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COMBINING TAKT PLANNING WITH PREFABRICATION FOR INDUSTRIALIZED CONSTRUCTION

Krishna Chauhan¹, Antti Peltokorpi², Olli Seppänen³ and Klas Berghede⁴

ABSTRACT

Prefabrication and takt planning and control have been discussed a lot among lean construction researchers and practitioners. However, prefabrication and takt planning together as a way to promote industrialization in construction have been under explored in earlier research. Based on a literature review and two case analysis, this study explored the synergies between prefabrication and takt to promote the industrialization in construction. First case applied prefabrication and takt planning together and the second case applied takt planning, without prefabrication. Our results demonstrate that the two concepts together lead to better results and just implementing takt without prefabrication eventually moves the bottleneck of the project to drying times that could be solved with prefabrication. Therefore, both prefabrication and takt planning benefit from the combination and we argue that industrialization in construction requires both concepts.

KEYWORDS

Lean construction, Prefabrication, Takt planning, Industrial construction

INTRODUCTION

Industrial construction is a concept which aims at upgrading traditional site-based construction practices towards industrialized production systems (Gibb, 2001; Mao *et al.*, 2015). Implementation of industrialization would give several benefits to the construction industry, such as reduction of cost, minimization of waste, speeds of the project time and reduction in number of needed workers (Zhang, *et al.*, 2014). Literature has proposed different approaches and methods to industrialize construction, including lean

¹ Doctoral Candidate, Department of Civil Engineering, Aalto University, Finland, Krishna.chauhan@aalto.fi

² Assistant Professor, Department of Civil Engineering, Aalto University, Finland, antti.peltokorpi@aalto.fi

³ Professor of Practice, Department of Civil Engineering, Aalto University, Finland, Olli.seppanen@aalto.fi

⁴ Klas Berghede, Dir. Production Innovation, BOLDT, klas.berghede@boldt.com

construction (Gann, 1996), prefabrication (Gibb 2001), re-engineering processes (Winch 2003), and new practices for planning and scheduling (Austin et al. 2000).

Prefabrication of building and its parts off-site and assembling them on site has been one of the major practices to enhance industrialization of the construction. Pre-fabrication is an umbrella term that denotes different types of practices, such as pre-assembly and off-site production. Prefabrication can cover production of volumetric rooms or structural components including beams, panels, walls, and accessories. Technically, any building that has been divided into sub-sections or sub-products which are produced in factory environment and combined on site, can be considered prefabricated buildings. Numerous benefits have been mentioned regarding the utilization of prefabrication technology in construction (e.g. (Paudel et al. 2016)). Prefabrication is essential for completion of project on time, on budget and with intended quality. According to Poudel et al., (2016) use of pre-fabrication has increased by 86 % in the last two decades.

Despite the increasing role of prefabrication to foster industrialization of construction, in practice, productivity development of construction has still been lagging behind other industries. It can be argued that moving assembly work to factories has not improved productivity in remaining assembly activities on site. Koskela (2003) suggests, that eliminating non-value adding onsite activities is another way of promotion of industrialization concept in construction. In addition, Lessing, (2006) has defined eight areas of continuous improvement for the promotion of industrialization in construction, including not only prefabrication but also the use of takt principles in production planning. Therefore, we argue that the missing link in fostering industrial construction through prefabrication may be in inappropriate planning and control methods in on site activities. On the other hand, takt principles are becoming more popular in construction projects to increase productivity and reduce waste and costs (Frandsen, et al., 2013). We argue that the use of prefabrication in material and component delivery would help to achieve the benefits of takt in projects. However, existing research is lacking to address the role of prefabrication and takt principles together to promote industrialization in construction.

The purpose of this research is to analyse the potential synergies of combining prefabrication and takt planning for more industrialized construction. To address this purpose, the research aims at answering the following research question: *What are the synergies of combining prefabrication and takt planning for industrialized construction on project level rather than utilizing them as separated strategies?* By synergies, we mean how the adoption of these two practices together lowers or removes the barriers or hindrances associated with adopting these practices in stand-alone implementations.

