CASE STUDIES OF EXISTING STRATEGIES AND BIM PRACTICES IN PREFABRICATED CONSTRUCTION

By

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2015
To my Grandmother for her unconditional love
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<td>Full Form</td>
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</tr>
<tr>
<td>AEC</td>
<td>Architectural, Engineering and Construction</td>
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<tr>
<td>ANSI</td>
<td>American National Standard Institute</td>
<td></td>
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<tr>
<td>ASCE</td>
<td>American Society of Civil Engineers</td>
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<tr>
<td>ASHRAE</td>
<td>American Society of Heating, Refrigerating and Air-Conditioning Engineers</td>
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<tr>
<td>ASTM</td>
<td>American Society for Testing and Materials</td>
<td></td>
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<tr>
<td>BAC</td>
<td>Building Automation and Control</td>
<td></td>
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<tr>
<td>BIM</td>
<td>Building Information Modeling</td>
<td></td>
</tr>
<tr>
<td>BMP</td>
<td>Best Management Practice</td>
<td></td>
</tr>
<tr>
<td>CADM</td>
<td>Computer Aided Document Management</td>
<td></td>
</tr>
<tr>
<td>CDM</td>
<td>Construction Design and Management</td>
<td></td>
</tr>
<tr>
<td>CDW</td>
<td>Construction and Demolition Waste</td>
<td></td>
</tr>
<tr>
<td>CERL</td>
<td>Construction Engineering Research Laboratories</td>
<td></td>
</tr>
<tr>
<td>CFR</td>
<td>Code of Federal Regulations</td>
<td></td>
</tr>
<tr>
<td>CNC</td>
<td>Computer Numerical Control</td>
<td></td>
</tr>
<tr>
<td>D/B</td>
<td>Design/Build</td>
<td></td>
</tr>
<tr>
<td>EPA</td>
<td>Environmental Protection Agency</td>
<td></td>
</tr>
<tr>
<td>GIS</td>
<td>Geographical Information System</td>
<td></td>
</tr>
<tr>
<td>HVAC</td>
<td>Heating, Ventilation and Air-Conditioning</td>
<td></td>
</tr>
<tr>
<td>IBC</td>
<td>International Building Code</td>
<td></td>
</tr>
<tr>
<td>LEED</td>
<td>Leadership in Energy &amp; Environmental Design</td>
<td></td>
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<tr>
<td>MBI</td>
<td>Modular Building Institute</td>
<td></td>
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<tr>
<td>MEP</td>
<td>Mechanical Electrical and Plumbing</td>
<td></td>
</tr>
<tr>
<td>NAHB</td>
<td>National Association of Home Builders</td>
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</tr>
</tbody>
</table>
NIST  National Institute of Standard and technology
O&M  Operations and Maintenance
OSM  Off-Site Manufacturing
OSHA  Occupational Health and Safety Administration
PPVC  Prefabricated Pre-finished Volumetric Construction
RCC  Reinforced Cement Concrete
UL  Underwriters Laboratory
VDC  Virtual Design and Construction
Abstract of Thesis Presented to the Graduate School of the University of Florida in Partial Fulfillment of the Requirements for the Degree of Master of Science in Construction Management

CASE STUDIES OF EXISTING STRATEGIES AND BIM PRACTICES IN PREFABRICATED CONSTRUCTION

By

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December 2015

Chair: Raymond Issa
Co-chair: Ian Flood
Major: Construction Management

Even though prefabrication in construction has been practiced for a few decades, documentation of this technique of construction remains sparse. The few existing studies dealt with some pros and cons of the off-site construction. The current study will expand on those studies and evaluate the benefits and barriers in off-site construction and collaboration with traditional construction. Recently, there has been more advancement in off-site construction and the industry is getting more familiar with modular structures. In addition, new technology has revolutionized construction and consequently BIM (Building Information Modeling) has become an adhered part of the construction project.

The research basically deals with three main areas; 1) Reanalyzing off-site construction with respect to the traditional construction, evaluating basic concepts like schedule, cost, safety, outside temperature and weather, labor and similar aspects. 2) Evaluating how recent advancements in BIM and automation has affected the prefab construction industry. 3) Evaluating the feasibility of the combination of Off-site and Traditional Construction. Interviews will be conducted and case studies will be done of
each type of construction. Detailed analysis of the cases will be done and data will be compared. The end result of the study is not to proof that one technique is superior to others, but coming up with a better understanding of off-site technique and evaluating new strategies for proposing a method to overcome the barriers faced in modular construction.
CHAPTER 1
INTRODUCTION

1.1 Modular, Prefab and Off-Site Construction

The best way to deliver a big task is to break it down into “modules.” The construction industry is not immune to this principle. The method of building a structure by assembling modules together onsite and fabricating or manufacturing them offsite is called Modular Construction (sometimes referred to as off-site fabrication or prefabrication). This method was initiated a century ago and was used extensively during World War II. Recent decades have witnessed rapid advancements in the use of modular construction. Whenever a building component is fabricated off-site and then installed or assembled on site to form a structure the process can be classified as modular construction.

Figure 1-1. Typical modular construction process
This method is more convenient, less costly, consumes considerably less time, and saves on budget. Also, the unit or module is built inside a factory with controlled conditions, so safety and weather delays are not as problematic compared to traditional construction. It is also environmentally more sustainable as the waste produced relative to the traditional construction is about 52 percent less (Gunawardena et al. 2013). Environmentally, modular construction is saving nature by creating considerably less debris than that of the traditional method. As of now, sustainability is certainly the top concern for most building projects. Rapid advancements in technology and time savings have made this method more prevalent in recent times.

However, modular construction has its flaws and drawbacks. First, the transportation of the modules is a big problem. The units are picked up from the factory, placed on a vehicle, and then delivered to the site. This loading-unloading process deteriorates the integrity and quality of the components. If the delivery site is far from the factory, it may not be feasible to transport large modules. The coordination of lift operators, project manager, engineers, field workers, etc. is essential. The plans and drawings are misleading sometimes, and coordination can be hard to achieve. Many efforts are have been made to improve this technique such as Life Cycle Analysis, use of robots, quality management, etc. Still, the modular construction industry lacks the confidence and robust structure that the traditional method is known for. If uncertainties in delivering this method are revealed beforehand in a project, it will be far easier to counter the problems comprehensively. Lu (2009a) ranked the hindrances in prefabrication as shown in Table 1-2.
Table 1-1 Challenges of using off-site construction technique for A/E’s

