple levels. This paper explores and presents the current research and demonstrates how BIM software technology can be utilized to further innovation and increase the opportunities for prefabrication of MEP systems for modular construction projects.

Key Words: Building Information Modeling (BIM), Information Technology 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). To be considered a modular construction project, buildings normally consists of multiple rooms in which a majority of the structure has been construction in a controlled environment and a significant amount of the mechanical electrical and plumbing system components has been installed (O’Brien, 2000). A large portion of construction research that has been conducted in the United States has documented that the use of modular construction is able to provide many
significant advantages over on site construction. These include the reduction of overall project schedules, the improvement of product quality, increased onsite safety performance, a reduction in the need for onsite skilled workers, and a decrease in the negative environmental impact caused by construction operations (Gann, 1996; Hsieh, 1997; Edge, 2002; Gibb, 2001; Venables, 2004; Lu, 2007).

Whether Mechanical, Electrical and Plumbing (MEP) systems are installed onsite or in a factory as part of modular construction project, the coordination and fabrication has historically been a challenge (Tatum, 2000; Korman, 2001; Lu, 2008). The coordination process involves defining the locations for building systems components in congested spaces, to avoid interferences and to comply with diverse design and operations criteria. Prior research has revealed that the coordination process has been historically fragmented between design and construction firms and that the level of technology used has varied significantly between engineers and construction contractors (Korman, 2001). Using Building Information Modeling (BIM) software technology as a tool to assist coordinate, document, and fabricate MEP systems in modular constructions appears to be an effective approach to overcome these challenges.

**Building Information Modeling Technology and Current Applications**

BIM is commonly defined as the process of creating an intelligent computable data set and sharing the data among the various types of professionals within the design and construction team. The use of BIM technology software allows for the creation of intelligent contextual semantic digital models which are able to provide a virtual construction solution where the design (3-D), schedule (4-D), cost (5-D), and life-cycle analysis (6-D) that can be interlinked.

This is achieved with the use of BIM software technology by creating objects that have data fields attached to them. The objects form a virtual model of a building or facility where the data can be associated with individual components or assemblies which can support procurement, fabrication, and installation activities. Therefore, the use of BIM technology allows designers, engineers, and construction contractors to visualize the entire scope of a building project. BIM reaches far beyond simply creating a 3-D model of the building or facility. When most professionals refer to a BIM model, they are only referring to 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.

**MEP Innovations and Improvements**

As discussed above, an advantage of using the BIM process is the ability to create digital models which are able to provide a virtual construction solution where the design (3-D), schedule (4-D), cost (5-D), and life-cycle analysis (6-D) that can be
interlinked. The potential innovations and improvements for each dimension in modular construction are discussed below.

**Geometric (3-D) Innovations and Improvements**

Initially, the initial users indentified BIM technology as a valuable tool for designers, engineers, and construction managers to visualize the design of an entire building project. The first benefits most professionals began to realize was their ability to create, visualize, and present a building in 3-D. This included the entire building as well as individual building modules – their geometry, location, space, and relative position to each other. Additionally, as users became more skilled with BIM technology software and the software evolved, the BIM model become used to generate 3-D renderings of the proposed final product, including external and internal finishes to owners, designers and construction managers.

Perhaps, most valuable to designers, engineers, and construction managers using the BIM process for modular construction projects is that the BIM process facilitates collaboration and communication among all project participants and allows for the simultaneously creation of construction documents, product imagery, rapid prototypes, exterior envelope, interior finishing, and MEP fixtures of building modules. Through this single information platform, the BIM process promotes collaborations between the architectural design team, engineering consultants, construction managers, and the owner representative for the client.

With all project participants involved in the BIM process, virtually constructing their portion of the building or facility in the model, the ability to indentify conflicts, interferences, and collisions between MEP systems virtually prior to fabrication and installation of systems was realized. This has proven to be a major benefit of the use of the BIM process and creation of a common model. For example, MEP building system interferences can be indentified visually, presented, and displayed in 3-D, rather than discovering them through the traditional process of overlaying translucent drawings on a light table or discovering conflicts during the installation process after components have been fabricated for specifically for installation.
Upon completion of generating a complete virtual model through use the BIM process, fabrication and shop drawings can be more easily generated with more confidence and less risk that the system will change prior to installation, which of course, results in less material wasted. In addition, the virtual models generated through the BIM process are beginning to become more acceptable for use in code reviews and have be used by building officials and fire officials for code compliance reviews.

**Schedule (4-D) Innovations and Improvements**

Construction sequencing provides a complete construction schedule for material ordering, fabrication, delivery and onsite installation of each building systems. With the integration of 3-D modeling, 4 D (3D model + scheduling information) is more easily generated during the project design and construction phase Projects teams are becoming more knowledgeable in their ability to link a construction schedule with individual building systems and building components to analyze proposed construction schedules and to sequence critical construction operations. Known throughout the manufacturing industry, scheduling allows for just-in-time delivery (JIT), which in tern allows for concurrent prefabrication of mechanical, electrical, and plumbing and reduced installation times.

The figure below demonstrates how prior to the use of the BIM process, individual components would be delivered to the site of where the modular building was being construction and then assembled on site. Using the BIM process, sections of the MEP systems can be prefabricated and then installed on site.
Cost (5-D) Innovations and Improvements

Being experimented with now is the 5th dimension of the BIM – cost data, where the 4D BIM model objects and assemblies have the capability of having "cost" data associate with them. Cost estimating provides for cost estimating, material quantifications, and pricing to be automatically generated and modified while changes are applied for each building module. This new dimension provides many possibilities for project teams including: cost estimating. The cost information contained in the BIM can be used to estimate and perform project cost tracking. Prior to the use of BIM technology software solutions, cost estimates could be generated from quantity take-offs using electronic 2-D construction drawing. The use of 3-D BIM allows for automated quantity take-offs, provided that the components have data associated with them identifying them, and 5-D BIM will be able to generate automated cost estimates when components have cost data associated with them.

The figure below demonstrates how prior to the fabrication and construction of any building system, the exact quantities can be determined from the model. Then using the associated data fields with an individual building component a materials price and installation productivity rate can be applied to each system component.
Figure 3 – Ability to associated cost information with MEP system components

Life-Cycle Analysis (6-D) Innovations and Improvements

Life-cycle is relatively new in the BIM process. It focuses on the forward-thinking ways to design, construct and manage modular buildings that are resource efficient, environmentally responsible, cost effective, and healthy for all occupants. Using the BIM process and the model created it is possible to analyze a modular building in an interactive format, considering the use of sustainable building materials, specific site evaluation, energy efficiency and lighting, green materials selection, indoor environmental quality and health factors, water conservation and quality protection, sustainable job site operations, and building operations and maintenance.

Figure 4 – Life-cycle analysis using BIM process
Findings and Conclusions

The use of BIM technology encourages multi-disciplinary collaboration. 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. Through several 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 that 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 firms cannot afford special teams and man-hours to aligning BIM; however as the knowledge increases the number of specialists also increases that are able to develop, maintain and operate BIM models for each project. 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.

References


