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Research Paper

Analyzing Methods of Prefabrication and their Application in the Construction of Habitat for Humanity Housing

Sabrina Senninger[1], Tamer Breakah[2]
[1]*(Department of Architecture Ball State University)*
[2]*(Department of Construction Management and Interior Design, Ball State University)*
Corresponding Author: Tamer Breakah

ABSTRACT: *This study presents an analysis of the cost, benefits and challenges of prefabricated construction methods: panelized and modular, and tectonic construction systems: advanced framing, extended plate and beam, double stud, structurally insulated panels (SIPs), and cross laminated timber panels (CLT). The main goal of this analysis is to provide a framework on how to select a panelized or modular prefabrication system and subsequent tectonic construction method for the construction of a Habitat for Humanity house.*
KEYWORDS: *Structurally Insulated Panels (SIPs), Tectonic Construction Systems, Cross Laminated Timber Panels (CLT), Habitat for Humanity*

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I. INTRODUCTION

The homebuilding industry has traditionally utilized stick building methods, with minimal evolution in construction methods. The technological evolution throughout other industries begs the question on how the homebuilding industry can adapt and evolve with the technological advancements. In varying levels of exploration over the years, prefabrication is viewed as a construction method for the future of the industry due to its construction benefits and environmental impacts. The benefits typically associated with prefabrication include increased speed of construction, material efficiency, improved quality, improved worker safety, and the minimized environmental impacts in the construction process.According to Hoover et al. (2017), prefabrication is reported to be inefficient by more than 50% of the contractor and they recommended to have further development in that field. Prefabrication can cut down the project delivery time as most of the work is done in a factory and the site work becomes uniform. The output quality is improved and the waste is reduced by the reduction of mistakes and enhanced productivity (Fishking2011).As an example of the benefits of panelized construction, Cross Laminated Timber (CLT) panels can be used in conjunction precision cutting techniques that can implement digital design. The use of these systems can reduce the construction duration by more than 50% (Lehman 2013). They do not only compete with timber construction, but they also compete with other building materials (Brendner et al. 2016). Prefabricating in factories and then transporting to construction sites lead to less waste generation, time and cost reduction (Akok and Prakask 2017).

Prefabrication methods in construction can be categorized into components, panelized, modular, and hybrids. Panelized prefabrication utilizes wall/floor/roof panels that are manufactured in a controlled facility and transported to the site where they are installed on the foundation. This method of construction requires the remaining exterior and interior fit out to be completed with conventional construction methods and materials. Whereas modular prefabrication consists of module sections of the building that are manufactured in a controlled facility and transported to the site where they are installed on the foundation and connected. This method of construction typically requires minimal exterior and interior fit out since the modules are typically constructed to 90% completion.

In this analysis of prefabricated construction methods, the focus is placed on panelized and modular prefabrication methods. The study compares the advantages and disadvantages of different prefabrication methods. The study then presents a proposed houses for use by Habitat for Humanity and analyzes the benefit of using prefabrication for such houses.

II. BENEFITS AND CHALLENGES OF PANELIZED AND MODULAR PREFABRICATION

There is a distinct set of benefits in selecting panelized and modular prefabrication over conventional stick-built construction, which include increased speed of construction, material efficiency, improved quality, improved worker safety, and minimized environmental impacts. However, how do the benefits and challenges of panelized and modular prefabrication compare? Table 1 summarizes the benefits and challenges of panelized and modular prefabrication.

Table 1: The Benefits and Challenges of Panelized and Modular Prefabrication

	Benefits	Challenges
Panelized	Lean Construction Environmental Impact Reduced Waste Schedule Transportation Equipment and Machinery	Quality Control On-Site Work More Trades On-Site
Modular	Lean Construction Environmental Impact Reduces Waste Schedule Quality Control On-Site Work Fewer Trades On-Site Cost Effective	Transportation Equipment and Machinery Additional Materials

A. Benefits Shared by Panelized and Modular Prefabrication

The benefits shared by panelized and modular prefabrication methods include lean construction, environmental impact, reduced waste, and schedule. While these benefits are shared by both prefabrication methods, there are differences in the benefits between the two prefabrication methods. The following part will discuss the details of each of these benefits.

