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Utilization of procurement process in support of takt production

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ABSTRACT:
Issues related to productivity and its poor development of the construction industry are widely recognised. Lean production and lean construction developed from it have been proposed as a solution to the lagging productivity. Takt production is a location-based production controlling method developed from the principles of lean construction.

This thesis seeks to identify the focal factors that affect to the lead-time of interior phase production in residential construction. These identified factors are aimed to address by means of procurement process and takt production to reduce lead-times in the future projects. Previous studies on takt production have reported promising results in reducing lead-times and improvements in productivity from the utilization of takt production.

This study is executed as an exploratory case study which consists of multiple case projects of the Case Company. Data was collected from semi-structured interviews. Interviewees were both representatives of the Case Company and subcontractors. Literature review of the thesis is based on university course books, peer-reviewed scientific articles, and conference papers. Data from the interviews and literature was analysed for the conclusions of the study.

Findings of the thesis indicates that takt production and procurement process can support shortening the lead-time of the interior phase production. However, there were identified factors that affects to the interior phase production that are required to be tackled for successful takt production. Support of procurement process to successful takt production arises from supplier selection, contracting, and supplier management.

In this thesis, focal factors that are affecting to the lead-time of the interior phase production was identified. Based on interviews, previous studies, and the literature review solutions were presented. The findings of this thesis can be utilized in the future projects and thus implement takt production successfully with support of the procurement process to shorten lead-time of interior phase production.

KEYWORDS: takt production, procurement, residential construction, interior phase production

VAASAN YLIOPISTO
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TIIVISTELMÄ:
Rakennusalan heikko tuottavuus ja sen kehitys ovat laajalti tunnistettu ongelma. Lean-tuotannolla ja siitä kehitetyllä lean-rakentamisella on pyritty vastaamaan tuottavuusongelmiin. Tahtituotanto on paikkakohtainen tuotannonohjausmalli, joka pohjautuu lean-rakentamisen periaatteisiin.

Tämä pro gradu -tutkielma pyrkii tunnistamaan keskeiset tekijät, jotka vaikuttavat asuntorakentamisen sisävaiheen läpimenoaikaan. Tunnistettuihin tekijöihin pyritään vastaamaan hankintaprosessin ja tahtituotannon avulla läpimenoaikojen lyhentämiseksi tulevilla projekteilla. Aiemmat tutkimukset tahtituotannon hyödyntämisestä ovat osoittaneet lupaavia tuloksia lyhentämällä läpimenoaikoja ja samalla parantaen tuottavuutta.

Tutkimus on toteutettu tapaustutkimuksena, jossa tutkittiin useaa Tapausyrityksen projektia. Tutkimuksen tiedot kerättiin puolistrukturoiduilla haastatteluilla. Haastateltavat olivat Tapausyrityksen ja aliurakoitsijoiden edustajia. Tutkimuksen kirjallisuuskatsaus pohjautuu Vaasan yliopiston kurssikirjoihin, vertaisarvioituihin tieteellisiin artikkeleihin ja konferenssipapereihin. Tutkimuksen johtopäätökset on tehty analysoimalla haastatteluista ja kirjallisuuskatsauksesta saatuja tietoja.

Tutkimushavainnot tukevat väitettä, että tahtituotannon ja hankintaprosessin avulla sisävaiheen läpimenoaikaa voidaan lyhentää. Tutkimuksessa kuitenkin havaittiin myös sisävaiheen tuotantoon vaikuttavia tekijöitä, joiden ratkaiseminen on edellytys onnistuneelle tahtituotannolle. Hankintaprosessin tuki onnistuneelle tahtituotannolle kumpuaa toimittajavalinnasta, sopimuksien tekemisestä ja toimittajahallinnasta.

Tässä tutkimuksessa tunnistettiin keskeiset sisävaiheen läpimenoaikaan vaikuttavat tekijät. Ratkaisut löydöksiin esitettiin haastattelujen, aiempien tutkimusten ja kirjallisuuskatsauksen pohjalta. Löydöksiä voidaan hyödyntää tulevilla projekteilla ja siten toteuttaa tahtituotanto onnistuneesti käyttämällä apuna hankintaprosessia sisävaiheen läpimenoajan lyhentämiseksi.