<table>
<thead>
<tr>
<th>Categories</th>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inability to make changes onsite</td>
<td>35</td>
<td>54.69%</td>
</tr>
<tr>
<td>Transportation restraints</td>
<td>34</td>
<td>53.13%</td>
</tr>
<tr>
<td>Limited design options of using offsite construction techniques</td>
<td>31</td>
<td>48.44%</td>
</tr>
<tr>
<td>General contractors do not have expertise of assembling building components onsite</td>
<td>22</td>
<td>34.38%</td>
</tr>
<tr>
<td>Lack of skilled assembly craft works locally</td>
<td>10</td>
<td>15.63%</td>
</tr>
<tr>
<td>The projects owners do not allow using offsite construction techniques</td>
<td>10</td>
<td>15.63%</td>
</tr>
<tr>
<td>Using offsite construction technique will increase the construction cost</td>
<td>8</td>
<td>12.50%</td>
</tr>
<tr>
<td>Any other reason</td>
<td>8</td>
<td>12.50%</td>
</tr>
<tr>
<td>The local building regulations restricts the use of offsite construction technique</td>
<td>6</td>
<td>9.38%</td>
</tr>
<tr>
<td>The local zoning ordinance restricts the use of off-site construction techniques</td>
<td>5</td>
<td>7.81%</td>
</tr>
<tr>
<td>Designing offsite construction components requires special computer software</td>
<td>4</td>
<td>6.25%</td>
</tr>
<tr>
<td>Using offsite construction techniques will increase design cost</td>
<td>3</td>
<td>4.69%</td>
</tr>
<tr>
<td>The financial institution restricts the use of offsite construction technique</td>
<td>0</td>
<td>0%</td>
</tr>
</tbody>
</table>

1.2 Classification of Modular Structures

The definition of various types of modular methods is as follows (Lawson et al. 2014):

- **Modular Construction** – A structure which is three dimensional or volumetric unit, often called modules, which vary in sizes and shape as per design. These modules are manufactured in a factory off-site and then assembled on-site as a complete structural building.

- **Planar Construction** - It comprises of panels which are two dimensional such as walls, floors, and ceilings. These are usually prefinished with boarding and insulation before delivered to the site.

- **Hybrid Construction** – When linear elements, panels and modules are collectively used it is called Hybrid Construction. It may also include the conventional construction process integrated.

- **Cladding Panels** – To form the finished building envelope prefabricated façade components are installed to the building.
• Pods – Usually complete prefabricated units which are non-structural, such as toilets, washroom, kitchen etc., and can be installed readily inside the building.

Prefabricated construction can also be classified on the basis of the type of installation onsite and the size of pieces/module manufactured in a factory as:

• One Block Prefabricated House – This kind of houses are manufactured in factory as single unit. The one block prefabricated house is created not on site, whereas it is fully pre-made with all furniture and MEP installations. Idea behind such house manufacturing is to deliver it as a single piece and ready to use.

• Multiple Blocks of Prefabricated House – When modules are built as blocks and then strategically placed together this type of housing is delivered. This system permits building blocks placed together in that way creating a multi-storey prefabricated house

• Modular House Assembled Onsite – This kind of module house is a prefabricated home built in an offsite factory, which is then brought by truck to the home site, and assembled by an onsite construction team.

• Container Homes - Another kind of construction is container system. Basic container is attuned to planning of ground floor, the windows and doors are cut out in required places and then secured on edges. Also sometimes they are stacked together onsite for concluding the structure.

1.3 Hybrid Construction or Semi Modular Construction

In last decade the number of projects using combination of Modular and Traditional construction has increased. The combination can be just prefabrication of small part like washroom units or it can be more than half of the building. As it is more feasible to use modular construction methods when there are repetitive units or modules in the building, the combination might decrease the time and cost if delivered in the right way. This technique is also involved when we plan to install module components on existing structure.

1.4 Automation and Technology in Prefab Construction

Building Information Modeling (BIM) has been helping in traditional construction for more than a decade. BIM Automation in modular construction has not been
potentially exploited, which leaves the possibility of performing some analysis of what more should be done. A focus of this research is on the utilization of BIM for strategic 4D modeling and planning, which creates the scenario from beginning to the end of a project with tasks divided by days/weeks. This modelling will act as a pre-lecture for all workers, lift engineers, crane operators, safety coordinators, project managers, etc. while starting the work for the day/week. BIM can integrate information along with a component which can be used further for planning and control, estimating, and safety. (Neelamkavil 2009) has suggested usage of BIM in three ways:

- Prefab Module Manufacturing Process (panels, units, formwork, parts, etc.)
- Assembly procedure in which construction components are built together.
- The processes involved with the business and information side (planning and scheduling, document management, workflow management, and change updates)

This technique will create animation (modeling) from the ground up, manufacturing parts, handling of modules, and assembling of modules to the finish of project, with respect to time. Historical data will be analyzed and information will be inserted into the database to factor in the duration of similar activities. The size of modules and details of material used, type of labor employed, machinery used, productivity, and miscellaneous characteristics also will be included. This data analysis and 4D output will give the project manager an idea of what is to be done as well as furnish details and a preview of the task. Hence, the usage of this technique removes uncertainty, misunderstanding, and unfamiliarity with the project, which causes delays in schedule, increased costs, and sometimes abandonment of the project.

The construction industry requires more accurate and swift methods to save time and money as well as maintain quality. Modular construction certainly offers these
attributes but only if delivered with precision and expertise. Modeling software such as Autodesk Revit, Navisworks, and 3Ds Max provide the required features. The calculation of schedule, along with the planning of transportation of units from the factory to the site and lift procedures involved, generates the reliable information. Virtual reality facilitates real-time viewing and analysis of spatial data. The virtual prototyping environment is created, and the most satisfactory method is selected from “what-if” investigations.

### 1.5 Statement of Problem

The current state of prefabrication in construction is undefined with its progress and possibility of advancements. How much is prefab involved in the construction industry and the probability of its further usage in different sectors is undetermined. All the factors involved in prefab are scrutinized and strategies for improvement is proposed. This study is oriented towards current practices at the industry, not only modular but traditional construction also. The degree of involvement of BIM in prefab is studied, and as it is relatively new concept in the prefab industry the cost, time and skill required is studied.

Three case studies of three different companies is done to assess prefab practices in these companies. The technique of semi modular construction is also discussed and reported. The companies selected for evaluation in the case studies practice three different scales of prefabrication:

- The first company does 50-75% of a project with prefabrication and has its own manufacturing factory.
- The second company does 15-65% of a project with prefabrication and does not have its own manufacturing plant.
- The third company is a complete modular construction firm and has its own manufacturing plant.
CHAPTER 2
LITERATURE REVIEW

Selection of a construction delivery method has long been an important decision for any project. Similarly, how buildings should be constructed — using traditional, modular, or semi-modular methods? The question still remains to be answered perfectly. Modular construction is a type of construction that is mostly prefabricated in a factory in small units called “modules” and then assembled onsite. Modular construction often is considered to be the future of construction, but there still are some uncertainties in ensuring that is realized. Let us first look back at the history of modular home construction.