1) Lean Construction

Both panelized and modular construction methods benefit from lean principles which “focuses on removing waste from construction processes to make them more efficient**”** (Nahmens and Ikuma 2012). The integration of lean principles in the construction of prefabricated homes will be beneficial when it comes to sustainability. It provides environmental, economic and social sustainability. Environmental sustainability is due to the seduction of the solid waste amounts from residential construction that will be deposited in landfills. The economic sustainability aspect appears in the improved productivity of the construction operations. Finally, the improved safety and health of workers is considered social sustainability. (Nahmens and Ikuma 2012).

2) Environmental Impact

The utilization of prefabrication construction methods leads to the lessening of construction’s environmental impact. While both panelized and modular construction contribute to a reduced impact, the level of impact is different for each construction method. It has already been examined that onsite construction has 20 percent to 70 percent higher impacts than modular construction. Use of energy in the factory and onsite are the main drivers of impacts. On average, for all environmental impact categories, fewer impacts are caused by modular construction as compared to onsite construction (Smith and Quale 2017).

3) Reduced Waste

The lessening of environmental impacts by both panelized and modular prefabrication also extends to the reduction of construction waste. The waste reduction from prefabrication has been confirmed by the National Association of Homebuilder’s (NAHB) green building guidelines which include the use of prefabricated components in their rating system as an approach to reduce the quantity of materials and waste. In the materials category, the use of modular construction for the entire house is rated the highest (Nahmens and Ikuma 2012). The inclusion of prefabrication methods within the rating system illustrates how they are viewed as a method of incrementally reducing construction waste in which panelized is a first step, and modular above that. The waste reduction stems from the amount of construction conducted off-site since off-site prefabrication has reduced waste due to the reduction in the construction time and the time required on-site, which leads to less damage to the home site and environment surrounding it (Nahmens and Ikuma 2012).

4) Schedule

Prefabrication, both panelized and modular, brings about a quickened schedule from the overlap of on-site and off-site construction activities, in addition to quicker construction due to off-site prefabrication methods. In the specific case of modular prefabrication, the quickened schedule occurs since the modules can be manufactured in parallel with the site and foundation preparation not after them. Modular construction reduces construction times by 30 percent to 50 percent (Quale el al. 2012).

B. Benefits of Panelized Prefabrication

While there are the shared prefabrication benefits, those specific to panelized construction include transportation, and equipment and machinery.

1) Transportation

Transportation is typically seen as a restriction for prefabrication methods, however panelized prefabrication lends itself to benefit in transportation more than modular construction. Prefabricated panels can be stacked and fit in smaller trucks due to the construction of the panels and their light weight and flat square configuration (Lopez and Froez 2016). This configuration of the prefabricated panels helps in achieving an optimized and efficient transportation method. Additionally, in the transportation of prefabricated panels, the panels can be stacked and placed securely, tightened and strapped to a flatbed truck. This prevents the movement of the panels leading to little to no damage in the panels (Lopez and Froez 2016).

2) Equipment and machinery

In addition to the simplified transportation of prefabricated panels, this also brings benefits in regards to construction equipment and machinery. Due to the panel size and construction, smaller equipment can be used to install them. These equipment are easier to transport, such as a telehandler forklift or zoom boom (Lopez 2016). The ability for installation with smaller equipment simplifies the construction process since the equipment previously mentioned is quite typically utilized on a construction site.

C. Benefits of Modular Prefabrication

While there are the shared prefabrication benefits, those specific to modular construction include quality control, on-site work, fewer trades, and cost effective.

