A Case Study Comparing Panelization and Modularization Construction Methods

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Construction industry is notoriously inefficient industry with a lot of room for improvement. Construction companies are constantly looking to increase their efficiency. NCC Finland decided to explore the method of modular construction as part of the efforts to increase production. NCC also happened to build a similarly sized project with the more traditional method of panelization and tilt-up construction. This Case study explores the experience of NCC as the general contractor of both projects. The aim is to understand the differences of the challenges and benefits experienced by the team from NCC. The findings show that Modular construction offers wide potential for faster and more streamlined experiences that reduce the risk taken by the general contractor in the form of less on-site construction, higher reliance on external pricing, and more predictable construction times. However, at the same time it implements more difficult logistics, less flexible designs, and longer lead times. Overall, the superintendent for the project gives modular construction good reviews while also recognizing that it has not yet reached full maturity and will require more experience from his part to fully utilize the full benefits that modular construction has to offer.

Key Words: Modularization, Panelization, Timber, Case Study, Effciency

Introduction

The housing market has changed drastically in the past half a century. The average home price in the US has increased tenfold (Folger, 2021) since 1975, whereas inflation has only been about half of that. Housing in specific areas like San Luis Obispo has skyrocketed in value. There is a need for more affordable housing solutions to combat the rising demand for housing, especially in communities with limited land resources.

Prefabricated construction has been gaining popularity in the construction industry. Nabi and El-Adaway state in their research that the construction industry is expected to grow 5.7% by 2024 whereas modular construction is expected to grow 8.16% during the same timeframe (Abdul Nabi & El-Adaway, 2021). Previously prefabrication in Finland has been limited to panelization (see figure 1)

which in this paper refers to single sheet panels that can form a wall, floor, or a ceiling, however, they are limited to 2D objects. Recently a newer method of prefabricated construction is gaining momentum. Modularization (see figure 2) refers to 3D modules that are substantial in size and are finished to the most feasible extent in both interiors and exterior finishes, as well as any fixed furniture.

Modularization has a lot of theoretical benefits. Finnish research by the Tampere University of Technology writes about modular construction "In comparison to traditional construction, modular construction has benefits. In factory conditions, the process is protected from rain, snowfall, and temperature-related issues. When 85% of the construction process is transported into factory conditions, the site will experience measurably less noise, pollution, and waste, when compared to traditional methods of construction." (Kotilainen, 2013). In addition, she states that modular construction can reduce construction times by 30 to 50%. However, as it is with any new technological advancement, there is relatively little data when compared to tried-and-true methods. Therefore, it is important to consider the experience of the contractor and understand potential improvements and obstacles that must be overcome for modularization to become more widespread.

Nordic Construction Company Finland (NCC FI) Recently built two projects as part of the Linnaflätti development in Turku, Finland. The first project named Puulinna was built 2016-2018 using the panelization method and took 18=6 months to complete after brownfield clearing. It is a two-building 94 apartment unit project. The project also included a 55-spot subgrade parking garage. The second project with the name Puubyygeli was built 2018-2020 in only 11 months after similar brownfield conditions were cleared. Both times are on-site construction. Puubyygeli project used modularization. It is a two-building 70 apartment unit project. This project only included external parking and did not have any subgrade construction apart from the foundation.

An interview with the superintendent (Seppo Kalliola) will be conducted to explore the differences in the overall project performance, issues, and benefits from the view of modularization. Both supply chain and site logistics will be considered, and the evaluation will be made from the general contractor or construction management standpoint. The interview will be semi-structured.

Literature Review

Both panelization and modularization use factories to build their prefabricated parts, however, panels can be packed side by side onto a truck, whereas modularization requires more complex supply chains. (Hsu et. Al. 2019) investigated the possibility of creating a mathematical model for considering the supply chains of modular construction in London, a busy city with small cities. The study considered factors such as factory production rates, factory storage capabilities, temporary storage site options, on-site storage capabilities, weather conditions, etc. Important points brought out by their study consider the different costs of different facilities and different distances from the factory to warehouse and from warehouse to the site. The research shows that "Z1 (warehouse 1) was chosen as it produces the arrangement with the lowest cost value…Z1 is closest to the site and therefore is associated with least probability of delivery delays. On the other hand, it has the least capacity and the highest establishment cost. Nevertheless, our analysis indicates that a distance reduction between the construction site and the warehouse can reduce the probability of delivery delays, in turn reducing idleness in the assembly process and higher overall construction efficiency" (Hsu et. al. 2019). This shows that cost on paper isn't always accurate, and it is important to consider the overall project efficiency. However, supply chains are just a part of the risk factors related to construction.