2.1 History of Prefab

The pioneering of modular homes started back in 1908, when kit homes were sold by Sears Roebuck & Company which was initiated through its famous catalog. Further noted in “History of Modular Construction” (2009) was that in 1913 Henry Ford, an automotive innovator, used modular units for his factory and introduced the assembly line concept. During World War II, there was widespread usage of sheet metal for military barracks and houses. Further along, modularity became a booming industry with works like Habitat 67 by Moshe Safdie (Marquit and LiMandri 2013). This article suggests that modular construction struggled with the association with temporary or trailer homes until the beginning of the twentieth century. In 1968, iconic modular building was constructed in San Antonio, Texas called as Hilton Palacio Del Rio. This 500 deluxe room hotel was design, manufactured and assembled in 202 days. First four floor were built with conventional method and rest prefabricated as fully furnished modules in the factory, source MBI (2007).
2.2 Available Literature

At present, the perception of modular construction has not significantly changed. But with the growing trend of design techniques, such as Building Information Modelling (BIM), the prospective for modular elements is surpassing its previous challenges (Marquit and LiMandri 2013). Neelamkavil (2009) concluded that the trend is prevalent in the industry with respect to automation and gives an idea on the implementation of automation in this industry. Automation is becoming an inseparable aspect of construction projects, and its potential is yet to be fully exploited, including offsite construction.

Understanding the efficiency of modular construction along with the type of project is imperative (Smith 2011). Each of the main priorities of the project—time, money, aesthetics, sustainability, and quality—must be minutely evaluated. (Tam et al. 2007) discussed various obstacles in prefabrication, supervision, and how effective prefabrication models can assist in quality assurance, waste reduction, and money savings.

Modular construction is far from being completely globalized, although it has made significant advancements in past 20 years toward being a greener, more efficient, and affordable alternative for delivery of building projects (Said et al. 2014). Exploration of this topic has been done from many aspects such as cost, duration of the whole project, waste management by working offsite, sustainability benefits, and manpower utilization. A variation of interchangeable terms are used for “offsite construction” in the international construction industry, comprising modularization, preassembly, prefabrication, and offsite fabrication (Mao et al. 2013). Prefabrication comprises the construction of all building components that eventually are fragments of large ultimate
assembly (Gibb 1999). The application of prefab modular construction is vast and includes residential, commercial, industrial, bridges, etc. The components of prefabrication can be categorized into four types with increasing degree of required labor:

- Modular structure (least)
- Penalized structure
- Single assembly prefabricated components
- Processed material (most)

The above categories are suggested by Schoenborn (2012). Offsite industry produces “modules,” which may be a room in a house or complete structure and are transported to the site for assembly as a building. Modular construction covers two types:

- Permanent Modular Construction (PMC): If the components are attached to the permanent foundation and it is immovable, then it is PMC.
- Temporary (Re-locatable) Modular Construction (TMC): This type maintains its mobility and can be relocated.

Some uncertainties in construction can be controlled by the usage of modular construction, because when the components are manufactured in the factory, they do not have delays due to weather conditions, unavailability of labor, or large amounts of debris. Khalili and Chua (2014) found that the usage of integrated prefabrication configuration and grouping of components for resource augmentation of precast production satisfied design flexibility, production constraints, and installation necessities. Time savings is a big criterion for a project. There is a keen interest in the architectural, engineering, and construction (AEC) industry in developing an approach to building that is more efficient and precise, makes better usage of the declining manpower, is
environmentally responsible, and provides shorter construction cycles (Smith 2011). Offsite construction has shown the capability to fulfil these goals.

The difference between onsite construction schedules and modular construction schedules is shown in Figure 2.1 (Schoenborn 2012):

![Figure 2-1 Time-Saving Comparison](image)

Along with the benefits of offsite fabrication, there are some cons too. The biggest one is the transportation of the modules from the factory to the site. The significant challenges include: 1) transportation constraints and negative effect on integrity of the component while in transit; 2) inability to make onsite changes; and 3) limited design choice (Lu 2009). (Mao et al. 2013) discussed 18 critical factors that hinder the progress of offsite fabrication in China. The five categories that he identified were government regulation and policies, technological innovation, industry policies, cost, and market demand. The establishment of critical factors delivers a platform for
local construction sectors to better equip themselves (Zhang et al. 2014). These factors are close to the critical factors suggested by Mao et al. (2013).

In the U.S., offsite construction can be useful in overcoming the challenges, including the scarcity of workforce and competitive scheduling (Lu 2009). Lu (2009) recommends providing awareness of offsite construction techniques to the general contractor, designer, and manufacturer and developing new offsite certification schemes. Permanent modular buildings make up approximately 42 percent of total modular construction in North America (Permanent Modular Construction Report, 2011). In China and India, the market for modular construction would equate to nearly $10 billion USD, five times the size of the U.S. market. Europe is using modular construction widely for multi-story residential building. In fact, the U.K. is the world leader in high-rise modular construction (2011; Lawson et al. 2011). In the U.K. the market for modular construction is approximately $2.44 billion USD, whereas the fields in which offsite construction is more prevalent are similar to those in the U.S.—education, healthcare, and offices.

Lawson et al. (2011) showed that modular construction can be effectively used for residential buildings up to 25 stories, with stability provided by concrete or steel framed core. The data indicated that the period of construction was reduced by 50 percent and waste was reduced by approximately 70 percent in contrast to onsite work. In multi-story building, a shoulder or saddle is formed at the top of the supporting column for supporting the adjacent module placed directly above the module on each side of the supporting column until the concrete has been poured between them (Gutierrez and Ray 1976). Also, strategies must be incorporated for a better
performance in modular construction. (Pan et al. 2012) concluded from studies that organizational learning and information exchange embraced the usage of offsite production, although extra reporting and management effort perpetuated a layer of bureaucracy.

Scheduling in modular construction is not the same as that of traditional methods. Basic CPM-based scheduling applications such as Primavera Project Planner and Microsoft Project are not effective. The scheduling for modular construction in assembly yards is evaluated, and an effective framework is developed with information about efficient allocation of space and crew skill. This system serves both as a schedule and a progress tracking tool and gives various graphical data, including module location and resource operation (Taghaddos et al. 2014). This method of scheduling is helpful for better allocation of yard space, providing color-coded graphical data as well as shift and crew management. The other simulation techniques developed suggested that proper management of the initial factory output and available resources could prevent delays in the delivery of final components (Mohsen et al. 2008). Critical details are shown of placing small components of the module, methods for level assembling of prefabricated modules, and processing (Ruano 2009).

