Prefabrication and Modular Construction:
CM 214 Residential Construction Learning Module

Matthew V. Keeth
California Polytechnic State University
San Luis Obispo, CA

The residential construction industry in the United States has certainly stuck to the conventional methods of stick-built construction nationwide. What if there was a better way? This project seeks to educate future Construction Management students about a smarter, more efficient, and sustainable method of homebuilding: Modular Construction. Distinguishing the difference between prefabrication and modularization is a necessary standard. Prefabrication is defined as the process of manufacturing the essential structural components of a home at a factory off-site. The large-scale structural components of a home are then transported to the jobsite for easy installation. In addition, Modular Construction is defined as the comprehensive method of residential construction that emphasizes the procurement, preconstruction and prefabrication of the crucial structural partitions that comprise a home. I In essence, the means of prefabrication play an imperative role in the development of a modular home. The integration of Prefabrication and Modular Construction within the Cal Poly Construction Management curriculum should be of high importance as it is the future of the residential construction industry.

How the Project Came to Be

From the beginning of my Senior Project brainstorming and research, I knew that I wanted to bring light to alternative methods of residential construction that are not commonly utilized in the United States. After taking various classes and labs in the Cal Poly Construction Management curriculum, I found that there was an absence of more efficient methods in the residential construction industry. With that being known, I strived to create a learning module that would enlighten students to the means and methods of prefabrication and modularization.

History of Modular Construction and Prefabrication

The means and methods of Prefabrication and Modular Construction made its introduction in the 20th century predominantly in Eastern Europe and Asia. At the time, this method of construction was developed based on the natural conditions specific to such countries like Japan, Australia, The Soviet Union and other European countries.

The concept of standardized design that came into fruition in the 1960's, is commonplace in modularization. However, the idea of universal production and the advantages that come with this means of construction have brought considerable interest. Such interests that spread worldwide at this time were predominantly based on the significant increase in speed of construction and the reduction of production costs. According to the research article, *Research on Design Optimization of Prefabricated Residential Houses Based on BIM Technology*, written by Nan Liang and Mengxuan Yu, "Britain, France, the Soviet Union, and other countries first tried these buildings. Prefabricated buildings quickly spread around the world because of their speed and low production costs. The early prefabricated buildings were rigid and uniform in appearance" (Liang 3). This uniform design was instilled initially due to the overall inexperience with such methods of modular construction. Eventually, later improvements were integrated that allowed for these modules to be built in batches and in a variety of styles. Generally speaking, the

comprehensive method of modular construction and prefabrication has not been adequately introduced into the homebuilding sphere of influence in the United States.

Prefabrication VS Modularization

The research article titled, *Research on Design Optimization of Prefabricated Residential Houses Based on BIM Technology*, written by Nan Liang and Mengxuan Yu, defines modularization as "the foundation of the development of prefabricated buildings and the basis of realizing the standardized production of components" (Liang 6). In other words, Modular Construction can be defined as the alternative method of residential construction that involves building the essential structural components of a home at a controlled, off-site location. This method utilizes the same materials and methods as that of the conventional residential construction process. However, unlike on-site construction, this method significantly improves the overall efficiency of building a home. Such efficiency benefits include ecological efficiency, cost efficiency and time efficiency. There is a common misconception that modular construction and prefabrication are the same thing. This is not the case. Prefabrication itself, is the most prominent factor in constructing a modular home. However, the means of prefabrication focus specifically on the process of off-site, factory construction. To further clarify, Roland Meissner explains the difference between the two in stating "Modularization can be done in bits and pieces, as site-specific needs dictate. For instance, préfabrication, preassemblies and packaged or skidded components all fall under the umbrella of modularization, and all can help a project owner to overcome factors that may present technical or economic obstacles to traditional construction approaches" (Meissner, 2003). In essence, prefabrication can be defined as the manufacturing of any specific components of a home at an off-site factory but falls under the overall means of modular construction. He goes on to speak about the efficiency of prefabrication and modularization which will be explained in detail later on.




Steps to Understand the Prefabrication & Modularization Industry

Means of Prefabrication

This means of construction transfers a large amount of on-site work in the conventional construction method to an off-site factory, processes the building accessories at the factory, and transports them to the site for assembly. There are many different prefabricated material assemblies and panelization means used in modularization including concrete systems, steel structure systems and wood structure systems. According to the research article *Research on*

Design Optimization of Prefabricated Residential Houses Based on BIM Technology, such prefabricated components have the following characteristics:

1. A large number of building parts are completed by workshop production and processing; the main types of components are outer wall panels, inner wall panels, laminated panels, balconies, air conditioning panels, stairs, precast beams, precast columns, and so on.
2. A large number of on-site assembly operations, much less than the original cast-in-place operations.
3. The integration of construction and decoration design and construction; the ideal state is that the decoration can be carried out synchronously with the main construction.
4. With the standardization of design and informationization of management, the more standard the components are, the higher the production efficiency will be, and the corresponding component cost will decrease. With the digital management of the factory, the cost performance of the whole prefabricated building will be higher and higher.
5. Meet the requirements of green building.
6. Energy saving and environmental protection.