Abdul Nabi & El-Adaway in their research investigating the top risk factors associated with modular construction started with a wide list of 50 different factors and narrowed it down with the help of surveys to find the most relevant factors. The survey measured two different aspects of the risk factors: Likelihood of occurrence, and impact on performance. The study took the 10 highest rated items from each of the two categories and overlapped them to find 7 that held in both aspects. The risk categories are shortage of skilled labor, late design changes, poor site logistics, unsuitable designs, contractual disputes, lack of collaboration, tight tolerances, and poor activity sequencing. Abdul Nabi and El-Adaway bring out valid points of modular construction, however, the survey alone fails to draw comparisons to different types of construction. Many of the risk factors chosen could affect any type of construction especially since the survey was conducted with a number scale and not a free-response answer.

Fire protection is essential in any type of construction; however, timber construction brings out new challenges and in some areas, the fire protection requirements can be harsh. Jouni Björkman talks about performance-based fire safety design. He mentions that "…in large scale timber projects, fulfilling the traditional code requirements for fire safety might have risen as a problem." (Hynynen et al. 2015) He brings out an example that in the current code regulations in Finland, building over 8 stories with timber is impossible. He mentions that "we are used thinking that timber houses are unsafe against fire and that concrete houses are stronger." (Hynynen et al. 2015) However, he does bring out a point that "Long before heat and flames cause injuries or death, the smoke has already killed anyone inside." (Hynynen et al. 2015). He also talks about the loads that materials can handle in the case of a fire. Even though fire spreads more easily on wooden surfaces, the wood has a tendency to char can protect the core and make it surprisingly strong in the case of a fire. Steel on the other hand gives out at just 500 degrees centigrade. The solution he mentions for the problem of the fire spreading comes in two parts, naked wood surfaces can be covered with drywall for example, and sprinkler systems can be installed to slow down the further spread. The points brought out in Bjorkman's article, can be found in both projects examined in this case study.

Research Methodology

It is rare to come across two projects that are so similar in so many aspects yet have one distinct difference in the methodology. A case study is a method chosen to evaluate the two projects from the view of the general contractor. In many other forms of research, it is difficult to reduce variables to the point that can be done with the projects chosen. An interview with the Seppo Kalliola was conducted. Kalliola has the equivalent role of a superintendent when considering his responsibilities. Notable is that the responsibilities of staffing in Finnish construction companies may not fully resemble the responsibilities in the United States.

The purpose of the interview was to get the best possible picture of the experiences had by the superintendent and in this way the general contractor. The purpose of this study is the need to get the actual experiences of the general contractor, not what could be theoretically concluded by analyzing previous research. This way we can investigate what the general contractors can expect to experience in Finland in either delivery method and bring out points of emphasis that a general contractor should pay attention to when doing panelization or modularization.

The interview was semi-structured to keep it on-topic questions were formulated based on the literature review and additional talking points were added according to the responses. The interview was conducted virtually in Finnish and recorded for accuracy. The responses were then translated for the parts referenced in this paper. The question started with general information on each project to double-check data that could be found online and to get a better overall picture of both projects. The

questions were then aimed more precisely towards each project with more emphasis being on the modular project. Panelization in concrete is very common in Finland and even though timber is a new material for multi-story construction it shares more characteristics of the more known methods of construction, hence the emphasis was put on modularization. At the end of the interview, Kalliola was given the freedom to comment on the overall experience and the takeaways Kalliola had during their first modular project.

Case Study

The interview confirmed many of the aspects that can be assumed with modular construction, however, it also shows some new aspects associated with the method of construction. The two projects were built in an area that has been zoned for timber construction. The projects are slightly different sizes, however, the main differentiating factor is the Puulinna includes a parking garage underneath the buildings. Both projects were on relatively small lots and each building would be right against the property lines and the street on their outer facades. Kalliola went into the projects with no special experience in the styles of construction, although, the tilt-up timber construction did share characteristics with other concrete projects he has worked in. This means that Kalliola went into the project with a clean slate and his experiences can directly reflect the experiences any company that is thinking about modular construction can expect to experience.

Production and Delivery

According to Kalliola Puubyygeli was chosen to be modular for testing purposes. NCC wanted to see if there are benefits to modular construction as opposed to the traditional mode of panelization. The building was designed in Finland by Schauman Arkkitehdit Oy and a structural engineer would approve all modules, although, the design and delivery of the modules including installation were provided by Astel Modular from Estonia. This would mean that the modules would need to be shipped to Finland. Kalliola did not mention any hiccups in the deliveries even though they would have to be moved on a ferry and then via road for the last 100km. The only delivery that caused some issues was the modules on the top floor since they had a truss structure for the roofing and for that reason were taller than the other modules. For this site, however, these modules were directly shipped to the Turku harbor and the only adjustment that had to be done was with the train track cables that led to the harbor. These cables had to be lifted for the deliveries to get through. Additionally, the lead times for the modules were slightly longer than the panels, however, since the construction could be done simultaneously with earlier parts of the project, it still allowed for faster overall schedule.