The implementation of BIM in modular construction has facilitated the growth of information exchange and preconstruction design and production. Prefab construction automation is all about functionality and quality. A virtual environment that supports the design of the modules, their integration and assembly, and generating a suitable schedule will become standard practice (Neelamkavil 2009). Various information regarding the mechanical, plumbing, and electrical wiring and units in the integrated
final output of modules must be gathered and represented. Strategies for safe
deployment of modules for transportation, monitoring productivity, and real-time
conditions must be incorporated. (Alwisy et al. 2012) proposed a parametric algorithm
with a three-generation stage as follows:

- Creation of a model of adequate building information
- Modular construction manufacturing generation
- Detailed shop drawings generation

Nawari (2012) proposed a complete manufacturing concept that covers the path
from the offsite module prefabrication to factory production line assembly to final onsite
assembly of the modules. The information exchange also is a necessity which includes
the general contractor, architect, engineer, fabricator, subcontractor, and other
procurement identities. The automation pertaining to prefab mostly belongs to one of
three categories:

1. The manufacturing of the modules, which primarily deals with the building blocks.
2. Putting together or assembling components.
3. Construction business processes such as project management, document
   management, change monitoring, planning, and scheduling.

Neelamkavil (2009), apart from the above data, concluded that the ultimate
objective of automation in modular construction is to improve productivity, quality, and
safety, which facilitates cost reduction. There are many ways the off-site fabrication aids
in price savings as, with machines and other rentals, operation cost, general conditions,
common requirements, reduction in labor wages, safety advantages in working in a
controlled atmosphere and prospective to get wholesale material (Javanifard et al.
2013). Data must be linked with the model for the designers to evaluate their decision
impact on the overall construction. The information must be effective enough that it not
only ensures the materialistic side, i.e. item produced for building, but also the management of preconstruction process and assembling procedure (Baldwin et al. 2008). Also, the life cycle cost, life cycle impact and impacts of decision on overall construction must be understood for “waste management.”

2.3 Building Information Modeling (BIM)

The usage of BIM in modular construction enables designs with integrated data and more accurate outputs for the overall project. Simplification of modular construction for enhanced scheduling and workflow, i.e. reduction of complexities in policies and knowledge regarding this type of construction method, is of priority. To review the barriers to offsite utilization in the current environment, review schemes and plans endorsed for emboldening the usage of off-site technological knowledge centered on perception of people, facilitate procurement, delivering enhanced cost data, observe regulations and overall planning, and suggesting right virtue on decision making (Pan et al. 2007). Automation of residential modular building can be broken down into simpler modules to effectively deliver the final product. Notably, BIM features control in facilitation of life cycles from the beginning of the project planning (Yoo and Park 2015).

Vast research has been done in evaluating the benefits and barriers in prefabrication method of construction. Potential benefits includes (Mitchell and Hurst 2009):

- Lack of skilled workers and its continuous decline in number.
- All manufacturing and processing of modules takes place under the factory shelter and hence weather damage is not possible
- Quality of manufactured pieces is better, comparatively the environment inside the factory is more comfortable, and also existence of quality control program is more likely in such conditions.
The reduction in construction time consequently results in smaller period of capital outlay.

Use of materials can be done more efficiently with the help of BIM and computerized optimization.

Multiple components can be manufactured at the same time if enough labor and resources are available.

Inventory can be regulated and materials can be utilized in better ways resulting in less waste.

![Bar chart showing comparison of Modular, Semi-Modular and Traditional in Time, Cost, Safety and Waste](image)

**Figure 2-2 Comparison of Modular, Semi-Modular and Traditional in Time, Cost, Safety and Waste** *(Permanent Modular Construction Report, 2011)*

Also a glance at the barriers in the prefab industry give a balanced approach to analyze the current issues. The first problem is insufficient familiarity of the owner, contractor, architect, sub-contractor and labor with the Off-Site Manufacturing (OSM). This is not their fault as if they are unfamiliar with the potential of prefabrication and related benefits. Necessity of skilled labor, equipment cost for manufacturing, early decision for prefabrication, set regulations and policies for modular specific construction, precise manufacturing and onsite assembly etc. are few obstacles too. Transportation is one big hindrance in adoption of this technique. Recent advancements in technology, social media and BIM has played an important role in eliminating few barriers in
modular construction. Table 2.1 shows a matrix of how BIM can help overcome obstacles in prefabrication construction industry.

<table>
<thead>
<tr>
<th>OSM Barriers</th>
<th>BIM Benefits</th>
<th>Optimized Schedules</th>
<th>Reduced Costs</th>
<th>Improved Design</th>
<th>Better Training</th>
<th>Better Collaboration</th>
<th>Better Logistics</th>
<th>Reduced Design Errors</th>
<th>Accurate Extensive Amount of Information</th>
<th>Reduced Modification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Need for high level of IT integration</td>
<td></td>
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<td></td>
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<td>Bad reputation</td>
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<tr>
<td>Limited experience</td>
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<tr>
<td>Modification Difficulties</td>
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<tr>
<td>Transportation problems</td>
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<tr>
<td>Longer lead-in times</td>
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<tr>
<td>Higher costs</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Poor aesthetics</td>
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<td></td>
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<td></td>
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</tr>
</tbody>
</table>

Figure 2-3 Matrix of OSM Barriers and BIM Benefits - Adapted from (Ezcan et al. 2013)

Prefabrication is manufacturing of the parts which are planned to be assembled on-site to complete the final structure. Pre-assembly and modularization are not any different techniques but an extension of prefabrication concept (Cereceda 2015). Efficiency of prefabrication can be increased with usage of BIM and lean construction (van Mulligen 2012a). The current state of Off-Site manufacturing is explained by Khalfan and Maqsood (2014). They point out:

- Issues associated with the readiness of supply chain to assent the prefab must be evaluated.
- BIM has been researched and approved for adoption in conventional construction, but Off-Site construction needs some substantial insight.
Sustainability in prefabrication should be made evident through research investigation.
Incentives on usage of prefabrication must be done for both client and constructors.
Collaboration between researchers and practitioners is required.

Proper production sequencing is required to enhance the production of panelized construction (Liu et al. 2015). Examples of recent excellent modular construction are project at Atlantic Yards B2 tower and proposed sky city in China. This prefabrication method has led to many sustainability and constructional benefits (Lawson et al. 2014). This research will evaluate current prefab trends not only from the perspective of the modular constructor but also from companies using prefab in small/some degree.

Next Chapter 3 will discuss the methodology used in this study.
CHAPTER 3
METHODOLOGY

3.1 Overview

The introduction of modular construction during the twentieth century led to new possibilities. People experimented with this technique to achieve better output compared to traditional methods with respect to cost and time. The units built in the factory are assembled in a much more controlled environment and finish quality. The workmen enjoy convenience and safety inside such a factory. The amount of labor needed in offsite manufacturing is less than that of onsite construction. The startup cost is bit higher, but as the project goes on, cost savings are experienced. This unconventional alternative in construction delivery had its impact on the project in terms of requiring less time and less budget. The beginning of the twentieth century saw a new revolution in this sector as the sustainability and waste management achieved by this technique was comprehensively enhanced. All of these factors combined to make it a standard approach for construction.