1) Quality Control

While prefabrication in general makes steps towards construction quality control, it is mainly beneficial in modular prefabrication. The level of quality control for modular construction is available due to the offsite construction in which the modules are manufactured and prepared in a controlled environment in a centralized location in a manufacturing facility. This leads to better quality control practices which in turn helps in achieving higher than average quality (Lopez 2016).

2) On-Site Work

While prefabrication in general reduces the amount of on-site construction, it is mainly of benefit in modular prefabrication. The level of on-site work in modular prefabrication is significantly lower since modules arrive on-site at 90 to 95% completion, and the main site activities are installation using a crane then fastening them together. This requires a few workers for a few days (Lopez 2016).

3) Fewer Trades On-Site

As a result of less on-site work from modular prefabrication, an additional benefit is that fewer trades are required on-site. This is in part due to the fact that modules arrive at 90 to 95% completion and so when they do arrive on site connecting the modules requires the involvement of fewer trades. Also, there is a reduction in the in the amount of work needed and the time spent on-site. During the connection of the modules, there is a need for a general contractor in addition to electricians and plumbers in order to connect the systems between the modules and to connect to municipal utilities (Lopez 2016).

4) Cost Effective

All of the benefits so far have led to the cost effectiveness of modular prefabrication compared to panelized prefabrication in which modular construction method is considered to be marginally more cost effective. The estimated cost difference is approximately 11% (Lopez 2016). Additionally, the cost effectiveness of modular prefabrication is also due to the economy of scale in which companies producing the modules can achieve more economic cost when they order materials in bulk, produce modules in parallel and reduce material and machinery transportation (Quale et al. 2012).

II. CHALLENGES OF PREFABRICATION

While there are numerous benefits to prefabricated construction methods, there are challenges faced when comparing panelized and modular prefabrication. Panelized prefabrication compared to modular prefabrication is challenged in the areas of quality control, quantity of on-site work, and more trades on-site. Modular prefabrication compared to panelized prefabrication is challenged in the areas of transportation, equipment and machinery, and additional materials.

A. Transportation Restrictions for Prefabricated Construction Methods

1) Transportation Cost

To be practical and cost effective, travel distance for prefabricated construction elements is limited to150 to 200 mile range from the factory. Another challenge for transportation is the suitable truck types suitable for use in transporting, which can significantly vary the cost. The suitable trucks, arranged from the least to the most expensive are Flatbed, Box Trailer Flatbed, Single-Drop Deck and Double-Drop Deck.

2) Trucking Regulations

Truck regulations are divided into federal and state regulations. The federal requirements are set by the Federal Highway Administration (FHWA) and the state requirements vary by state. The Federal Size Regulations for Commercial Motor Vehicles (FHWA 2004) limits the truck width to 8'-6" and if the width of the truck exceeds this value, it must issue a special over-width permit. For the state of Michigan, where the selected Habitat for Humanity case is presented, the following are the maximum legal truck dimensions (MDOT 2019):

Width: 8'-6"
Height: 13'-6"
Body Length: 53'
Overall Length: Normally 65' and goes up to 75' with a commercial driver's license.

B. Challenges of Panelized Prefabrication

1) Quality Control

The higher level of quality control is a typical benefit in prefabrication, however in panelized prefabrication it is more difficult to attain the level of quality control found in modular prefabrication. This challenge in panelized prefabrication is because this construction method only prefabricates panels (floor, wall, roof, etc.) in a controlled facility whereas the other building components like electromechanical systems, dry walls, and others, which would influence the control of quality (Lopez 2016).

2) On-Site Work

Panelized prefabrication takes a portion of construction work off-site, however in comparison to modular prefabrication, the challenge lies in that much construction is left to be completed on-site. Panelized prefabrication requires the dedication of more time and work on-site to finalize to the work in the interiors, which includes drywalls, appliances and cabinets (Lopez 2016).