THEORETICAL BACKGROUND

INDUSTRIALIZATION IN CONSTRUCTION

Industrialization in construction has been discussed by many industrial researchers and academics and it is defined in different ways, however it is lacking a widely accepted definition (Lessing, 2006). Traditionally, industrialization in construction was mainly focused on the utilization of machinery and automated systems that replace labor doing manual work. Over the years, industrialization concept started to get broader as it was

understood as offsite prefabrication of building and its parts which involves the design and manufacturing of more complex parts of the building. Today, industrialization in construction is not just limited to off-site prefabrication and factory production; it is more focused with the process than just a project which includes the systematic, controlled and standardized production in well-defined building systems (Andersson and Lessing 2017). This understanding of industrialization has been confirmed to increase the performance of construction process. A clear example can be seen in the results of Hooley et al (2002); utilization of industrialization in construction process led to savings of 16% in labour and material costs, reduction of material utilization by 26 %, and reduction of building time by 37% in North America and in Europe.

Industrialization is often understood as a gradual outcome of continuous improvements in construction processes. In other words, it is a process for finding opportunities for streamlining work and reducing waste. To define the areas for continuous improvement, Lessing (2006) focuses on eight different areas to be implemented for achieving the industrialization in the construction industry:

Planning and control of the processes; project must be pre-planned before implementation paying special attention to design activities.

Developed technical system; the suitable technical product solutions will be developed and upgraded and implemented into the systems.

Prefabrication of the building parts; this is one of the most important areas of construction industrialization. Off-site manufacturing is better suited for efficiency because working conditions have less variability and sophisticated equipment can be utilized.

Long-term relations; stakeholders and participants such as project planner, architecture, and structural engineer are engaged in the long-term relations.

Integrated logistics; The material and information flow in the construction sites and factory plants are combined with the design, production and construction process.

Use of ICT; Utilization of ICT tools such as BIM helps to enable industrialization in construction also management information system supports managing the information through all process and technical systems

Re use of experience and measurements; Performance measurement provides situational awareness about the process and enables learning.

Customer and market focus; getting knowledge of customer expectations and needs..

Continuous improvement of all these eight areas defines the current description of industrialized construction. All of these eight strategies will have different role for the implementation of industrialization. Offsite prefabrication of building and its parts has been treated as a major part of the industrialization in construction history. Hence, in this research, prefabrication as a factor of the industrialized construction will be focused.

PREFABRICATION IN CONSTRUCTION

Prefabricated construction is an alternative solution to the traditional site-based construction, which helps to increase productivity, reduce waste, increase predictability and environmental performance over life cycle, and has benefits for all the stakeholders

involved in the construction process (Pan, *et al.*, 2012). Elimination of waste is an important part of lean philosophy. The goal of the Flow view in Koskela's (1992) TFV-model is to increase the value-adding time by decreasing waste related to flows. The focus is on providing more value added solution to the customer (Aziz and Hafez, 2013). Currently, implementation of lean principles and tools is becoming more popular in construction projects, and it recognizes as an essential concept to be successful in the current industry (Aziz and Hafez, 2013; Bashford, *et al.*, 2005).

In industrialized construction, implementation of new technology to decrease waste is necessary. Many researchers have suggested prefabrication technology as the best tool for the minimization of waste in construction (Lu and Yuan, 2013). This is exemplified in a research by (Tam *et al.*, 2005) that shows that concrete waste could be reduced by 51% to 60%, and construction waste from the adoption of timber formwork could be decreased by 74% to 87% by using steel formwork through the utilization of prefabrication. Prefabricating MEP systems has been reported to decrease man hours related to MEP installations by 30% (Khanzode, *et al.*, 2008).