The Panels on the other hand were produced in Finland by Hartola but all construction-related activities were left for NCC. This panelization is the primary method of construction in Finland, although, it has been traditionally done from concrete panels instead of timber. Timber in this case is used due to the zoning laws. The benefit that comes from the Panels is that more of them could be loaded onto a truck, however, Kalliola mentions that the trailers would then have to be left on site until the panels were lifted whereas, in the case of the modules, they could be lifted off and directly to the final location as soon as they arrived. The Puubyygeli project managed to erect roughly a floor per day with 6 truckloads, “a clear benefit of modular construction” according to Kalliola. This type of streamlining bypasses what (Hsu et al. 2019) found in their research, since the modules could be delivered directly to the site, and would not have to be stored at a warehouse, although this is dependent on the producer of the modules.

Quality Assurance

For the modules, the main steps NCC took according to Kalliola was numerous visits to the factory even before the start of the construction. Kalliola himself was not responsible for this part, however, he says that the manufacturer built a finished module before NCC placed the order. This module was checked multiple times for all quality and code-related aspects and everything that could be checked before construction was assessed. Kalliola had been part of another project on a close-by site that NCC was only responsible for the basement and foundation of. Kalliola later heard that on this project the company that delivered similar modules had been a lot harder to work with and they faced numerous code violation issues. It is essential to have a vigorous quality assurance plan for modular projects.

Tilt-Up and Installation

The installation aspect is where the two projects had the most differences. Kalliola was extremely happy with the service provided by Astal Modular. They provided high-quality modules that were as finished as it would be convenient to do, including most interior finishes, as well as MEP runs and fire protection. A crew would then be sent to install the modules as well as the remaining MEP connections through the buildings. When compared to panelization, Kalliola says that modularization is a lot easier and less stressful for the general contractor. Even though Kalliola has years of experience in tilt-up construction it would still be a lot harder to coordinate and make everything run smoothly in the panelization project, especially since the service provided by Astal Modular was so comprehensive that it would transfer most of the liability from the general contractor to them. The only on-site work that Astal Modular did was the exterior façade and according to Kalliola, this was for quality purposes. It is better to install the façade after seeing how the modules sit together, this will eliminate gaps and other quality defects in the façade of the building.

Assembly

Astel modular provided full service and sent their workforce, in other words, they had the role of a supplier and a subcontractor at the same time. The assembly project for Puulinna took only 6 days to complete apart from a minor design flaw that had occurred. Kalliola wasn’t exactly sure where the mistake was made, however, the foundations that NCC had done, did not exactly match the size of the containers, and NCC was forced to rework some of the foundations. This caused about a 10-day delay during which some modules had to be stored at the harbor which caused NCC some extra expenses, however, Kalliola does not seem to point the issue towards Astel modular, rather it is a miscommunication between all parties. Even with this delay the assembly after the foundation phase took about as long as it took with the Puulinna project.

The Puulinna project followed a traditional pattern of tilt-up construction and according to Kalliola, it was a noticeably heavier workload for NCC. It took roughly two weeks to complete the tilt-up of the frame not to mention all the other aspects that needed to be built, for example, insulation and finishes. Fire protection installation caused, subcontractor coordination, weather, and cleanliness, were some of the points Kalliola brings out. Despite the convenience of the weather protection for Puulinna, one of the ends ripped open in a storm which required NCC to waste days drying the Timber structure, this is a substantial benefit for modular construction. Not only is it easier to weather seal modular construction, due to it being quicker, in addition, weather complications can also be mitigated, especially in climates like Finland where rain and high wind are a frequent occurrence.

Weather

The weather in Finland can be very volatile, in fact, during the interview with Kalliola, which took place in November 2021, he mentioned that he is working on another timber project that is now getting delayed due to more than expected rain. Kalliola spoke highly of the method they used to construct Puulinna, the project that used panelization. For that project, they built a rain cover that was permanent for the duration of the project (See Fig. 1). This could be achieved by building a heavy frame and attaching a crane to a beam that would run on rails inside the cover, this way the cover would not need to be opened at any point of the project and they even built the cover over the storage area so the same crane could do all the lifting. Kalliola said that it was an advanced method for NCC and that for the most part, it worked well. Regardless of the advanced systems in place, Kalliola mentions that modular construction was again the better experience. Since the modules wouldn't need to be worked on on-site, they could be wrapped up in weather-sealing plastic until they were fully installed and protected by other modules of the exterior façade. This combined with the faster installation times gave Kalliola peace of mind during this part of the project. He wouldn't have to worry about weather nearly as much as in the tilt-up construction.