AVAINSANAT: tahtituotanto, hankinta, asuinrakentaminen, sisävaiheen tuotanto

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List of Abbreviations

GBA	Gross building area
HVAC	Heating, ventilation, and air condition
IGLC	International Group for Lean Construction
LC	Lean construction
LP	Lean production
SSU	Standard space unit
TPS	Toyota production system
TTP	Takt Time Planning
TPTC	Takt Time and Takt Control

1 Introduction

1.1 Research background

Issues related to productivity and its poor development of the construction industry are widely recognised (Fulford & Standing, 2014; Bajjou et al., 2017; Ahonen et al., 2020). In Finland development of productivity in the construction industry almost non-existent and is lagging compared to other industries (Ahonen et al., 2020).

Lean construction has been suggested as a solution to overcome productivity issues (Aziz & Hafez, 2013) and takt production which is developed from the lean construction (Lehtovaara et al., 2019). Takt production is a location-based production controlling method developed from the principles of lean construction. Takt production aims to equalize production rates between different tasks (Keskiniva et al., 2020) and thus ensure stable flow of production (Lehtovaara et al., 2021). By implementing takt production, lead-times of construction have been reported to reduce significantly (Frandson et al., 2013; Binninger et al., 2018). Lehtovaara et al. (2019) identified procurement and its possible impact to takt production by influencing to subcontractors and suppliers. This aspect is the central focus of this thesis.

Importance of procurement is extremely vital in the construction industry performance due to high percentage of outsourced work (Zeng et al., 2018). Hence, main contractor's dependency to subcontractors and suppliers is high (Bemelmans et al., 2012). Work at construction site is performed for the most part by subcontractors and it can cover up to 90 per cent of all work of the project (Karim et al., 2006), 60 to 70 per cent of project costs are material costs (Yunna & Ping, 2012), and up to 90 per cent of project's revenue is related to purchasing of goods and services (Bemelmans et al., 2012).

1.2 Case Company

The Case Company is one of the world’s leading construction and project development company founded in late 1800s. Geographic markets of the Case Company focuses to the Nordic region, Europe, and United States of America. Services of the Case Company consists of civil engineering, residential construction, and commercial project development.

In Finland, the Case Company is one of the largest companies within the construction industry. Focus of the construction services is on residential construction, commercial project development, civil engineering, rental of construction equipment, and building services engineering.

1.3 Research objective

The objective of this thesis is to study the current state of interior phase production in residential construction. The thesis seeks to identify the focal factors that affect to the lead-time of interior phase production. These identified factors are aimed to address by means of procurement process and takt production to reduce lead-times in the future projects.

This thesis has two research questions based on which steer this study to develop solutions to thesis objectives:

1. What are the focal factors affecting to the lead-time of the interior phase production?

2. How procurement process and takt production can support shortening lead-times of the interior phase production?

1.4 Scope of the thesis

This thesis focuses on residential construction in Southern Finland. More precisely the scope of the this is limited to interior phase production. In this thesis interior phase production covers all the required activities occurring inside the frame of the building to complete the project. However, focus is on certain categories of work: wall levelling and painting, floors, cabinetry, HVAC, and electrical work. Interior phase is by its nature repetitive and therefore considered to be suitable for takt production (Binninger et al., 2018; Lehtovaara et al., 2019). Also, interior phase production is comparable between different projects.

Data will be collected from project data and documents together with interviews. The data is used to find out the focal factors affecting to the duration of lead-time in the interior phase production, what causes the disturbance in the interior phase production and how procurement can address these findings to reduce lead-times.

1.5 Thesis structure

The structure of the thesis consists of literature review, case study, results and discussion, and conclusions. The literature review focuses on production control and scheduling from the perspective of lean construction and takt production followed by a section covering procurement and procurement process. The literature review is primarily based on peer-reviewed scientific articles from different journals, conference papers, and university course books.

Literature review is followed by empirical part. The empirical part of the thesis is case study based on the literature review, research questions, and previous studies. Interviews for the case study was executed in two parts with separate interview structures and contents. First part consists of current state analysis of interior phase production in different projects in which interviewees were Case Company’s employees. Second part of interviews were executed with Case Company’s suppliers that covered current production and takt production from their perspective. Finally, results of the case study are summarized and analysed followed by conclusions and further research are proposed.

2 Production control and scheduling

2.1 Lean production

Lean production (LP) can be defined as production that spend less resources in every stage of the production to create more efficient and streamlined process (Womack et al., 1990, pp. 13). Implementing LP results as better quality and continually improving production. Pacheco et al. (2019) describes LP as an alternative integrated production model that combines tools, methods and strategies in product development, and supply and operation management into a one whole.