Despite so many beneficial factors in modular construction, it is still far from dominating the traditional method (O’Connor et al. 2014), (van Mulligen 2012b) and (Said et al. 2014) have suggested methodology and implementation for modular construction. The purpose of this research is to verify the limitation of modular construction among the construction companies serving different sectors and also existing 3D techniques/BIM. The first thing that is to be done is to understand all limitations and uncertainties involved in offsite construction. The limitations and vagueness might be relevant to design, onsite delivery, manufacturing, transportation, assembly, lift operations, management, and scheduling. Once the limits are properly
defined, an argument is developed which helps in realizing the feasibility of going for modular construction with usage of given limitations. This might also depend on the location and type of construction; i.e., hospital, residential, shopping mall, etc. The methodology developed will be helpful in evaluation of the prefab usage by different firms and analyzing current practices and barriers. This research collects the data from the companies and compares the prefab deliverability by both traditional and modular firms. Developing a 3D scenario of the project from start to finish can help with the choices available.

The method should be divided into numerous attributes of the project. The breakdown of procedure is as follows:

- Reviewing the research already done in estimating the feasibility and final output of a construction project (including barriers/improvements in modular construction).
- Proposing a better tool feasible for selecting the suitable method.
- 3D analysis of the complete project in both traditional and modular ways.
- Comparing the data and identifying the most important attribute; i.e., cost, time, aesthetics, safety, sustainability, initial cost, etc.

The aim is to minutely identify pros and cons with perspective of different type of firms/company delivering the projects in different sector. These companies might use prefab in various ways in their projects and a study of these aspects should result in understanding the current prefab trends in business. There are numerous other factor that are prone to prefab/modular construction only, such as the following:

- Transportation of modules analysis, so that the size of the envelopes can be defined.
- Lift process simulation and avoiding conflict.
- HVAC collaboration for the ease in installation and energy saving.
- Facilities available for the manufacturing base and its cost.
- Scheduling project duration from start of manufacturing offsite base setup to the end of the project.
- Governmental regulations and permits required.
- Modular construction experience of the contractor and architect.
- Packaging and storage of the modules.
- Distance of the offsite manufacturing unit and the construction site.
- Planning for multiple cranes working at the same time for large projects.
- Cost incorporated by maintaining a factory and all related requirements.
- Identification of similar projects delivered in the past, then acquiring details. Often big projects involving modular construction end up in delays or suspension due to unawareness and inexperience.

The traditional method can be delivered as it has been done until now. A 3D model should be developed for both approaches. All information is integrated in the model, utilizing Building Information Modeling (BIM). BIM enables the virtual beforehand process of the actual construction, giving the workers, managers, operators, engineers, etc. a 3D perspective of the overall project. Usage of BIM depends on type of project and the type of company. As prefabrication is done both for modular buildings which are fabricated in modules and also for a building which is built traditional and then prefabricated components such as drywalls or bathroom pods are installed.
The 3D model should contain the details of types of walls and dimension. The model will be initiated by creating the module identity, production flow rate and module completion and assembly. The BIM model will be evaluated on several attributes and the rating for overall comparison will be developed. Even collaboration of both type of construction modular and traditional will be proposed if necessary e.g. a five story building can be made on-site for foundation and first floor and then for the superstructure of the building, the modules can be designed and assembled together. There are some example of use of automation in construction as FIATECH (2004) creates a path to follow for integrating planning/management and overall project together. Figure 2-2 displays the details of FIATECH Roadmap.
This methodology will facilitate the modular construction in an efficient way. The duration of activities, cost, and sustainability would be the main factor to consider. Quality and aesthetics will be of importance too. Other points to be considered will be whether the design of the building allows for modular construction. Big malls, highrise towers (30+ stories), etc. are mostly unsuitable for modular construction. Hence, this techniques give an owner or contractor a solid perspective on whether to construct modular, traditional or a combination of both.

### 3.2 Data Collection

Both quantitative and qualitative data are collected through literature review, interviews and case study. Three Prefab companies are interviewed for getting insight of prefab trend and then a recent modular project is evaluated. The case studies in this
research are focused on current practices by companies and understanding the current barriers and benefits of prefab. To broaden the results of the research a recent prefab project is reviewed. Challenges and necessity for adoption of BIM and advanced technology is also studied.

### 3.3 Limitations of Research Study

In the effort to evaluate the details, certain situations will limit the research:

- Ability to collect the details depends on the will of the participant to share the company (project) data.
- The companies interviewed are Florida specific and results might differ in other states.
- Focus is mainly on the prefab practices and use of BIM in prefab.
- Limited number modular companies in the locality.

### 3.4 Case Study – What is a Multiple Case Study?

Case study approach is best suited for this research as the concerning questions were dealing mainly with “how” and “why”. Case study is a method to explore an individual or organization (The “case”) in real world context, as the boundary between the context and phenomenon is unclear (Yin 2013). A case study was chosen because the case was current prefab trend and factors that influence the prefab usage. Different sectors and companies integrate prefab in their work and various factors govern their limitations and future trend.

A multiple case study approach provides an overall scenario of the problem statement. In this research, the author had 3 cases of 3 different company:

- First, the firm incorporates 50-75% of prefabrication and has its own manufacturing unit.
- Second is large General Contractor who incorporates from nothing to 50% of prefabrication on its projects, it does not own prefab factory.
- Third is a Modular manufacturing company which does almost all of the projects with prefabrication in its own manufacturing plant.
There is no one correct way of reporting a case study (Baxter and Jack 2008). The multiple cases will be later manipulated comparatively and individually too. For ensuring the quality and trustworthiness of the case study it will be ensured that enough information is collected on the problem stated.
4.1 Case 1

4.1.1 Participants and Roles

The first case study looks at a theming prefab company. This firm has been performing artistic and prefab work for more than 26 years. The company currently employs about 300 workers. About half of its employees work in the manufacturing and prefabication department, the number varies depending upon the phase of the project. This company does most of its projects in theming construction which includes work for Museums, Zoos, Aquariums and Theme parks.

4.1.2 Background

Acknowledging the necessity of the construction industry to complete projects faster, the company started prefabrication. In the preceding decade its work has been more prefabrication intensive and that has provided schedule benefits to the company. The projects that the company works on are not modular or prefabricated buildings, but prefabricated components or art-pieces. These components are mostly manufactured in the shop and then transported to the site. The theming construction industry has evolved a lot in last decade and the use of prefabrication has been facilitated by BIM and automation.

Previously, it was difficult to keep errors and budgets in control as everything was done in the field. For example, a project done by this company 15 years earlier in Myrtle Beach was a 25 ft. tall statue. The company built the statue on-site and the workforce and materials were on site. A lot of changes were made to the statue while it was under construction and after it was finished also. This caused more budget and time
increases. Another reason that adds on to the budget is union labor cost which is comparatively higher than what the workers were getting paid at the factory. Nowadays, BIM has revolutionized the industry in all sectors and thus computerized models created before the actual construction begins, help in overcoming any errors and changes during the building process. The company is able to show the owner the design and get the design approved as a 3D model and if there is any change the owner pays for it. Moreover a BIM model has integrated information about the material, schedule and dimensions which aids the workers on-site as well as in fabrication.