3) More Trades On-Sites

The previous challenges of quality control and on-site work outline that these challenges come about from the greater amount of on-site construction in the panelized prefabrication method compared to modular prefabrication. In turn, more on-site construction also means more trades are required for on-site construction. The trades on-site for panelized prefabrication include a general contractor, electricians, plumbers, and may also need carpenters, dry wall installers and painters. All these trades and others are required in order to completely install and connect the systems in the house and to finish the interiors. This needs longer time and more workers in each trade (Lopez 2016).

C. Challenges of Modular Prefabrication

1) Transportation

In prefabrication methods, transportation is more favorable for panelized prefabrication compared to modular prefabrication due to the construction method. The challenge of transportation for modular prefabrication is because the size of prefabricated modules calls for the use of larger trucks. In addition, a truck can transport a maximum of one or two modules leading to a large number of trucks going to the construction site (Lopez 2016). Additionally, since modules are transported at 90 to 95% completion, the transportation of these modules, there will be some space in between that reduces the efficiency of the transportation process (Nahmens and Ikuma 2012).

2) Equipment and Machinery

Just as modular prefabrication requires larger trucks for transportation of the modules, the requirement for larger equipment and machinery extends to when the module arrives on-site and need to be installed. Due to the large size of the modules, the installation of prefabricated modules needs a larger crane because the modules are much bigger and more complicated to handle. The need for large trucks and large equipment to move the modules is a complicated issue if the access to the site is narrow or difficult (Lopez 2016).

3) Additional Materials

Due to the transportation and the connecting placement of modules, modular prefabrication leads to additional materials being utilized in the construction. Since prefabricated modules are transported at 90 to 95% completion, it is necessary for the modules to be built not only to typical building structural requirements, but also to withstand the transportation process as not to become damaged in transit. The necessity for structural integrity adds additional materials at the joining module walls in which there is an additional 25% in the mass of the wood in the buildings needed for the marriage walls that are required to transport and join the modules (Quale et al. 2012).

III. PREFABRICATION METHODS SUMMARY

Each of the three prefabrication methods - panelized, hybrid, and modular - have their strengths and challenges compared to each other and to conventional stick frame construction. A summary of the comparison is presented in Table 2.

Table 2: Evaluation of Prefabrication Methods

	Stick Framed	Panelized	Hybrid	Modular
Cost	$	$$	$$	$$
Speed of Construction	*	**	***	****
Quality Control	*	**	***	****
Worker Safety	*	**	***	****
Maximized Off-Site Construction	*	**	***	****
Transport Efficiency	*	****	***	**
Minimized Equipment/ Machinery	****	***	**	*
Reduced Waste (Material / Labor)	*	**	***	****

Poor ***** to Excellent ********

IV. TECTONIC SYSTEMS

In both panelized and modular prefabrication there are a variety of methods to approach the tectonic system construction, this leaves a range of options to meet the structural requirements, energy performance, and workforce capability. The tectonic systems analyzed within this discussion include: Extended Plate and Beam, Double Stud, SIPS (Structurally Insulated Panels), and CLT (Cross Laminated Timber Panels). A summary of the benefits and challenges of tectonic systems is presented in Table 3.

Table 3: The Benefits and Challenges of Tectonic Systems

	Prefabrication Method	Benefits	Challenges
Extended Plate & Beam	Panelized Modular Hybrid	Less Framing Simplified Construction Incorporates Insulation Flexibility Reduces Waste Minimal Thermal Bridging	More Planning Plan for Overlap at Connections Requires Longer Nails
Double Stud	Panelized Modular Hybrid	High Insulation Value Minimal Thermal Bridging	Custom Frames at Penetrations More Materials Requires Fire Blocking Moisture Risk
SIPS: Structurally Insulated Panel System	Panelized Modular Hybrid	Stronger More Fire Resistive High Insulation Value	Size Constraints Careful Planning for Penetrations Moisture Risk EPS Insulation
CLT Panels: Cross Laminated Timber	Panelized Modular Hybrid	Can be Thermal Mass Minimal Thermal Bridging Reduces Waste	Size Constraints Careful Planning Future Inflexibility if Used for Interior Walls