History of LP springs from Japan after World War II by Toyota (Womack & Jones, 1996, pp. 9). Toyota's unique way of manufacturing, The Toyota Production System (TPS) was the basis for the LP (Liker, 2004, pp. 7). TPS was Toyota's variation of mass production technique to meet the characteristics of the Japanese car market (Holweg, 2007). Western model of mass production was not suitable as such to the smaller Japanese car market since customers demanded different car models, lack of financial resources and absence of Western manufacturers (Rymaszewska, 2016). The concept of LP was popularized by Womack, Jones, and Roos in their book The Machine That Changed the World (1990, pp. 49).

LP aims to eliminate all waste from production by means of work practices that are aimed to meet the customer demand and maximize the throughput of the bottleneck resources (Pacheco et al., 2019). Waste in LP is any operation that adds no value to the final product i.e. customer (Jasti & Kodali, 2015). Different types of waste in production are presented in Table 1. However, it is argued that it is impossible achieve zero waste in production and thus striving for waste-free production operations is a never-ending process in which continuous improvement is an essential (Rymaszewska, 2016).

Table 1. Different types of waste in production (adapted from Liker, 2004, pp. 28-29).

ID	Waste	Description
1	Overproduction	Items are produced without existing demand that causes overstaffing, inventory, and transportation costs.
2	Waiting	Time spent on waiting the next process to start.
3	Transportation	Time and resources are wasted, and costs increased when there are unnecessary movement of products and materials.
4	Inappropriate processing	Process includes steps that are not adding any value e.g., poor designing or planning and tools.
5	Inventory	Excess inventory, work in progress or finished products which cause longer lead-times, damaged products, and transportation. In addition, it refers to unbalanced production.
6	Motion	Wasted movement that is performed by people when performing work e.g., looking for tools and equipment.
7	Defects	Any product failure: repair or rework, replacement production or scrap.
8	Skill misuse	Lack of utilization of employees' skills, knowledge, and abilities.

2.1.1 Lean in context of construction industry

Lean construction (LC) is proposed as a solution to improve lagging productivity in construction (Aziz & Hafez, 2013). Implementation of LC has shown promising results as increasing productivity and quality in construction industry (Sarhan et al., 2017). LP in the context of construction and developing of LC is not a new concept and first academic publications appeared in the beginning of 1990s (Alves et al., 2012; Biton & Howell, 2013). The definition of LC varies in the literature (Li et al., 2020). Established description for LC defines the concept as a set of LP methods and tools applied to construction industry, or as a theory to form a new production model to construction industry based on the concept of LP.

Non-value adding activities i.e. waste within construction production can be specified under material-related waste and time-related waste (Sarhan et al., 2017). Material-related waste consists of overproduction, surplus of purchased quantities of materials, inappropriate processing, defects, and issues related to inventory. Time-related waste is related to e.g., waiting, miscommunication, rework, and production interruptions. Bajjou et al. (2017) stated that 25 to 50 per cent of construction costs are linked to waste in production, and 57 per cent of production is equal to waste. According to Bajjou and Chafi (2020) the five most common critical waste factors in construction are delay in start of activity, rework, skill misuse, long approval process, and unfinished work that affects to flow of the production. Sarhan et al. (2017) highlighted waiting as the primary source of waste in construction projects.

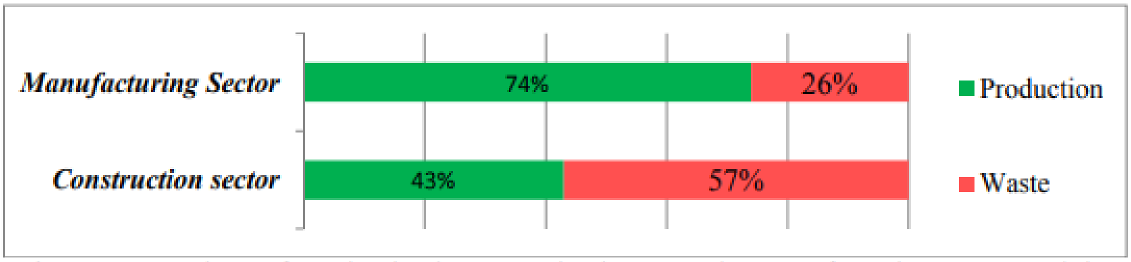

Figure 1. Comparison of production/waste ratios between the manufacturing sector and the construction sector (Bajjou et al., 2017).

