

Factors Influencing the Construction Industry's Shift to Modular Construction

Namhun Lee Ph.D.
Central Connecticut State University
New Britain, Connecticut

Seong Jin Kim Ph.D.
Minnesota State University Mankato
Mankato, Minnesota

Current practices in the construction industry emphasize on increasing productivity through several approaches. Building Information Modeling (BIM) technology is one of the approaches to improving work productivity. It opens up a channel to the increased use of prefabrication and modularization. Model-driven prefabrication becomes a way to design and construct prefabricated modular buildings. Furthermore, current influential construction trends such as Lean Construction and Green Building have caused many construction professionals to bring prefabrication and modularization back into the spotlight. Modular prefabricated construction can reduce on-site activities, site disturbance, and waste or pollution through more efficient processes. Consequently, modular prefabricated construction has become more prominent in the construction industry. The primary benefit of modular construction is the increased productivity, especially when schedule is tight, there is a weather concern, and skilled labor is not available. The main objective of this study is to identify factors influencing the construction industry's shift to modular construction and make some suggestions for its application to future vertical-extension projects. To achieve this objective, this paper reviews modular construction processes and building codes and permit requirements for modular prefabricated buildings. Also, the paper investigates current methods of modular construction through an industry survey and discusses possible benefits from modular construction methods and potential barriers in utilizing them.

Key Words: Modular Construction, Prefabrication, Building Codes, Construction Methods

Introduction

Construction projects are labor-intensive and embraced by various risks inherent in the project. Current practices in the construction industry emphasize on increasing productivity through several approaches. One approach to increase productivity is prefabrication and modularization. Modern prefabrication and modularization actually started in the early 1900s. Europe and Japan have adopted these methods for a long time. Also, in the United States, modular construction has been widely used in military and commercial buildings.

Current influential construction trends such as Lean Construction, Building Information Modeling (BIM), and Green Building have caused many construction professionals to bring prefabrication and modularization back into the spotlight. The National Research Council (2009) recommended prefabrication and modularization as an "opportunity for breakthrough achievement" to improve productivity in the construction industry. There are some factors influencing the construction industry's shift to modular construction. Consequently, modular prefabricated construction has become more prominent in the construction industry due to its ability to combine all the current construction trends.

Modular Prefabricated Construction

Modular construction is a process in which building units are prefabricated in a safe and controlled setting at a manufacturing facility, transported to a construction site, and erected into their final position on site (Gassel & Roders, 2006). This process has been utilized when onsite construction is limited by constraints such as space limitations, tight schedules, and adverse weather conditions. Especially for mechanical, electrical, and plumbing

(MEP) components, factory-built units have been used often (Lu & Korman, 2010). These modular units are constructed in an enclosed facility where constraints hindering the construction timeline can be controlled.

With advancing Building Information Modeling (BIM) technology, model-driven prefabrication becomes a way to design and construct modular buildings (Bernstein et. al., 2011). It has been used for a wide variety of building types, ranging from apartment buildings to healthcare facilities. This building method can provide a project with several benefits, compared to conventional construction practices.

The primary benefit of prefabricated modular construction is the increased productivity, especially when a schedule is tight, there are weather concerns, or skilled labor is not available. Other benefits include enhanced and simplified site logistics, a lower risk of theft or vandalism, and better protection from weather damage. Prefabricated modular construction helps to decrease material waste and create less disruption to the surrounding environment (Bernstein et al., 2011).

Shelley (1990) argues that five to ten percent of the total cost for most projects can be saved using modular construction. Typically, labor rates in the fabrication shop are less expensive than ones on the jobsite (Hesler, 1990). In addition, required equipment and tools remain in the fabrication shop. Therefore, equipment cost can be saved through the transfer of field works into shop works. This results in overall cost and time savings especially when work is repetitive (e.g. 90 modular units of the same bathroom).

Most benefits to modular construction result from working in a controlled indoor environment. Modular buildings can be constructed with a faster schedule and in a safe environment. The quality of production can be increased because prefabricated modules are constructed in a better work environment and are inspected by third parties. Safety can be also improved through modular construction because the majority of work is performed in a controlled factory setting. Construction time can be reduced by carrying out several tasks independently. For instance, the schedule can be accelerated by working the module assembly and site development concurrently. In modular building projects, several activities can go on in parallel that would typically be performed in series. This results in earlier completion of a project. Therefore, financing expenses and associated costs can be reduced (Shelley, 1990).