Table 4: Evaluation of Tectonic Systems

	Extended Plate & Beam	Double Stud	SIPS Structurally Insulated Panels	CLT Cross Laminated Timber
Cost	$	$	$$	$$
Design Flexibility	****	***	**	**
Speed of Construction	**	*	****	****
Energy Performance	**	****	****	****
Sustainable Materials	****	***	*	****
Construction by Unskilled Labor	****	***	*	***

Poor ***** to Excellent ********

V. EXPLORING THE CONSTRUCTION OF HABITAT FOR HUMANITY HOUSING

Habitat for Humanity has constructed affordable housing and built up communities across the world since the organization's establishment in 1976. Over these forty-three years, the construction of Habitat houses has utilized the traditional method of conventional stick framing. In recent years, several Habitat affiliates have adjusted their construction methods to include prefabrication and alternative tectonic systems in place of conventional stick framing. The need now is to affordably advance construction methods – prefabrication methods and tectonic systems – to increase their utilization in Habitat for Humanity housing.

A. Habitat for Humanity Housing Prototype

The prefabricated housing prototype for Habitat for Humanity is designed as an adaptable housing solution that utilizes a kit of parts to offer affordable personalization opportunities. Each prototype includes the programmatic spaces of bedrooms, bathrooms, kitchen, dining room, living room, flex space, and an unfinished basement. The proposed prototype illustrated below is a base scenario with four bedrooms and two bathrooms located in Grand Rapids, Michigan. The floor plans and the building section of the prototype are presented in Figures 1 and 2 respectively.