LP principles has been implemented in the construction industry since 1990s (Shang & Sui Pheng, 2014). However, LC is still in transition phase within the construction industry (Sarhan et al., 2017). Transition to LC is slow due to lack of understanding of the concept of lean and how to implement the principles of LP to construction. Shang and Sui Pheng (2014) argued that the major barrier to the LP implementation is a lack of long-term philosophy and missing a culture required to lean adaptation from the top management.

2.2 Takt production

Effective production planning and control has a significant role in successful construction production (Lehtovaara et al., 2021). As the concept of LC has matured over time, new location-based production control methods are created to overcome the shortcoming of traditional production planning methods. One of the new methods that has received attention is takt production (Lehtovaara et al., 2019). Takt production origins from the lean concept of takt.

2.2.1 Definition of takt and takt time

Word takt is a German word for a fixed time-interval (Hopp & Spearman, 2011, pp. 161) e.g., rhythm or meter (Liker, 2004, pp. 94) that is precise, as the time-interval in a metronome. In lean production systems, word takt is used to define rate of a customer demand. Takt time is available time for production divided by the demand within that time (Bozarth & Handfield, 2008, pp. 194). Within properly defined takt time, production flow is smooth, and each output runs through the production system without distraction (Hopp & Spearman, 2011, pp. 467).

$$\text{Takt time} = \frac{\text{available time for production}}{\text{customer demand}} \qquad (1)$$

Takt time thus describes the maximum amount of time that can be used for ready products to meet the demand.

2.2.2 Takt in context of manufacturing

In lean manufacturing systems, takt time is utilized in line balancing (Bozarth & Handfield, 2008, pp. 194-195). Line balancing seeks to minimize idle time between different workstations. Line is perfectly balanced if each workstation is assigned to equal amount of work but in most cases, there are always variation between the workstations thus production lines are imbalanced. If the production line produces faster than the takt time, the production line generates overproduction and if time consumed in production line is greater than the takt time, it is a bottleneck of the production (Liker, 2004, pp. 94).

Takt time defined for production line is required to be reactive in order to meet the demand (Womack & Daniel, 1996, pp. 56). Takt time is fixed for the time of certain period, but if there is a change in demand, the takt time is adjusted with the demand. Every step of production and time requirements of the tasks is required to be identified to balance production line (Bozarth & Handfield, 2008, pp. 194-195). Based on demand and time required for production, takt time is defined to set the pace of production. Production line is the most efficient and optimized when it operates with minimum number of workstations. If bottleneck or waiting occurs within the production line, workstations are increased or decreased to match the production with the takt time.

2.2.3 Takt production in construction

Pacing of the production based on different activities is not a new concept in construction (Frandson & Tommelein, 2014). Construction of Empire State Building in 1930s was paced by four activities which were defined as "pacemakers" of the production. Takt time in construction appeared first time in the 1970s in Germany (Binninger et al. 2017), but more detailed approach to takt production appeared not until 2010s (Lehtovaara et al., 2021). In construction, takt is used as a frame for production (Tommelein, 2017). This framework is then utilized to schedule and control work of the project.

Takt production in construction aims to equalize production rates of different tasks and thus secure a continuous workflow (Keskiniva et al., 2020). Concept of equalizing the production rate by utilizing the takt time is the same as in manufacturing industry. However, there are a difference within the process. In the stationary industry, the product (object) runs through between workstations with labour (subject) while in the construction industry the process is the opposite in which the labour (subject) runs through the construction project (object) (Dlouhy et al., 2016).

Implementation of takt production has shown great potential to reduce lead times of construction projects (Lehtovaara et al., 2019). Binninger et al. (2018) have reported up to 70 per cent reduction in durations. Takt production is also stated to improve productivity, elimination of waste (Frandson et al., 2013), and transparency and communication between different parties within the construction project (Dlouhy et al., 2016).

Concept of the takt has been implemented into various construction projects (Frandson et al., 2013). There are documented cases of implementation of takt production e.g., in residential construction (Lehtovaara et al., 2019), civil projects (Fiallo & Howell, 2012), residential renovation projects (Keskiniva et al., 2020), and in business construction (Dlouhy et al., 2016). Examples of existing documented implementation of takt production in construction projects are listed in Table 2.