These wood structure systems are separated into different components of the home including beams, walls, stairs, roofing, balconies etc. Each component manufactured off-site consists of separate designs that have their own standard of production in the factory. Panelization is the most consistent prefabrication method. The term panelization is defined as the manufacturing of wall panels at an off-site factory. The development of these prefabricated panels are intended to expedite and increase the efficiency of homebuilding that currently is lacking in the conventional on-site, stick-built residential construction. A significant percentage of preconstruction and procurement must be front loaded in order to ensure maximum efficiency in constructing a modular home. With that being said, it is important to confirm the final design of the home early and determine which prefabricated components must be constructed first in order to minimize schedule delay. Building Information Modeling is one of the critical components initiated into the preconstruction stage as it provides accuracy and quality assurance for each project. Once a complete information model is approved by the architect in accordance with the BIM engineer, the carpenters hired to construct the floor and wall partitions are cleared to begin the layout and assembly.

BIM Involvement in Prefabrication

For this method of constructing modular homes to be deemed effective, there is a significant amount of preconstruction and BIM coordination necessary. According to an article written by Autodesk, the industry leader in building information modeling, the use of various BIM software, is “essential to accurately compose structural components with defined parameters and in dynamic parallel connection” (Autodesk). The article goes on to state that BIM model detection tools aid in discovering conflicts between various elements of the modular home. The advantages of clash detection limit the probability for schedule delays in the building phase. A Complete Information Model (CIM) is defined as a specific type of BIM model that “can connect the data, process, and resources in different stages of the construction project life and is a complete description of the engineering object, which can be widely used by all the participants of the construction project” (Liang 2). The key contributions of the CIM include a cost-efficient solution for the resources management and savings, a project life-cycle reduction by

reducing the time taken from the idea's generation to its practical implementation, and improved building quality, better visualization, communications, and coordination.

Means of Modularization VS Conventional Residential Construction

As defined by the article, *Research on Design Optimization of Prefabricated Residential Houses Based on BIM Technology*, written by Nan Liang and Mengxuan Yu, Modular Construction is defined as "the foundation of the development of prefabricated building components…" (Liang 6). This promising method of homebuilding integrates large-scale, structural components of a home that are constructed at an off-site factory and assembled on the jobsite. Modularization improves the overall speed, efficiency, and quality assurance that the conventional stick-built methods entail. Additionally, such efficiency can be utilized in not only single-family homebuilding, but also multi-family and affordable housing projects.

The aspect of quality assurance and control when it comes to various unforeseen conditions that are commonly experienced with traditional residential construction, instills a sense of certainty that both the builder and the client appreciate. Conventional residential construction can be a source of various problems in regard to quality, schedule and cost. When we are speaking on modular homes built with lumber specifically, there are many benefits that these prefabricated panels and modules include. When it comes to quality, modular wood frames are commonly manufactured using kiln dried material. What is significant about kiln dried lumber is that it is straighter, eliminates shrinkage and reduces moisture content. These three material qualities make the overall quality and tolerance more beneficial compared to conventional stick-built construction. The reduction in moisture content creates less susceptibility to mold and insect infiltration which in turn improves the overall quality as well. Contrarily, the traditional method of homebuilding receives its structural lumber "wet". This lumber has a higher moisture content which creates a higher likelihood of twisting, warping, and bowing. With the unfortunate quality differences, other installations such as interior and exterior finishes can sometimes become problematic later on. In addition to material quality issues, unforeseen site conditions are more common and extend the project life cycle in conventional homebuilding. Poor soil conditions and hazardous materials tend to be discovered after breaking ground and have resulted in schedule extensions and a reduction in productivity.