On the contrary, cost increases emerge from the extra design and engineering and transportation and handling effort. This extra activity is required to avoid later design changes and withstand transportation and handling loads. In addition, more detailed planning and scheduling are required for a modular construction project than a conventional construction project since greater interdependence of construction activities associated with site logistics should be given. Therefore, the actual planning phase of a modular construction project is typically longer than in a conventional construction project (Mullet, 1984).

In modular construction, building units are prefabricated and assembled at various locations. Hence, it is not a simple process to communicate among fabricators for seamless coordination due to the increased interdependence of construction activities. Changes in a design can disrupt various inter-related activities. Thus, modular construction is not easily adaptable to design changes. Furthermore, transportation studies including route investigations are required early in the project not only to determine the size of factory-built units and equipment requirements with adequate lifting capacity but also to thoroughly analyze the possible transportation methods meeting transportation, handling, and erection requirements (Stubbs & Emes, 1990).

Building Codes and Permit Requirements

Building codes are the rules and regulations that specify the standards for constructed objects to protect public health, safety, and general welfare. Modular buildings are constructed according to the same state, local or regional building codes as site-built buildings. For example, the state building code of Connecticut (2017) specifies that “A certificate of approval by an approved agency shall be furnished with every prefabricated assembly, including modular housing, except where all elements of the assembly are readily accessible for inspection at the site. The building official shall inspect placement of prefabricated assemblies and the connections to public utilities and private water and septic systems at the building site, as well as any site built or installed components or equipment to determine compliance with this code. A final inspection shall be provided in accordance with Section R109.1.6.”

Local authorities may require that all foundations to be used in conjunction with the modular buildings meet either permanent or temporary standards. All site related works are subject to local permitting and inspections. For instance, the Florida state building code (2017) - Section 553.80(1)(d) articulates that "Erection, assembly and construction at the site are subject to local permitting and inspections." Furthermore, local building agencies may have standards for handicapped access and aesthetic elements.

Table 1

Currently adopted model codes

Code Type	Code Model
Building/Dwelling Code	International Building Code International Residential Code
Structural Code	International Building Code International Residential Code
Mechanical Code	International Mechanical Code
Plumbing Code	International Plumbing Code
Electrical Code	National Electrical Code
Energy Code	International Energy Conservation Code

Modular building contractors should know the regulations that apply to their own project based on the physical building site and the agencies that have jurisdiction over that area. They should check with the state and local agencies to ensure that their projects will meet or exceed the required building codes. Most states have commonly adopted the model codes presented in Table 1. These codes must be uniformly applied and enforced without any distinction as to whether building is conventionally constructed or manufactured. Onsite modifications to existing modular buildings must be also permitted and inspected by local authorities.

Building plans approved by the local building authority must be submitted with the building permit application. Under the jurisdiction of the local building department, a building permit application usually requires:

- *Site plan* which shows building onsite location, parking, landscaping, all rights of way, and all utilities serving modular building and on-site construction.
- *Foundation plan and installation details* which include fastening schedules and utility hook-ups.
- *Geotechnical report*
- *On-site construction details* for all stairs, ramps, handrails, carports, covered entries, and any other structures.

Local authorities are responsible for inspection of the on-site assembly and construction of modular buildings as well as all other site related issues including foundations and utility hook-ups. Therefore, modular buildings must meet the same building codes and permits as those required of conventionally constructed buildings.

The transportation method limits the size of modules since they need to be transported to the jobsite. This limitation is mostly based on state and federal highway restrictions. Thus, the size of modules depends on the variance allowed the local state transportation board and the condition of the local roadway from the prefabrication shop to the jobsite. Typically, the width of modules ranges between 10 and 15 feet; the length of modules is limited by the turns on the route (about 60 feet); and the height of modules is dictated mostly by highway overpasses or tunnels on the route (under 14 feet). For instance, the Connecticut guidelines and policies (2017) for transporting mobile, modular or sectional housing require the following restrictions:

> "Maximum width (14') fourteen feet including all roof overhangs, sills, knobs, and siding; maximum height (13'-6") thirteen feet six inches; maximum length (85') eighty-five feet, except that (90') ninety feet is permitted when the towed unit does not exceed (66') sixty-six feet in length excluding the hitch; maximum

gross vehicle weight of 80,000 pounds which is allowed when all the requirements of the Federal Bridge Formula are met."

Current Methods of Prefabrication and Modularization

Transportation, handling, and erection activities are performed at the end of the modular construction process. However, it is critical to prearrange special support for transportation and handling equipment depending on the modules' dimensions and transportation methods. Once building modules arrive at the jobsite, they will be erected into their final positions. The process of modular construction is illustrated in Figure 1.