Table 2. Documented implementation of takt production in construction projects.

Authors, year	Publication
Frandson et al. 2013	Takt time planning for construction of exterior cladding
Dlouhy et al. 2016	Three-level method of takt planning and takt control - a new approach for designing production systems in construction
Keskiniva et al. 2020	Takt planning in apartment building renovation projects
Fiallo & Howell, 2012	Using production system design and takt time to improve project performance
Binninger et al. 2018	Short takt time in construction - a practical study
Lehtovaara et al. 2019	Implementing takt planning and takt control into residential construction

2.2.4 Takt production models

There are two published and established models for the takt production implementation (Lehtovaara et al., 2019; Keskiniva et al., 2020). Documented results for both models have shown promising results (Frandson et al., 2013; Binninger et al., 2018). First model for takt production, Takt Time Planning (TTP) was introduced by Frandson et al. (2013) in the United States. The second model, Takt Planning and Takt Control (TPTC) was introduced by Dlouhy et al. (2016) in Germany. Both models are based on the principle of the takt time, although there are differences between TPP and TPTC (Lehtovaara et al., 2019).

2.2.5 Takt Time Planning

TTP is a method for work structuring (Tommelein, 2017) that aims to balance the duration of different tasks while meeting production rate that is in line with the master schedule (Frandson et al., 2013). In this model to balance different tasks, the project is divided into separate physical areas i.e. zones or takt areas. TTP have been tested in use and documented in case studies (Frandson et al., 2013; Frandson & Tommelein, 2014; Frandson & Tommelein, 2016).

Frandson et al. (2013) lists a six-phase process for the TTP implementation: (1) gather information, (2) define zones, (3) understand the trade sequence, (4) balance the workflow, (5) understand durations for each task, and (6) establish a production plan. First phase requires collaboration between different parties. Suppliers and subcontractors define the details of their work and their estimations for time required, to understand specific what is required to be done and where it is done at the site. Based on the information gathered, takt areas are defined. In Figure 2 is an example of zones defined to construction of exterior cladding. In an optimal situation, takt area consists of work packages in which each operator consumes an equal amount of time to complete their work.

Figure 2. Example of zones defined by information from the previous phase (Frandson et al., 2013).

After takt areas are defined, trade sequences need to be clarified based on concept of pull planning to develop the takt time (Frandson et al., 2013). For production planning, it is vital to understand who is working within takt area and in which order. Balancing of the workflow is possible after takt areas are defined and trade sequence understood.

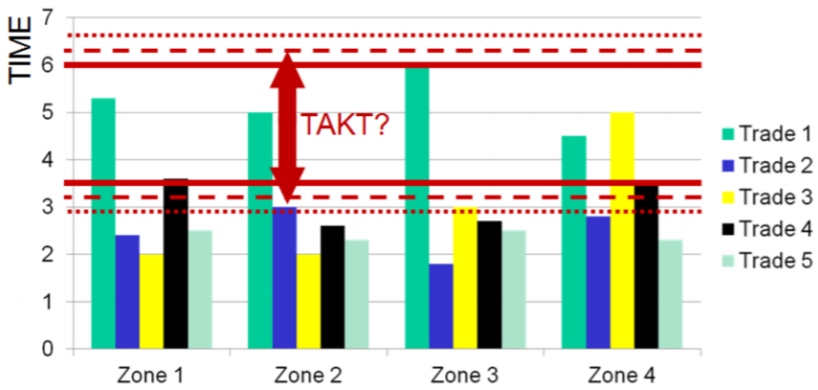

Figure 3. Selection of takt time vs. trade-specific duration of work in each zone (Frandson et al., 2013).

Different tasks are balanced within this phase by adjusting activities that are required to slow down or to go faster. Adjusting can be done e.g., by increasing labour or creating buffers. Balancing requires test-runs to establish accurate information. Balanced workflow of activities in the takt area finally defines the takt time. The takt time is adjustable and it can be changed during the process if necessary.

Frandson et al. (2013) reported TTP to increase required work compared to traditional production planning. This model requires collaboration and strong commitment from subcontractors and suppliers (Vatne & Drevland, 2016). However, using takt time in production planning overcomes some of traditional production planning shortcomings. TTP allows better discussion between different parties and creates the process more transparent (Frandson et al. 2013).