TAKT IN LEAN CONSTRUCTION

The term takt is derived from the latin term "tactus" which means a sense of touch or touch, later in the 16th century, takt was redefined in German as 'beat' (Haghsheno *et al.*, 2016). Takt time is understood as time span of two beats. The application of takt in a process is explained as taktung. Over the years, meaning of this term defined differently by different authors. Commonly accepted definition is given by Frandson, *et al.*, (2013) as "the unit of time within which a product must be produced (supply rate) in order to match the rate at which that product is needed (demand) rate". Which can be expressed in simple mathematical form as:

$$\text{TAKT time} = \frac{\text{Available net working time}}{\text{Customer demand in that time}}$$

Adoption of lean principles in the construction project plays a significant role in productivity improvement. As exemplified by Court *et al.*, (2009), implementation of lean and agile mechanical and electrical (M&E) construction system reduced 37% of the onsite labour work and increased productivity by 116% comparing with the traditional construction systems. Among the several lean tools and practices, takt planning (e.g. Frandson *et al.*, 2013) is one of tools related to production system design that has been claimed to help projects complete on time, within budget and with high quality. Adoption of takt time is a way to examine the speed of production to the rate of construction zones; construction zones mean an assembly of building fabric process (BFP) and Mechanical, electrical and plumbing (MEP) process (Court, 2009). Takt principles originated in lean manufacturing, where production rates are set to match the demand rate (e.g. Hopp and Spearman, 2008). In construction, the objective of takt planning has been to provide a balanced work flow for trades (Frandson and Tommelein 2016), and to decrease cycle times and increase productivity (Heinonen and Seppänen 2016). Takt time planning (TTP) has been proposed as a method by Frandson *et al.* (2013) and Takt Planning and Takt Control is a related method introduced by Dlouhy *et al.* (2016). The methods have in common that the work is broken down to small areas (takt areas), repetitive processes,

and each process is allocated a certain amount of time to finish each takt area (takt time). By removing buffers from between tasks, the project cycle time is decreased.

COMBINING PREFABRICATION AND TAKT FOR INDUSTRIALIZATION IN CONSTRUCTION

One of the key ideas of lean is to lead the continuous improvement (Kaizen) along with the elimination of waste (muda). Continuous improvement is at the heart of lean construction, lean management and lean production. Implementation of takt would seem to prevent overproduction, reduce lead times, reduce waiting times and finally make the process transparent so that continuous improvement required for industrialization can be realized.

Major focus of industrialized construction is to create a framework for continuous improvement of several areas defined by Lessing (2006). Incorporating prefabricated products plays a major role in achieving this goal.

Thus, both prefabrication and takt seem to be factors in enabling continuous improvement, therefore paving the way for industrialization of construction. As they both have similar goals but focus on different parts of the supply chain, we argue that by implementing both, construction industry could move towards industrialization (Figure 1).

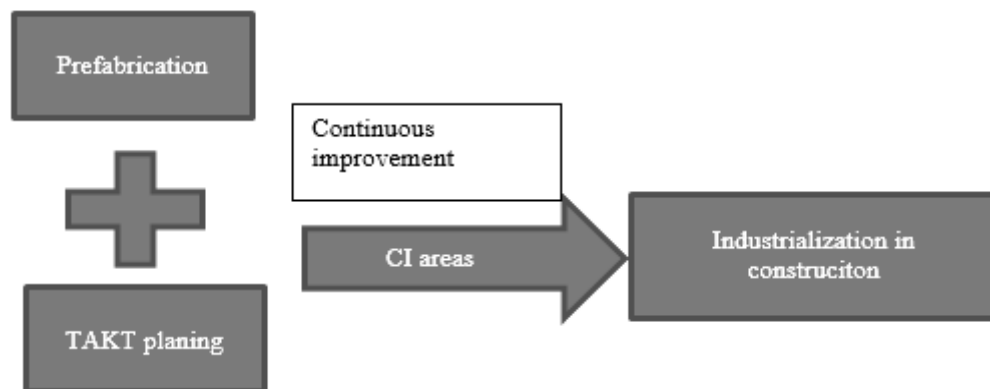


Figure 1. Prefabrication and takt role for construction industrialization

METHOD

In this paper, we first reviewed the existing literature on construction industrialization, prefabrication and takt planning in relation to the construction industry. Based on the literature, the role of prefabrication and takt planning for the promotion of industrialization in the construction industry is proposed. After that we used a case study design to empirically investigate the synergies of using takt and prefabrication for industrialized construction. We followed Yin's (2014) suggestion of analysing multiple case studies to get required variation in results by selecting two construction projects as our cases of which the first one has adopted both prefabrication and takt and the other only takt planning. This theoretical selection enabled us to investigate possible synergies of practices and to compare them to the situation in which synergies between practices

were not gained. We selected one case from US and another from Finland to increase the generalization of the results. In both cases, an action-based method was followed and one author was responsible for adopting prefabrication or takt planning principles. Project documents, observations, and meeting memos were used as primary data for analysis.