After the module design is approved and other interdependent activities are undertaken, the design should not be changed. Typically in modular construction, there is little flexibility in changes of module design. Hence, modular construction requires more time to complete design and engineering prior to commencing construction than conventional construction practices do. This may result in a tight schedule with little float time. To overcome this challenge, technology needs to support an effective modular construction process. Nowadays, technology has advanced enough to generate shop drawings and allow the fabrication of modules directly from BIM models. This enables just-in-time delivery for field installation on the jobsite. Just-in-time delivery is essential in modular construction projects. Otherwise, storage space may be required additionally to avoid onsite congestion.

Figure 1: Modular construction process

With BIM, it is possible to identify interferences and resolve any issues during a coordination session. This has evolved into an effective way for completing field installation with few errors, if any. Furthermore, it has become possible to drive cutting machines directly from the 3D model. Using BIM, it is possible to have full collaboration throughout the entire modular construction process. This collaboration reduces design errors and eliminates conflicts caused by uncoordinated drawings.

BIM provides not only the ability to validate the design and verify compliance but also the quality of the modules against an established set of standards or guidelines (e.g., code compliance, structural integrity, stability, tolerances and connections, etc.). In addition, BIM can be used to create shop drawing and support the coordination process among specialty contractors. BIM can be integrated with fabrication machinery and supply chain management systems to facilitate the specialty contractor's fabrication process. The following information can be possibly added on BIM models:

- Material quantities and ordering
- Work planning and labor codes associated with fabrication
- Field installation and assembly codes of modules

To create BIM models that support the shop drawing and coordination process, there are two key factors that should be considered: (1) design intents and (2) engineering knowledge of the fabrication and installation processes in modular construction. Figure 2 illustrates how the two factors are embedded in the iterative BIM-based coordination process.

There are other uses for BIM in modular construction projects such as visualization of design intents and site logistics plans, analysis and evaluation of alternative materials, and simulation of intended construction sequencing and installation. The use of BIM is a way for all project team members to accomplish their common goals by providing them with the benefit of improved visualization of a construction project through a shared 3D virtual model of that project.

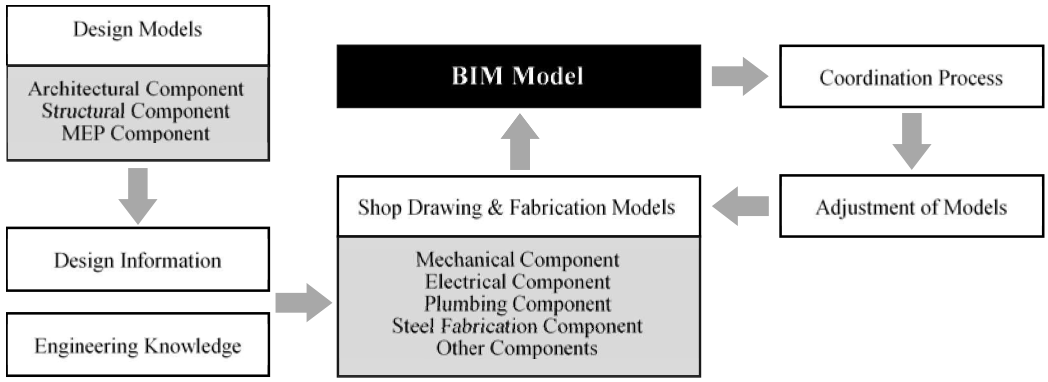

Figure 2: BIM-based coordination process

Industry Surveys on Modular Construction

Individuals from fifty companies were contacted to verify if they have currently had projects using modular construction. Of the fifty companies, seventeen individuals explained their recent modular building projects. Based on the project information described by them, the projects were grouped by the type of building. Table 2 lists the number of projects by the type of building.

Table 2

Type of building the respondents have been involved in

Type of Building	No. of Projects
Commercial Housing	7
Healthcare	4
Education	6
Retail	2
Office	2
Total	21*

Note: *This number is greater than the total number of the respondents which is 17 because some respondents mentioned more than one project

The seventeen individuals were asked again to participate a survey on modular construction. All seventeen individuals responded. The respondents' roles in their modular building projects are presented in Table 3. This survey focuses on the following information: (1) general information on modular construction practices and (2) specific examples of benefits from modular construction methods. The findings that have been derived from this survey are described below.