2.2.6 Takt Planning and Takt Control

Dlouhy et al. (2016) states that rarely knowledge and lessons learned from previous projects are transferred to the future projects and therefore potential of standardization of process structures will not be utilized. As a solution the authors have introduced a three-level method for the takt production (TPTC) that is applicable for different projects. It addresses both takt planning and takt control while model by Frandson et al. (2013) focuses only on takt planning. TPTC method have been implemented in construction projects and documented in several case studies (Dlouhy et al., 2016; Binninger et al., 2018; Lehtovaara et al., 2019; Alhava et al., 2019).

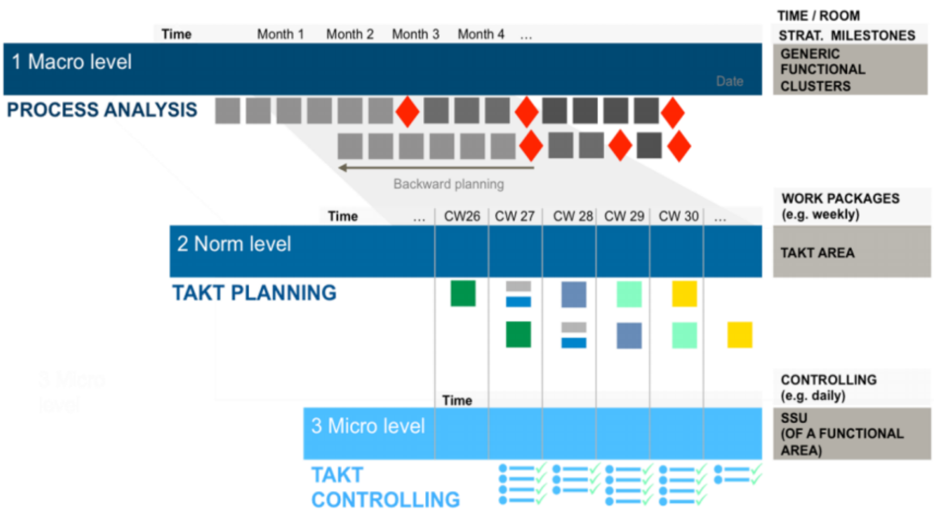

Figure 4. Overview of the three-level method (Dlouhy et al., 2016).

TPTC consists of three different levels: macro level, norm level and micro level (Dlouhy et al., 2016). The objective of the macro level is to create a process analysis to understand activities of the process that adds the most value to the customer. Outcome of the macro level is a milestone plan created in collaboration with other project participants. Data and knowledge from previous projects can be exploited. Based on customer requirements and macro level process analysis, the site is divided into functional areas. After successful process analysis, project participant shares a common vision on how the future project will be carried out.

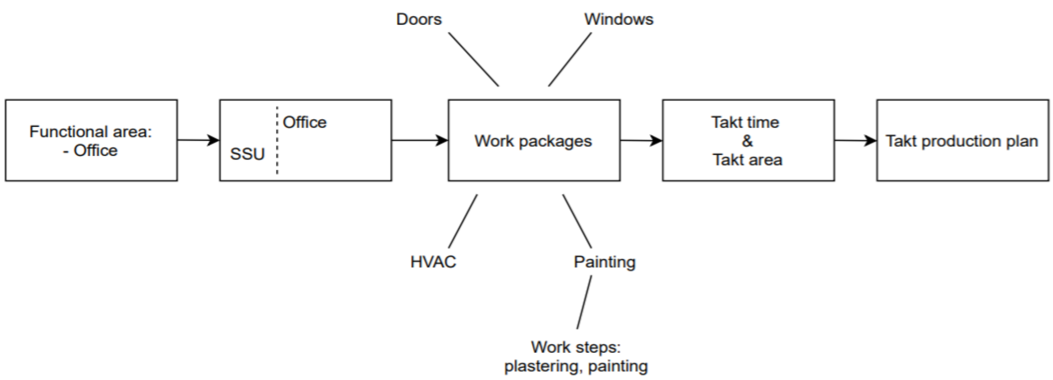

Figure 5. Takt production plan process.