4.1.3 Approach to Prefab

The company started to build prefabricated components more frequently and in larger volume in the preceding 10 years. As it was obvious that prefab can save time and deliver better quality if built off-site under controlled conditions. The company has a fabrication facility of over 100,000 square feet including artificial rockwork, millwork, fiberglass, carpentry, architectural metals, and Glass Fiber Reinforced Concrete/Reinforced Gypsum (GFRC/GFRG).

To ensure that any changes are noted earlier, the computerized model of the component to be manufactured is analyzed and corrected as needed. Hence for the precision of the size of the manufactured piece to fit and get installed easily on-site, BIM is helpful. Once the computerized model is ready, a CNC rebar bender and hot wire machine are used to get the desired practical model structure. Coordination of the on-site access and equipment required to maneuver the piece into the place is taken into early consideration. The company does most of its work in prefabrication and transportation, but usually for installation they hire a subcontractor.
The biggest challenge that the company encounters with prefabrication is the transportation of these components. Sometimes they break during transportation or cannot be transported because of size limitations. In addition, they may require to be escorted or need to be transported in the late night. These things increase cost and sometimes cause rework or reduction of the component size.

4.1.4 Prefab Practices

The laborers who work in the prefabrication or the manufacturing department do not require any certification or diploma. But they are brought up through an apprenticeship type of program. For structural workers, they do need certification for working in the metal department. The factory uses CNC machines for designing the components. Also they might create a dummy model with foam in 3D machine and ensure that all the details needed are known.

Figure 4-1 CNC machine finished form art-work in the factory.

Involvement of architects in these projects is not much different than in regular construction. But it is the owner who drives the responsibility and assignments to the
parties. Usually 50-75% of a structure is prefabricated for a theming project. But still these structures require mandatory permits and approval from local county/city. They have to submit the permit drawing and ensure that the structural components and materials are in compliance with building codes including fire and life safety codes.

4.2 Case 2

4.2.1 Participants and Roles

The second case study look at a global integrated construction and facility management provider. The company is basically a large General Contractor and employed 2500+ workers at the time. This company incorporates prefab in a few projects but does not manufacture any modules in a factory. The sectors served by company are Civic and Cultural, Higher Ed, Commercial, Criminal Justice, Environmental, Federal, Food and Beverage Manufacturing, Fueling, Healthcare, Restoration, K-12, Science and Technology, Mission Critical, Multi-Family, Sports and Recreational, and Transportation. This case study provides a look at the general perspective of traditional contractors on prefab and modular construction.

4.2.2 Background

The company incorporated aspects of prefabrication on almost all projects including piping and fittings, ductwork, precast concrete and incorporated a higher level of prefabrication on certain projects based on scalability, schedule, manpower and the components included modular bathrooms or pods. As far as a higher level of prefabrication which involves the completion of more than two-thirds of a project to be delivered off-site, the number is only a handful of these projects. The firm assesses each project on individual basis, however there is uncertainty to the level of prefabrication involved in a project in the year that is planned.
4.2.3 Approach to Prefab

In the preconstruction phase the activities include project planning, site assessment, phasing, scheduling, cost modelling, lifecycle analysis, construction approach, lean contractor selection such as design build, design-assist, Integrated Project Delivery. Prefabrication can benefit the cost and schedule of a project, but one of the biggest positives that is often not mentioned as primary decision driver is the increased safety associated with performing work offsite in a controlled environment. Any project that the company does critically involves Architect participation. However for many prefabrication components the design responsibility is transferred to subcontractors/ manufactures who have the creation recommendations on which items to approach with prefabrication.

Scalable projects with repetitive components such as multi-floor residential or office space areas are typically easier for the integration of modular construction. For many custom or unique projects without recurring common core elements, it is more challenging to invest the upfront costs associated with modular construction. The possibility of the company to collaborate with modular builder is not farfetched. The firm is interested in delivering a semi-modular project if clear cut details are available.

4.3.4 Prefab Practices

Even in traditional construction nowadays factory built modules or prefab components are often used. At this point in time, Revit is the most used BIM and automation software in the construction business. BIM has become an integrated part of construction and prefab construction is also not too far from this upgrade. But collective use in combination of manufactured components and their installation still need to be figured out.
From the owner side of the scene, familiarity with prefab depends from owner to owner. But usually the clients are asking about opportunities for prefab during the interview presentations and initial planning of the project. This firm always considers prefabrication options before going for the conventional method. According to the company the best way to save time, cost and labor is pre-planning, exploring all options, and collaboration between trade contractors and design team earlier in design phase. The firm does not uses CNC/Robotics on the majority of its projects.

4.3 Case 3

4.3.1 Participant and Role

The third participant is a prominent modular builder in the southeast. The company has a 75,000 sq. ft. factory which was started in the year 2000. The company has more than 150 employees. The company provides both temporary and permanent buildings. The sectors covered by this firm is largely Educational, Commercial, Dormitories (Residential), Government Buildings, Military, and Medical. This case study specifically deals with the current operations and practices in the prefab/modular construction industry which are basically more than 90 percent prefabricated.

4.3.2 Background

This modular company started with sixty employees and now it has emerged as the South’s premiere manufacturer of educational and commercial modular buildings. The firm has delivered more than 1200 projects and all of them were prefabricated. The building once manufactured in pieces is then transported to the site and assembled together. The size limitation for transportation in Florida is 16’wide x16’height x72’length. Each project delivered has different factors involved with it such as location and the State where project is being delivered to, the amount of finish required by the
owner i.e. a building can be completely furnished including the mirror installation or can be as raw as just the structure with dry walls and it all depends on the complexity of the project.

For example, the firm did a project in 2009 at University of Miami which was a research laboratory. It involved modules built for a dust free environment and other modern equipment installed within. This project was challenging in itself as the manufacturing people have to incorporate all these factors while they were building modules in the factory. The firm does not use advanced BIM tools or automation tools. All the drawing are made by AutoCAD and that is the extent to which they use designing software. The only projects for which a BIM model is developed is when the owner requests it, which are generally for governmental and military projects. The firm gets the BIM model done by a designer outside of the company.

4.3.3 Approach to Prefab

Every owner has different demands and thus each project has different levels of architect involvement. The drawings are industry specific and the drawings are a little different from the regular drawings. In some small projects architects are less involved but projects such as an emergency room or research facility require extensive coordination with architects. One upcoming project that the firm will deliver is a platinum LEED residential building completely prefabricated in the factory, which is intensely in coordination with the architects. Every project in which one has to build something different than the boxy structure, the architect has to step up and thus increasing their involvement.