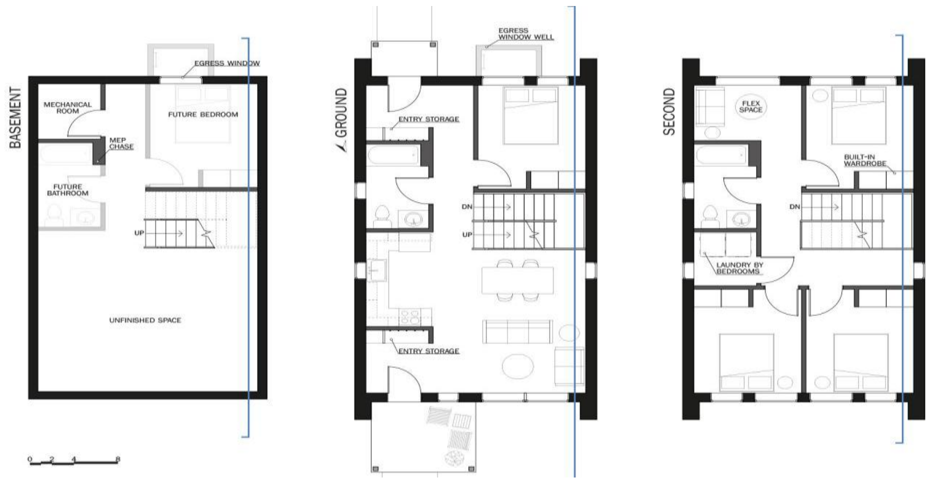

Figure 1: Prototype Floor Plans

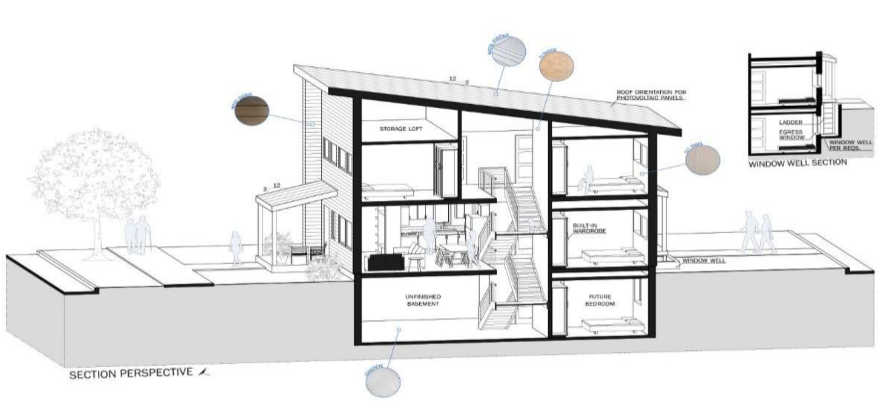

Figure 2: Prototype Building Section

B. Prototype Construction Method: CLT Panels

Based on the research and potential opportunities within the explored prefabrication methods and tectonic systems, the proposed Habitat prototype uses the panelized prefabrication method with a combination of cross laminated timber (CLT) panels and stick framed panels. The CLT panels make up the exterior enclosure and structure - exterior walls, floors, and roof - while the stick framed panels are utilized for the interior partitions.

Currently in the United States, CLT panel factories are mainly located in the Northeast and Northwest regions which are softwood rich locations. However, there is an opportunity in the Midwest's hardwood rich locations of Michigan and Indiana to create a regional hardwood CLT industry. Hardwoods are known to have better strength, consume less space and have better durability as compared to softwoods. Figure 3 Presents the CLT manufacturing locations and the suggested zone that can be served by a regional prefabrication facility.

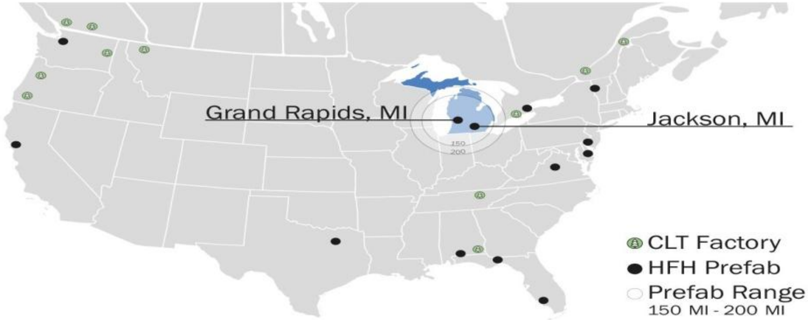

Figure 3: Prefabrication Locations Across the Nation

VI. COMPARISON OF CONVENTIONAL STICK FRAMING AND CLT PANELS

The goal of the proposed Habitat prototype is to affordably advance the house's construction methods – prefabrication methods and tectonic system. To understand if the proposed Habitat prototype achieves this goal, a comparison between conventional stick framing and prefabricated panels is conducted.

A. Comparison of Traditionally Built Habitat for Humanity Housing and the Proposed Habitat Prototype

For the purpose of this comparison, calculations include the prototype's building construction method from the ground floor up, as the unfinished basement's construction is identical in both the traditionally built and prefabricated panel scenarios. The quantity take off results are presented in Table 4.

Table 4: Quantities Take Off for the Comparison Items

Take-off Item	Unit	Quantity
Ext Walls	L FT	120'
	SQ FT	2,340
Int Walls	L FT	Floor 1 - 61' Floor 2 - 94'
	SQ FT	Floor 1 - 580 2 - 781
Floor (2)	SQ FT	1,272
Roof	SQ FT	1,105

According to the Habitat for Humanity of Kent County, Michigan, using a crew of 17 volunteers and 5 staff members, 56 panels were installed in 7.5hours. This means that it took them an average of 8 minutes per panel. Each wall in that project was composed of two panels (Habitat for Humanity 2019). The cost of CLT ranges from $48-56/square foot (CRSI 2018), which is about 40% higher than that of traditional stick framed construction. If this percentage is divided by the overall project cost, it will be much less.