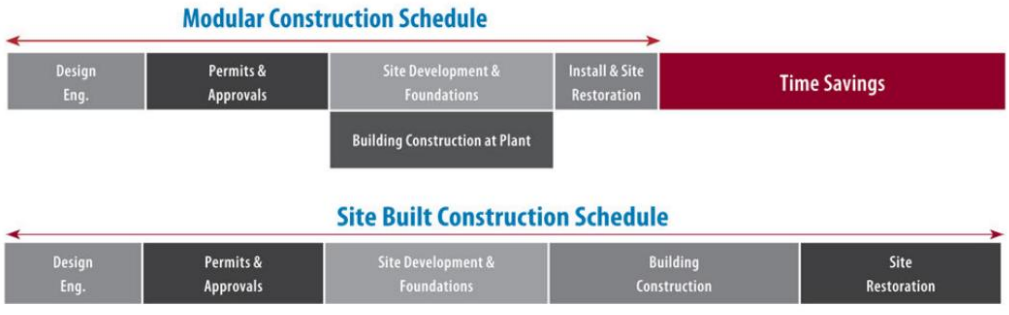
Regarding the building schedule and project timespan, Modular Construction utilizes the vast majority of its time front loading the project. What is meant by front loading is the process of emphasizing pre-construction procedures and solidifying designs, materials, and installation processes early in the project to minimize schedule delays and cost alterations in the actual building stage of the project. In the methods of modularization, a large majority of the project life cycle is spent in the preconstruction phase so that the mobilization and building phase happen quickly and effectively. When the wood panels of the modular home are constructed, delivered, and quickly installed, this means that the installation of the roofing components can be expedited. With a significantly shorter time span of the structural components, exterior and interior finishes can be installed faster as well. This linear process that follows ultimately saves both the client and the builder time and money. On the other hand, conventional framed homes are more susceptible to inclement weather which affects the amount of time that carpenters can install structural components and at a sufficient quality standard.

Another advantage of modular construction is its cost efficiency in comparison to the conventional home building method. As mentioned earlier, the integration of BIM technologies in the front end of the project life cycle, creates a considerable efficiency standard. When it comes to cost savings specifically, the accurate design specifications result in saving the owner and contractor large monetary investments. The monetary savings made is through the reduction in material ordered and or wasted. In the conventional stick-built method of construction, the amount of material waste that is incurred is absurd. In addition, cost savings are a direct result of scheduling reduction. It was reported that there was 25% to 30% reduction in the project's life cycle with modularization which has proven to save the owner and contractor money. After all, time is money. Concurrently, the indoor construction eliminates unforeseen delays such as weather limitations, clash detections and cost alterations. Also, with the factory line prefabrication, process efficiency is apparent which reduces the required labor in the building phase. This inherently reduces the contractors' direct labor costs. Finally, studies have shown that modularization and off-site prefabrication have resulted in reduced energy consumption which in turn saves the owners money in the long term.

Waste is much more significant in the traditional home building method and instills a larger carbon footprint from the waste itself, as well as the environmental cost of transporting and ridding of the waste within various scopes of work. Within modular construction there is a significant waste reduction due to BIM accuracy. The ability to determine materials used and the precise amount needed leads to less material needed to be purchased and therefore less material waste. Material waste in all aspects of the building phase of modular construction is reduced with a specific emphasis on framing, interior and exterior sheathing, MEP materials and interior finishes. With this being said, the process of modular construction looks to prevent these issues from happening in the first place. Outsourcing major components of a home implements major benefits for the owner, architect and not to mention its environmental improvement.

Advantages of Prefabrication and Modular Construction

Many of the advantages of Prefabrication and Modular Construction have been previously mentioned above. However, to dive deeper, according to an article written by Autodesk, the main advantages that are apparent with the integration of prefabrication and modular construction include, a controlled environment, an increase in safety, material waste reduction and time savings. Cost savings is one of the most overarching benefits of modularization as it is included within waste reduction and time savings. A reduced disruption to the surrounding communities incites another huge benefit to this method of construction. Additionally, as previously mentioned, the main advantages of prefabrication and modular construction include time efficiency, labor efficiency, cost effectiveness, sustainability and waste reduction. All of these advantages coincide with each other and certainly show the significant, beneficial difference between conventional stick-built construction and modularization. According to the research article written by Nan Liang and Mengxuan Yu, such advantages "...can save labor, reduce processes, save time, reduce energy consumption, and reduce pollution, thus promoting the successful transformation and upgrading of the construction industry and supply-side reform" (Liang 2). In regards to time efficiency specifically, a recent survey conducted by the National Institute of Building Science (NIBS) discovered that off-site construction has the potential of reducing the building phase by an upwards of 73.2%. In addition, the NIBS concluded that the common issue with project deadlines is significantly reduced with the implementation of modular construction. The efficiency and quality control standards is considered the primary feature that distinguishes modular construction from the traditional residential method. The figure below outlines and compares the momentous time savings with prefabrication and modular construction.



Source: Modular Building Institute. CC BY-SA 3.0.