The firm has its own design and engineering team, they draw plans which are then reviewed and send out to the third party for checking and approval. Usually the
third party is a licensed Engineer. A purchase order is necessary with the client to initiate the manufacturing process, as materials needs to be ordered, especially long lead items. The industry standard is to provide 1” allowance or tolerance between the module connections. The factory uses hoist assemblies which are manually operated. Once the modules are manufactured a GC is hired to assemble them on site. These buildings do need approval from the local county/city including for satisfactory wind load, heat gain loss, uplift, occupancy compliance. They often have a local fire marshal to overlook and check on such compliances.

4.3.4 Prefab Practices

The company has various stages to manufacture a module/piece of the building. A building might be divided into several pieces depending upon the size and type of the building. At first, in the weld shop, the structural metal base is constructed by certified welders. The second stage is to provide the floor decked with specific material generally concrete, wood, steel, viroc, veristeel and fortacrete. If requested, finish flooring is applied at this time. Then walls are erected and fastened to the constructed base. These walls already have electrical wiring, plumbing lines, insulation and specified wall covering. A roof component with HVAC and ceiling preinstalled is then attached to the finished module. The module then moves down the line where exterior cladding is applied. In the final stage of production line the paint and finishes are applied and module is prepared for shipment. Every stage of this process is inspected for quality and compliance not only by on-site QA team but a third party inspector.

The labor working in the factory do not require any certification, but they are skilled and trained in their trade.
4.4 Data for Comparison of Case Studies

- Number of safety Incidents in the company 1 average about 4-5 per year in the manufacturing department. Data for Company 2 was unavailable. Whereas, Company 3 had approximately 20 reported accidents per year.

- The ratio of onsite labor and factory labor is: (changes usually depending upon the phase of the project).
The biggest single piece fabricated in the facility was a 36 feet tower, which was divided in three pieces of 12 feet height and lowest piece had bottom width of 16 feet by Company 1. Company 3 stated that the maximum size that they can fabricate was 16’x16’x72’.

In last 10 years Company 1 has delivered more than 100 projects involving prefabrication.

The amount of budget invested on machinery for prefab is approximately $500,000 for Company 1 and for Company 3 it was approximately $250,000.

Transportation costs vary based on the distance travelled and type of transportation, for example transporting any piece from Florida to California costs up to $4000 for Company 1 and transportation cost for Company 3 can be found in Table 4.1.
CHAPTER 5
RESULTS

Through the interview process, a real world perspective of the practices of prefab construction was determined from the companies. Each firm was different from every other firm and had various prefab usage. Prefab involvement in each project differs and feasibility of using prefab in each project depends on numerous factors. Next the three case studies are compared.

5.1 Permit Issues

Permit issues depend on the degree of prefabrication done on the building. Usually it is easy to incorporate prefabrication in small sections and modules. The companies which use the precast concrete or the bathroom modules have less chance of dealing with any permit issues. The permits and approval remains the same as traditional construction. The problem begins when you have a building which is completely built in a factory and has to be assembled on site. Mostly the construction of the building is regulated and permitted by the State agency as it is manufactured. But for placing onsite and for foundation the company has to get permits from the local county and it can be a stressful process sometime. There are some counties which are really hard to gain approval from.

Figure 5.1 explains the permitting process.
Transporting components has been the major issue since the beginning of this construction technique. The size limitation for the modules affects the maximum potential of construction manufacturing industry. The company 1 manufactures artistic prefab components which may vary in sizes. For transporting these manufactured component via trucks it costs about approximately $4000 from Orlando to Los Angeles. Hence if feasibility of the cost associated is sorted out then transporting a building on a longer route is costlier and even more so if it requires an escort.
Table 5-1 Transportation cost for shipping the module on-site

<table>
<thead>
<tr>
<th>Width (feet)</th>
<th>Length (feet)</th>
<th>Height (feet)</th>
<th>Cost of Transport* (dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Up to 70</td>
<td>Legal Height of 14.5</td>
<td>350 per 100 Mile</td>
</tr>
<tr>
<td>14</td>
<td>Up to 70</td>
<td>Legal Height of 14.5</td>
<td>500 per 100 Mile Includes Escort</td>
</tr>
<tr>
<td>16</td>
<td>Up to 70</td>
<td>Legal Height of 14.5</td>
<td>700 per 100 Mile Includes Escorts and Permits</td>
</tr>
<tr>
<td>12 to 16</td>
<td>Over 14.5</td>
<td></td>
<td>700 per 100 Mile Includes Escorts and Permits</td>
</tr>
</tbody>
</table>

*Cost data represents figures of February 2011, numbers might change as per fuel prices and time

Source: Company 3 Interview

Table 5-1 shows the shipment cost associated with the manufactured component depending on the size. Problems associated with transportation are:

- Installed fragile components might break during its journey to the destination.
- For bigger modules which requires escorts and permits the transport may be required to be done overnight.
- Longer distance results in increased cost which makes project unfeasible.

5.3 Prefab Perspective

When the manufactured home industry started, it was basically a quick and temporary method of construction. In last couple of decades the construction industry has been revolutionized by technology and new techniques, and also the modular industry. Still a majority of the population has a bad perspective towards the prefab industry. When prefabrication is done in the conventional construction for 15-20% there is less explanation to do and it saves time and labor. The problem is when a complete manufactured building is done. The stereotype of construction trailer and RV impacts its desirability.
In the case studies three different levels of user involvement in prefabrication were documented. A few factors analyzed from their perspective are shown in Figure 5-2. 

Figure 5-2 Comparative prefab perspectives of the companies

Figure 5-2 indicates that the more a company uses prefab, the more owners and subcontractors are familiar with prefabrication. The company which does traditional construction is more likely to work with people who know and want to construct building with conventional method. Vice versa, the company which does almost every project prefab will work with owner and subcontractor who have good idea of prefabrication. The companies were asked to rate the factors influencing the implementation of the prefabrication into the project (0-least and 10-most affecting) as shown in Figure 5-3.
5.4 Crane Operations

This aspect mostly deals with the volumetric units which are prefabricated. On the job site some conditions prevail like weather, wind and rainfall. Also the height of the structure, skill of the operator, the crew on site giving directions to the operator, type of crane used etc. are influential factors in assembly of the modules. Sometimes there are delicate pieces like mirrors and furnished electronics in the module which needs more care that the regular modules. Tolerance for modules to set can be as low as 1/8th of an inch, hence precision in design and placement cannot be ignored. The crane operator must be educated enough or should have taken training on placing modules to be free of errors and deliver the assembly effectively. A 3D model of the possible location of the crane should be developed and most productive path should be noticed. Also simulating a 4D model can depict any conflicts in the operational path of the crane and the volumetric module.
5.5 BIM Involvement

BIM in conventional construction has become an integrated part and is used from small scale projects to large scale. A set of standards and programs are available for BIM development and integrating into a project. Often the general contractors has no trouble using a program like Revit, Primavera or Tekla into their projects which also helps in scheduling and estimating. The prefabrication industry is still struggling in this scenario.