One of the questions was "what percent of work is done typically in the manufacturing factory?". Most of the respondents answered that 60-80% of work is completed in the manufacturing factory. Another question was "how much cost savings occur from prefabrication and modularization?". Five respondents mentioned an average of 6-10% cost can be saved compared to on-site construction. However, most of the respondents stated that the cost is not necessarily less all the time. The next question was "How much time can be saved from modular construction?" Fifteen respondents mentioned that the project schedule can be reduced by about 1-2 months. Three respondents indicated that the schedule can be decreased by 5 months or more, compared to conventional construction methods.

This survey also tried to identify if there was a common reason for using modular construction methods in building projects in which the respondents were involved. Most of the buildings had to be functional much faster than was possible with conventional construction methods. This was the most common answer to the question, "why was modular construction chosen?". Also, this survey found that only three respondents stated they used BIM for modular construction projects.

Table 3

Roles of respondents

Role	No. of Respondents
Owner	2
Designer	3
General Contractor	5
Modular Manufacturer	7
Total	17

From this survey, several specific benefits and barriers in utilizing modular construction methods were also identified. The benefits and barriers identified by the respondents are summarized in Figure 3.

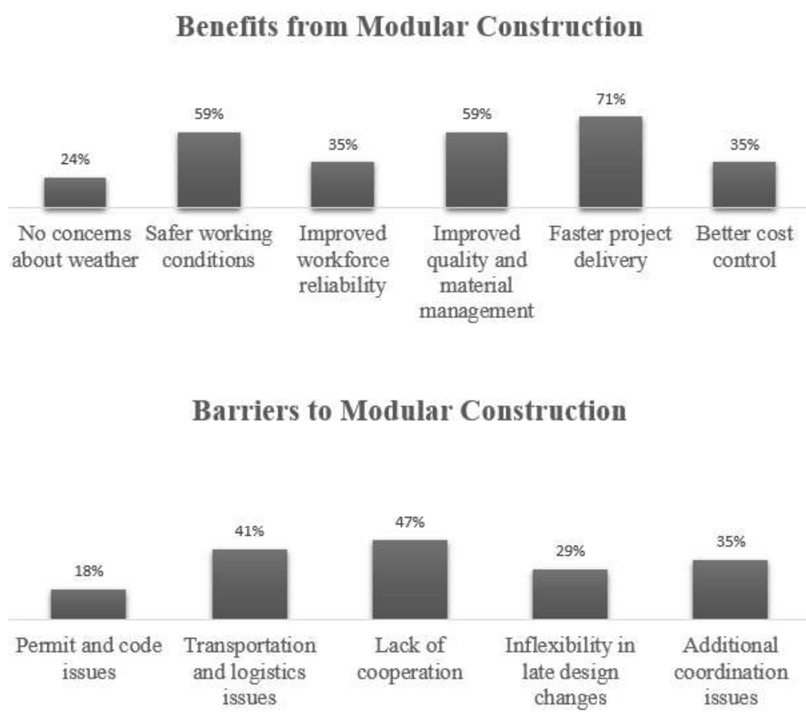

Figure 3: Current benefits and barriers in utilizing modular construction

As shown in Figure 3, 71% of the respondents mentioned faster project delivery as the main benefit from modular construction. 59% of the respondents explained safer working conditions and improved quality and material management as the benefits from modular construction methods. Also, 47% of the respondents indicated a lack of cooperation between design and construction as well as between off-site work and on-site work as the main barrier in modular construction projects. 41% of the respondents mentioned that transportation and logistics issues should be managed carefully.

Discussions

Modular buildings use the same materials and must comply with the same building codes and standards as site-built facilities. Furthermore, each module is engineered to independently withstand the rigors of transportation and hoisting. Once all modules are assembled and sealed, they reflect the identical design intent and specifications of their site-built counterparts. Modular construction can reduce the number of change orders due to inflexibility in design changes as well as controlled factory settings. The design should be completed before the module unit is produced and should not be changed during production of modular units. In this way, the cost of modular construction can be managed and controlled. This would be one of the reasons why modular construction is cost-efficient compared to conventional construction.

Modular construction projects can be completed faster than conventional construction projects. This is possible because modular units can be built in a factory simultaneously with site and foundation works. For this reason, modular construction reduces construction time and mitigates the risk of weather delays during construction. It is a key factor as to why modular construction is used in building projects. Moreover, modular construction ensures improved quality and material management. Materials are delivered and stored at the manufacturing plant safely and securely, which prevents them from damage or quality deterioration. Also, it is possible for contractors to minimize the storage of hazardous materials on jobsite. Manufacturing plants can have stringent quality assurance and control programs with independent inspection and testing protocols, which promotes superior quality of construction.