According to the Modular Building Institute, modular construction can result in a significant reduction in construction schedule due in large part to the fact that offsite building fabrication and onsite preparation work can be conducted simultaneously.

Barriers and Limitations of Modular Construction

Labor circumstances

In the current climate of the construction industry, there is a notable demand for quality tradesmen. Unfortunately, the means of modularization further hinders this demand for qualified laborers in the residential construction industry. This is by virtue of the fact that it takes less people to construct the partitions of a home in an off-site factory versus on the jobsite. With this being the case, other problems come into effect. When it comes to current tradesmen, the majority are hesitant to conform to the methods of prefabrication and modularization in the fear that they may lose their job and their livelihood.

A considerable issue with modular construction compared to the conventional stick-built method is the distance between the production location and the site of installation. However, latent changes in design and consequently the lack of transparency between the owner, architect and contractor, poses an even bigger obstacle. Of course, the lack of cooperation in any method of construction inevitably leads to issues.

Safety

Construction safety is of the utmost importance when constructing any building. When it comes to the prefabrication and erection of residential wall partitions, there are serious hazards and risks involved. One of the biggest hazards faced in the modular construction industry is in the transportation efforts. Transporting large, heavy wall panels from the factory to the jobsite presents a major public safety hazard. In the article, “Construction of Manufactured Homes: Understanding the Hazards & Risks”, Maryam Fard and others dive into the various risks that come with modularization. Figure 4 of this article depicts the specific incidents that have happened along with the frequency of these events.

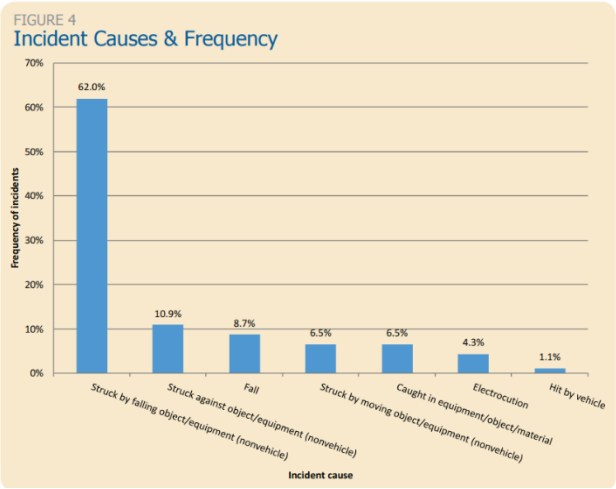


Figure 4 (Incident Causes & Frequency)
Figure 4 displays many accidents occurring from falling objects or equipment

Logistics

There are various logistics to be considered when deciding to use the method of modular construction versus traditional, on-site construction. Location of construction can affect whether modularization is the ideal method as such heavy components being delivered can come into issues with various site conditions and egress complications.

In regard to manufacturing logistics, most states require third-party agencies to regulate the design, inspection and approval of the off-site factory and the structural components being manufactured. The extent of their infiltration into the modular process comes with associated costs. Such regulations and comparative costs can disincentivize clients and builders alike, to utilize modularization. Other regulations including transportation are determined by the state as well. According to an article titled, *Off-Site And Modular Construction Explained*, written by Ryan E. Smith, further explains these transportation limitations. "Transportation regulations are also handled state-by-state. Therefore, shipping from a state in which a module is manufactured to another state where the site is located will require differing codes, permitting, lead cars, and various associated fees. Each project should carefully ensure this is well considered. A general rule of thumb is 500 miles maximum for shipping from a manufacturer to a job site. On average, modular manufacturers, for example, are approved to build in 20 states" (Smith 2016). In addition to the differing regulations, internal logistics planning can create problems depending on the location. When utilizing methods that require heavy load transportation, roadways and other external conditions can affect the ability to safely deliver and install the prefabricated panels and or the modules themselves. With the consideration of these potential complications, it is important to ensure that the modularization is the most beneficial method for the specific location.

Conclusion

Over this learning module we have discussed the methodology of prefabrication and modular construction. Within this uncommon means of residential construction, there proves to be an incredible number of advantages and reasoning as to why this method is better than the conventional stick-built approach. It is seen that there is a noteworthy increase in quality, time savings, waste reduction and cost savings. However, like any construction method, there are always barriers and limitations that follow. We find that there are safety hazards and risks involving transportation, laborers hesitant to conform to the method, and various logistical considerations that vary from state to state. It is with this research that I hope to inspire and educate future students of the Construction Management curriculum to further this research and bring light to the incredible benefits that Prefabrication and Modular Construction has to offer.

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