Company 2, which does all the work onsite and subcontracts the work of prefabrication and uses BIM as described previously. But the companies which have their own manufacturing unit and those who design the prefab modules or panels need an upgrade in BIM. Company 3 used AutoCAD as the only tool and Company 1 was starting to use Revit as a design tool but was not completely dependent on it. Both of the companies suggested that usage of BIM tools such as Revit was also subjected to the recommendation of the owner. The need is for a set of programs and standards for BIM in prefab/modular buildings and then to provide education and training and then commercialize the program amongst the manufacturing construction industry. Figure 5-4 shows BIM usage in the case studies:
5.6 Robotics and CNC

Robotics use in construction is fairly a new concept. This methodology of construction has yet lot be explored. Few advancements have been made into using machinery by itself for construction with just programing it and providing the materials. All the research and practices which have been done are at a lower scale and they are yet to be used in actual construction practices.

Whereas CNC is currently used by many manufacturers and two of the companies interviewed use CNC machines in their projects. The author attended the seminar of precast concrete company and the engineer confirmed the use of CNC in their projects. Hot wire machines and rebar benders were other equipment that was used by Company 1. Also companies use a 3D foam cutter to provide a base for GFRC and they also use a manually operated hoist to move and hold the modules.
5.7 Prefab Skilled Labor

The labor for manufacturing industry is not the same as traditional construction. They need to work on different set of drawings, different machinery and different coordination. There is a shortage of such labor and it is hard to find someone with such set of skills and training. The companies which work with precast concrete and detailed prefabricated components have workers experienced enough to perform that work precisely and quickly. There should be a proper coursework or training for the off-site construction workers, which would help in increasing their numbers and also the capability of off-site construction industry.

5.8 Miscellaneous Factors

Other factors which influence prefabrication are:

- Inability to make further changes on-site
- Less familiarity of Architects with prefab
- Necessity of set standards for prefabrication in conventional construction.
- Area where the manufacturing factory is located, it has limitation of serving to specific locality.
- Limited data availability for prefab/modular buildings, as such conventional construction has RS means and other vast database
CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

6.1 Future of Semi Modular Structures

When a building is completely prefabricated it offers many benefits but some constrains hold back the potential for the same. Recently, many general contractors have started to incorporate prefabrication into their projects. The benefits include comparatively less labor cost, controlled weather, better quality, schedule benefits etc.

In this method, time benefits can be achieved as the foundation is poured and it needs 28 days for curing and in that time frame components can be manufactured in the factory. Let us assume that the first floor is done by conventional methods, the second floor components which were manufactured earlier can be simply attached to the first floor thus offering some time savings. For commercial and educational buildings time savings is a big thing as quick turnaround is equal to quick revenue.

Company 3 is actually planning to build a bank with semi modular technique. The company contacted a traditional builder and they met with an architect on designing for this collaborative technique of construction. The proposal was for designing the modular blocks and then the transporting them on site to assemble and then the on-site contractor can place the ceiling with slab for second floor on top of the assembled module. Various constrains that were pointed out were:

- The height from floor to floor was greater than 15 feet. Hence the transportation limitation was an issue, so they had other way around.
- The architect needed to step out of the comfort zone and design this building for this combined effort.
- Also the manufacturer is taking the risk to build something different than regular modular building and yes it involves more risk.
6.2 Automation and BIM – Possibilities in Prefabrication?

BIM still has potential in the prefabrication industry which is to be explored. The current practices worldwide in small scale are done by few people or researcher. A complete model for modular and prefab industry must be proposed which has programs that features properties and information related to prefabrication and then assembly. For traditional construction Revit is considered as the most powerful and practiced software that is used worldwide as a BIM tool. Off-site construction needs such a tool that is specific to prefabrication and can integrate other information such as scheduling and on-site assembly. For current practices, the majority of prefabrication is dependent on AutoCAD for drawings and information exchange.

The effort must be to provide increased information with the usage of 3D technology and facilitate the precise and effective practice of modular construction. Hence, production effective policy and advanced technology must be integrated into modular construction. To this extent to which overall implementation of BIM in offsite fabrication makes the scope of the project more precise by modeling the details and picking minor conflicts that cannot be detected by plans and 2D drawings. The goal must be to develop a list of work to be done so that the people involved in delivering the task can have confidence and a blueprint of the activity and deliver it efficiently.

6.3 Global Consciousness of Prefab

The economy has raised the magnitude of modular buildings. Also for some owners who understand the potential of prefabrication and want to save time, prefer off-site construction. Also the global green initiative has led to buildings producing less waste. Off-site construction has shown that it can reduce waste and produce better quality.
For the public, the stereotype of trailer and portable classrooms is still in play. But recently social media and television has played an important roles in spreading awareness of prefabricated buildings. In the midst, rapid growth of prefabricated buildings in many countries across Europe and Asia especially China has somewhat displayed the capability of prefabrication industry.

6.4 Practical Analysis of Industry Prefab Usage: Drawbacks and Positives

Fewer conflicts in the schedule of work crew. Minimized requirement for on-site storage of the materials, hence fewer losses or theft of materials. Reduced workers on-site danger when fabricated components are hoisted and just placed in place using cranes. Moreover Union labor charges are very high rate if compared to the labor prefabrication off-site.

Prefabrication can save time as the construction schedule shrinks considerably which has been proven. Research suggest that prefab may not be much cheaper when compared to the conventional construction but it can save a big amount of time and finish the project earlier. There are many positives that prefabrication offers but total prefabricated components still remained questioned as to adopt it over traditional construction or not?

The conclusion of the author would be that the conventional construction should collaborate with prefabrication as much as it can and construction should be done on the basis of trustworthiness and technique which saves time and money and delivers better quality product. Contractors should be encouraged to adopt prefabrication, long-term benefits must be explained and the prefabrication industry must utilize new BIM tools for possible increase in productivity and enhanced information sharing.
6.5 Recommendation for Further Research

- Further research must be done in developing a BIM tool/program specific to construction prefabrication (start to finish) and evaluate the productivity and other advantages.
- Large scale survey must be done on prefabrication industry specifically and analyzing the perspective of company and its future expectation.
LIST OF REFERENCES


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BIOGRAPHICAL SKETCH

Amandeep Sekhon earned his master's (MSCM) degree from the M. E. Rinker, Sr. School of Construction Management at the University of Florida. He finished his undergrad in civil engineering. During his masters he worked as a research assistant on a Hinkley Center project for Solar Landfill. He also worked as a BIM research assistant on a project for Florida Building Commission.

Amandeep's research interest are related to modular construction, prefabrication, collaboration of prefab and conventional construction, Building Information Modeling and its implementation in modular industry. Solar energy and sustainability are other fields that also peak his curiosity.