RESULTS AND ANALYSIS

CASE I

The Van Ness and Geary Campus Hospital (VNGC) is a 91,974 square meter, 2.1 billion dollar construction. It is a 13-story, 274 bed acute care hospital with possible expansion to 304 bed and will be built in downtown San Francisco. It is estimated to open for patients in the first quarter of 2019. The construction site does not have any lay down area and is situated in the densest area of the city which has the second busiest traffic in the US.

Utilization of Prefabrication

At VNGC construction project prefabrication was the fundamental tool securing the completion of the project on time, on budget and with the targeted quality. The application of shared overhead utility racks for services, displacement ventilation and improved scheduling for the structural steel frame has led to significant amount of savings. Prefabrication in the factory site and site construction such as digging the base were continued in parallel, which in turn promoted the completion of the project on time. Similarly, parts were manufactured in the factory and were assembled on site that helped minimize waste on site as well as reduce the number of onsite workers.

Overall, the utilization of prefabrication technology has greatly benefited the completion construction process on time, on budget and with quality which is a major construction industrialization area defined by Lessing (2006). Prefabrication played a significant role in the improvement of other construction industrialization areas, such as in logistics management, planning and control of the whole construction process, development of the technical system in the off-site factory as well in on-site, long-term relations with all participants and other stakeholders. Thus, prefabrication technology had the vital role for continuous improvement of construction industrialization areas (Lessing, 2006) and finally it helped to promote the industrialization of construction.

Utilization of TAKT

The project decided to apply takt planning early and built a production system around standard durations and location-based hand-offs. Once the areas were established, the entire supply chain employed those areas to batch their work accordingly. To be able to install a certain scope of work effectively in area A, the team had to detail the shop drawings, order the material, fabricate the components, kit and package the material and information, and deliver everything the area A separately. Hence, the team managed to align the supply chain to the installation schedule by clearly defining the batches of work early and globally for all stakeholder to align to.

Further, using standard durations allowed for a stable and extremely simple and visual schedule that promoted a deeper understanding of the overall flow of the project and level loaded the crews and material demands. The crews had a set duration, 1 or 3 weeks in each area and a crew worked in one area at a time, moving clockwise up the project. This structure made sure that there was a high space utilisation rate where one crew was working in each area of the floor, and limited trade stacking as only one crew were supposed to work in each area per week.

It was realized shortly afterwards that the trades that had sophisticated detailing and fabrication processes such as mechanical trades benefitted exponentially from the cyclical and batch-oriented schedule as the site became a natural expansion of their fabrication flow. The project also saw that developing a steady overall flow allowed the supply chain to align closer than ever before, reducing the inventory needs and allowed a more level headed fabrication process as well. In the past, an extremely volatile site schedule essentially forced the supply chain to overproduce and have excess inventory just to be able to cover the stop and go reactions from project sites. This case illustrates well how prefabrication enabled creating more stable material and component flow to site. On the other hand, well managed material flow was the requirement for successful takt adoption in site operations.

CASE II

Case II is a 7-story residential building project in Helsinki Finland. The building includes 42 apartments. Takt planning and control is being implemented for interior finishes, starting from pouring concrete in bathrooms. Takt planning has been done in collaboration with the whole team, led by the General Contractor, Fira Oy. Prefabrication is not being extensively conducted in the project except for precast concrete structure.

The team implemented takt planning aggressively, going for a takt time of one day, and each apartment as a takt area. There are two trains, one for all other spaces within the apartment except the bathroom, which has a different work content and is considered a separate train. Takt plan of the building is shown in Figure 2, the areas outside of bathrooms are shown on the top and the bathroom areas at the bottom. This indicates that bathrooms are the bottlenecks in this residential construction project. They cannot be further accelerated because floor tiling requires concrete floor to be dry, and the floor drying cannot be further expedited.