The major advantage of CLT construction is that the whole house can be erected in one work day. This indicates that there is less need for volunteers and staff members to do the job. If the idea is implemented, having typical prototypes will lead to mass production of similar sized CLT's and this will reduce the cost of production significantly due to the economy of scale.

VII. CONCLUSION

This study presented a comparison between different prefabrication techniques and then typical prototype were proposed for implementation in Habitat for Humanity projects. It is proposed that these houses be constructed using prefabricated techniques and that this technology be implemented in habitat for humanity projects. According to the presented analysis, he following can be concluded:

- Prefabrication has the advantage of fast construction and less site work. It also provides better quality products.
- There are still some challenges for prefabrication that limits its use.
- It is proposed to use prefabrication in habitat locations near prefabrication locations or have prefabrication facilities constructed to serve neighboring habitat for humanity projects.
- There is some increase in cost that shows in the use of prefabricated elements but this cost is overweighed by a significant reduction in construction time, which means lower need for volunteers.
- Having standard prototypes will lead to standardizing the manufacturing of the prefabricated elements and this will lead to a significant cost reduction.

REFERENCES

[1]. Akok, J.Y.and O. Prakask,Modular Construction Technique. Journal of Engineerng Sciences and Research, 2017. **6**(3): p. 207–209.

[2]. Brandner, R., G.Flatscher, A. Ringhofer, G. Schickhofer and A. Thiel, Cross laminated timber (CLT): overview and development. European Journal of Wood and Wood Products, 2016. **74**(3): p.331-351.

[3]. Concrete Reinforcing Steel Institute – CRSI, Cost Comparison of Cross Laminated Timber (CLT) and Cast-in-place Reinforced Concrete Structures. CRSI Technical Note ETND-5-18, 2018. Schaumburg, Illinois, 4 pp.

[4]. Federal Highway Administration -FHWA, Federal Size Regulations for Commercial Motor Vehicles, 2004.

[5]. Fishking, T., Integrating BIM and prefabrication in healthcare facility design. 27th Annual AHCA Seminar and 49th Annual FHEA Meeting and Tradeshow, 2011.

[6]. Habitat for Humanity Kent County: Panel Set Timelapse. Available at: https:// www.youtube.com/ watch?v=tT4X5gtF40o&fbclid=IwAR0QvLQ09BH9lc1oMkcgl_-rniOjmZYItUILPxgfffAsH_-mp2YbQq5tKHo(Accessed September 10,2019).

[7]. Lehmann, S., Low carbon construction systems using prefabricated engineered solid wood panels for urban infill to significantly reduce greenhouse gas emissions. Sustainable Cities and Society, 2013. **6**: p. 57-67.

[8]. Lopez, D., andT. M. Froese, Analysis of Costs and Benefits of Panelized and Modular Prefabricated Homes. Procedia Engineering, 2016. **145**: p. 1291-1297.

[9]. Michigan Department of Transportation – MDOT, Maximum Legal Truck loadings and Dimensions. Available at: https://mdotcf.state.mi.us/public/webforms/public/T-1.pdf (Accessd September 15, 2019).

[10]. Nahmens, I. and L.H. Ikuma, Effects of Lean Construction on Sustainability of Modular Homebuilding. Journal of Architectural Engineering, 2012. **18**(2): p. 155-163.

[11]. Quale, J., M.J. Eckelman, K.W. Williams, G. Sloditskie and J.B, Zimmerman, Construction Matters: Comparing Environmental Impacts of Building Modular and Conventional Homes in the United States. Journal of Industrial Ecology, 2012. **16**(2), p. 243-253.

[12]. Smith, R. E. and J.D. Quale,Offsite Architecture: Constructing the Future. London: Routledge Taylor & Francis Group, 2017.

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