Takt areas are defined at the norm level more precise by breaking up the functional areas into standard space units (SSU) (Dlouhy et al., 2016). SSU is a small spatial and independent unit according to manufacturing characteristics e.g., corridor, roof, or bathroom. SSU consists of work packages e.g., heating, ventilation, and air conditioning (HVAC), painting, etc. (Binninger et al., 2017). Based on SSUs and work packages, the takt area and takt time are defined and adjusted (Dlouhy et al., 2016). Haghsheno et al. (2016) define equation for construction takt time as follows:

$$\text{Takt time}=\frac{\text{Content takt area [entity=m}^2\text{]*Effort value }[\frac{\text{time}}{\text{entity}}=\frac{\text{h}}{\text{m}^2}]}{\text{Selected manpower}} \tag{2}$$

This process is repeated for every functional area (Binninger et al., 2017). In TPTC these work packages are called figuratively as wagons. Together these wagons in a line form a work train passing through different takt areas.

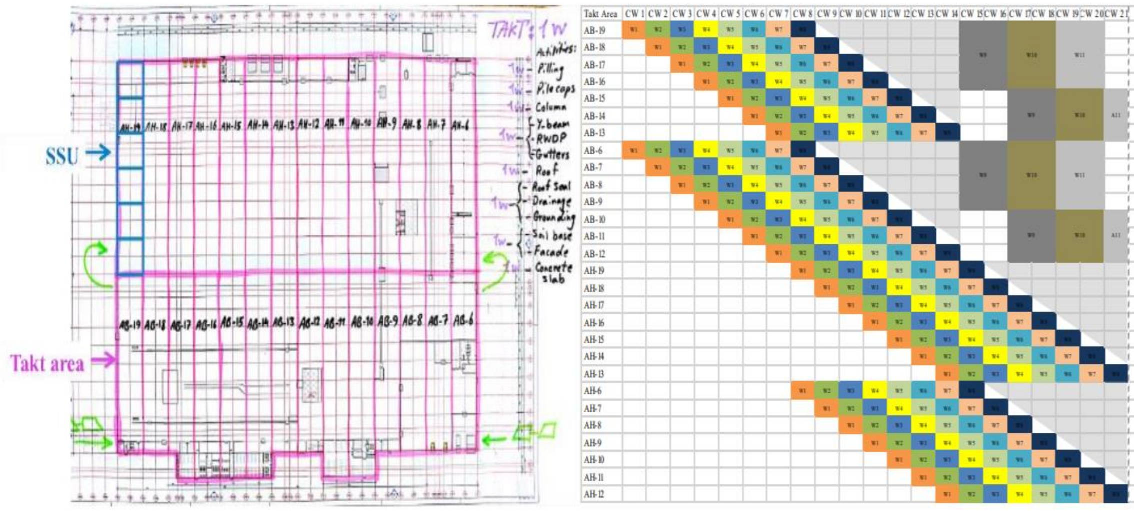

Figure 6. Defined takt areas with SSUs and the takt plan (Dlouhy et al., 2016).

Last of the three levels is micro level (Dlouhy et al., 2016). In micro level work packages are broken down into more detailed working steps and necessary buffers defined for takt areas. Defining working steps is done collaboratively with contractors and project management. Takt control aims to maintain required stability for production and continually improve the process (Haghsheno et al., 2016). Individual contractors are required to be involved to the takt controlling. Managing the execution and adjusting of production is implemented through daily takt status meetings (Dlouhy et al., 2016). Takt status meetings are intended to document the status of the production and to measure whether production fulfils the requirements of the norm level.

2.2.7 Takt production implementation in residential construction

Empirical documentation of takt production implementation in residential construction projects is scarce (Lehtovaara et al. 2019). Implementation of TPP in residential construction has been documented by Vatne and Drevland (2016), and implementation of TPTC has been documented by Lehtovaara et al. (2019) and Alhava et al. (2019). All these cases have documented reduction in lead-times and Vatne and Drevland (2016) in addition reported reduction in costs and stated that reduction in costs was limited due to piece pay payment term.

Lehtovaara et al. (2019) study focused on TPTC implementation to interior phase. The authors listed barriers, enablers, and actions for both planning phase and control phase. Barriers to takt planning were found from unfinished design solutions, subcontractors and suppliers were not prepared enough for TPTC, missing planning for e.g. logistics, drying, and other critical tasks. These identified barriers are suggested to overcome by more collaboration, more detailed planning, and by committing subcontractors and suppliers earlier on during the procurement process. Barriers regarding takt control was lack of understanding of the TPTC concept and its implementation, and deficient daily control. As a solution, the authors suggested that required knowledge concerning the implementation of TPTC should be ensured through training and by a softer start in implementing the TPTC in the project. Daily control requires committing by every participant within the project.