The General Contractor has been evaluating the use of modular bathroom units in other projects but has not been able to really figure out the value proposition. Aggressive cycle time reduction of the takt plan brought the bathrooms to the critical path for the first time and further time compression is only possible with a modular solution or with product development related to concrete drying solutions. This case illustrates well that cycle time compression with takt moves the bottleneck of the project and creates a compelling business case for modular prefabrication solutions.

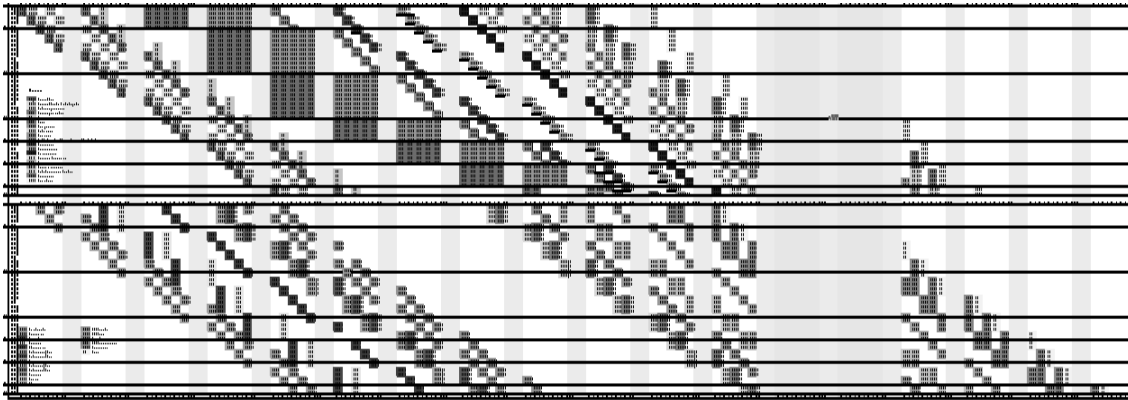


Figure 2. Takt plan of Capella project. The bathrooms are shown in the lower portion and are on the critical path. Drying time of concrete results in an empty area before floor tiling work.

DISCUSSION

This study showed that several synergies can be identified when adopting prefabrication and takt planning together in the same project. In the first case, prefabrication and takt planning together have significantly helped overcome several challenges such as traffic, residential neighborhood, logistics, storage and parking. By utilizing prefabrication, onsite and offsite activities were continued in parallel that expedited the project completion. Adoption of Takt helped to manage the same speed for both on-site and off-site activities, balance their resources with the plan and production process and reduce overproduction. On the other hand, Case II showed that several bottlenecks might appear during the takt implementation if the critical path on site consists of long phases, such as drying, in which active takt crews are not needed. Prefabrication, on the other hand, would solve this problem. Thus, the analysis shows that takt planning and prefabrication are not alternatives when shortening construction time but their effects show in different parts of the process, meaning that synergies can be achieved if they are employed together. In addition, takt planning on-site creates continuation for planning methods adopted in typical prefabrication processes. This indicates, that there is no need for additional material coordination between prefabrication and takt planning on site if cycle times in prefabrication and takt time on site are synchronized in the overall production planning. Prefabrication also enables less complex material packages to be delivered to the site thereby enabling more JIT based deliveries that are needed in takt planning.

CONCLUSION

Several approaches can be taken to reach the goal of the industrialisation in construction. To address the lack of earlier research on evaluating the role of prefabrication and takt time together to promote industrialization in construction, multiple case analysis was adopted in this study. Our analysis shows that takt planning and prefabrication play a significant role in industrialization areas such as in logistics by smooth material and information flow, in speeding up the project, in planning and control of the process, reuse

of materials, experiences and measurements, focuses on market and customer demand and in improving the long-term relationship with project stakeholders.

In summary, our research confirms that instead of seeing different practices to enable industrial construction as separated strategies (Lessing, 2006), prefabrication and modern production planning methods, such as takt planning, would benefit when they are adopted together. Further research is needed on how these synergies are more optimally achieved and what kind of solutions are most appropriate e.g. in logistics to support the combination of prefabrication and takt planning.

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