Modular construction removes significant numbers of on-site job activities and decreases a significant amount of disturbance resulting from labor, equipment, and suppliers, thereby improving overall jobsite safety and security. Laborers work in controlled environments, which significantly reduces safety incidents. Modular construction also promotes sustainability by reducing on-site operation, waste, or pollution through more efficient processes. Modular buildings can be disassembled and the modules can be relocated or refurbished for another use.

As described above, there are perceived benefits from modular construction. On the other hand, there are realized barriers in modular construction. First, there may be permit and code issues because building officials may not be knowledgeable about modular prefabricated construction. In addition, there may be transportation issues when the manufacturing site is in a different state. Late design changes, an adversarial climate between designer and contractor, and a lack of cooperation could be potential issues on utilizing modular construction.

This study identified that the primary factors influencing the use of modular construction methods include “faster delivery” and “cost savings” from the owner’s perspective and “safer working environments” and “better quality of construction” from the contractor’s viewpoint.

Conclusions

From this study, it can be concluded that several potential benefits can be achieved if modular construction is used under appropriate conditions. It should be also emphasized that modular construction is not for every project. Therefore, influence factors for modular construction must be identified before this method is adapted for vertical-extension projects. Modular construction can be a cost-cutting, time-saving option. Also, it can be a venue for exceptional safe records and quality project delivery.

In conjunction with BIM, model-driven prefabrication process can be efficiently and effective for modular construction. However, it need to be more involved in modular construction projects. Again, the key to success with prefabrication and modularization is strategy in selecting which projects are most appropriate for modular construction. One of the most critical criteria is to evaluate if buildings have a repetitive piece of work. This would be the reason why modular construction methods have been used commonly for housing, healthcare centers, schools, hotels, and dormitories.

Modular construction also requires a higher level of collaboration between project stakeholders. An integrated approach to project delivery increases the possibility for project success as well as collaboration. Therefore, it is beneficial for stakeholders to choose modular construction early in the project development process. In addition, it is essential for modular manufactures to get involved early in the design phase so that the benefits from utilizing prefabrication and modularization can be maximized.

Limitations of This Study

The authors were not able to obtain specific data such as actual costs and schedules of modular construction projects because the data is either proprietary or confidential. Hence, this study was not able to do comparative analysis with actual data of off-site vs. on-site construction. Nevertheless, the survey questions focused on comparing the two different construction methods since the respondents already know the difference between the two methods even though the data cannot be shared to third parties. Therefore, the authors believe that this study probed the difference of the two construction methods descriptively.

References

Bernstein, H. M., Gudgel, J. E., and Laquidara-Carr, D. (2011). *Prefabrication and Modularization: Increasing Productivity in the Construction Industry*. In SmartMarket Report, edited by McGraw-Hill Construction: National Institute of Standards and Technology

Connecticut Department of Transportation (2017, August 4). *Guidelines for Transporting Mobile, Modular or Sectional Housing, State of Connecticut* [WWW document]. URL http://www.ct.gov/dot/lib/dot/Documents/dpermits/eh_ndlgi.pdf

Connecticut Office of the State Building Inspector (2017, August 4). *Connecticut State Building Code* [WWW document]. URL http://www.ct.gov/dcs/lib/dcs/office_of_state_building_inspector_files/2013amdtosots.pdf

Florida Legislature (2017, August 4). *Florida Building Construction Standards* [WWW document]. URL http://www.leg.state.fl.us/statutes/index.cfm?App_mode=Display_Statute&Search_String=&URL=0500-0599/0553/Sections/0553.80.html

Gassel, F. V. and Roders, M. (2006). A Modular Construction System. How to design its production process *International Conference on Adaptable Building Structures*. Eindhoven, The Netherlands.

Hesler, W. E. (1990). Modular Design – Where It Fits. *Chemical Engineering Progress,* 86 (10), 76.

Lu, N. and Korman, T. M. (2010). Opportunities for Advancement of Modular Construction Projects using Building Information Modeling (BIM). *The 46th Annual ASC International Conference*. Boston, MA.

Mullet, T. A. (1984). Manage Modular Projects: Part I – Should Project Be Modularized?, *Hydrocarbon Processing*, Vol. 63 (7), 93-94.

National Research Council of the National Academies. (2009). *Advancing the Competitiveness and Efficiency of the U.S. Construction Industry*. Washington DC: The National Academies Press.

Shelley, S. (1990). Making Inroads with Modular Construction. *Chemical Engineering*. New York. 97 (8), 30.

Stubbs, D. L. and Emes, P. D. (1990). Modularization: Prefabricating a Process Plant. *Mechanical Engineering*, pp. 63-65.