Figure 1: Erection of weather protection for Puulinna.

Fire Protection

All modern timber construction in Finland is subject to strict regulations in terms of fire protection. This being Kalliola's first timber project, he was surprised by the amount of fire protection required, and the amount of budget the fire protection would require. For Puubyygeli it was simple, Kalliola said, mainly installing a sprinkler system, everything else was already in place including all fire protective coatings. For Puulinna, however, he brought up the requirement for a fire protective plasterboard which caused issues in two significant ways. Firstly, it was labor-intensive, due to the load-bearing capabilities, only so much plasterboard could be craned in place for each floor, the rest would have to be carried in later. Kalliola mentioned that it would take two to three layers of

plasterboard in some places. Secondly, it caused work in the cleaning of the site. Plasterboard was not a clean material to work with and on a relatively small construction site, it caused some logistical planning issues in terms of storage and dumpster requirements.

MEP

MEP is another benefit Kalliola mentions, even though NCC was responsible for some aspects of both projects, the modules were a lot easier in his words. The modules included fixture connections and individual runs in each apartment, NCC was responsible for the main connections, although even these were pre-planned and there was a built-in mechanical shaft for all required connections through which the main lines were run. This reduced the responsibilities of NCC and required less planning on the NCC side, although, Kalliola did mention that it causes a different type of stress since less can be affected until the modules are installed. Settling was also a concern since the modules are set so quickly and they are more finished, the wood had less time to settle, and connections are less flexible when it comes to structural framing.

Timeline

According to Kalliola the timeline for the two projects was very similar, to begin with. Both sites were former industrial areas and a substantial amount of site clearing and soil cleanup needed to be performed. For Design purposes, Kalliola did not mention that either project would've taken substantially longer, including subcontractor bidding. Kalliola points out that by the time NCC participated in the projects, the designs were mostly finished. He did mention that scheduling was easier for Puubyygeli due to the manufacturer providing most of the estimates for time, they also delivered on their promises. On the other hand, the permitting process for modular construction was slightly more complex due to the lack of precise building codes when relating to modular construction.

Where modular construction had a clear benefit was on the duration of the construction process. According to Kalliola, Puulinna took about 15-16 months to complete, whereas Puubyygeli could be finished in a relatively short period of 11 months of on-site construction. Although the projects are not the same size this difference of roughly 40% in the duration of the construction projects is an impressive difference. Considering that both projects had some issues and that the assembly of the Puubyygeli project took only about 2 weeks with less dependency on weather conditions, it can be said that in this specific case, modular construction was beneficial for NCC as the general contractor.

Experience

Most of Kalliola's comments were towards the timber construction in general, mentioning that the buildings are overall quiet and that he was surprised about the amount of settling both buildings experienced. Kalliola also questioned the efficiency of the modules and the fact that many modules had two supporting walls facing each other wasting material. Kalliola's main takeaway was the importance of vetting the producer of the modules properly for quality and code compliance, as well as, making sure that the manufacturer has the capital and capabilities to produce the modules. Overall Kalliola embraces the experience of modular construction whilst recognizing that it is isn't perfect yet and that there is room to grow on all sides of the modular construction industry. case, modular construction was beneficial for NCC as the general contractor.

Conclusion and Future Research

Construction is not a highly efficient industry and there is clearly a need for more efficient construction methods. Companies are constantly looking for ways to achieve faster, cheaper, and higher quality construction. Modular construction can offer a possible solution to all three aspects. Modular construction is still in relatively early stages, and it has not been widely adopted across the industry. There are multiple benefits to it when compared to panelization, these are show in (Table 1).

Table 1

Benefits and disadvantages of modularization when compared to panelization

Benefits:	Disadvantages:
- Shorter Tilt-Up times	- Reduced design flexibility
- More robust weather protection	- Hard to execute change orders
- Transfers liability to other parties	- Longer lead times
- Controlled conditions	- Logistics challenges
- Highly integrated	- Learning curve

Exploring a possible standardization of modular construction could be beneficial to the industry, it could reduce the learning curve, and it could implement more flexibility in design options. In addition, the full-service model Astel Modular followed begs the question of the need for a general contractor, in many ways it seems like Astel Modular was responsible for the bulk of the project and with few additions, they could be fully responsible and providing all necessary services. Exploring the business model for modular construction could be useful in determining whether general contractors should consider their own production facilities or if the production should be outsourced. Overall modular construction offers general contractors and new way to run projects with different risk levels.

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