2.2.8 Critique of takt production implementation

Despite the promising results of takt production implementation in case studies, also problems have occurred. Both takt production models TTP and TPTC are reported to require more planning compared to traditional production planning (Frandson et al., 2013; Lehtovaara et al., 2019). Implementation requires strong commitment and Alhava et al. (2019) have reported lack of commitment to TPTC in case project that led e.g., to increase in waste and repeating of mistakes.

Commitment to takt production applies not only to the main contactor but also subcontractors and suppliers. In takt production, it is important to ensure flow of production and therefore each takt area must be finished before moving to the next takt area (Keskiniva et al., 2020). Lehtovaara et al. (2021) studied six takt implementation cases and in all cases subtasks of takt areas were left unfinished which led to re-entrants to takt areas. According to Lehtovaara et al. (2019) if subcontractors are paid based on piece rates, work is tended to be sub-optimized and subtasks are left undone in takt areas. As a solution they suggest that committing subcontractors and suppliers to takt production should take place already at the procurement stage.

One of the most significant barriers to takt production implementation is lack of know-how (Lehtovaara et al., 2019). This should be addressed through training and a softer start in production. Adapting to new method of production planning requires a change in mindset from all different parties of the project.

Current available literature on takt production in construction industry are principally published in yearly conference papers (by IGLC) and peer-reviewed publications in scientific journals are scarce (Keskiniva et al., 2020). Literature on takt production is also limited mostly on single successful case studies (Lehtovaara et al., 2021). Impact of takt production is not obvious in every cases. Alhava et al. (2019) reported financially and qualitatively successful case study project with 30 per cent reduction in lead-time although implementation of TPTC had significant flaws.

2.2.9 Summary

In the construction industry productivity is lagging, and lean manufacturing concepts are suggested as a solution (Aziz & Hafez, 2013). Takt time as a concept is not new and it comes from the lean manufacturing systems in which it is utilized in line balancing (Bozarth & Handfield, 2008, pp. 194-195). In line balancing, idle time between each workstation is aimed to minimize. In the construction industry from the concept of LP and takt time is developed takt production which is relatively new concept which has evolved into its current form in the 2010s (Lehtovaara et al., 2021). As in the manufacturing industry, takt production in construction industry seeks to equalize different production rate of different work phases (Keskiniva et al., 2020).

There are two established models for takt production implementation: TPP (Frandson et al., 2013) and TPTC (Dlouhy et al., 2016). Promising results have been reported for both models (Frandson et al., 2013; Binninger et al., 2018). Binninger et al. (2018) have reported reductions up to 70 per cent in lead-times.

3 Procurement

Procurement is a combination of activities required to obtain product or service from a supplier to the specified destination (Weele, 2010, pp. 6). Activities of procurement describes all the activities connected to purchasing process. Main purpose of procurement is to select suppliers for products and services (Bozarth & Handfield, 2008, pp. 14). In addition, procurement is responsible for management of current suppliers. Importance of procurement in businesses results from its possibilities to generate financial impact as major share of company's revenue is spent on different products and services (Bozarth & Handfield, 2008, pp. 341-342).

In this section, established procurement process model by Weele (2010) is discussed thoroughly. Strategic aspects of procurement are briefly explained to understand the procurement process better.

3.1 Strategic approach to procurement

Value within supply chains and trend in outsourcing has been recognized among businesses and scholars. Hence, purchasing and procurement management has taken an approach to a more strategic planning process from a tactical approach (Johnsen, 2018). Ghanbarizadeh et al. (2019) states that strategic approach to procurement management is required to achieve better outcomes in production and overall performance of the project. For effective purchasing operations, purchasing strategy should be in line with the company's business strategy (Weele, 2010, pp. 61-62).

Carr and Smeltzer (1997) defines strategic purchasing as:

> *The process of planning, implementing, evaluating, and controlling strategic and operating purchasing decisions for directing all activities of the purchasing function toward opportunities consistent with the firm's capabilities to achieve its long-term goals.*

Strategic purchasing pursues to add value to purchasing operations (Brandon-Jones and Knoppen, 2018). Value improvement of the purchasing performance appears as an improvement in cost, quality, delivery, flexibility, and innovation (Nair et al., 2015) that is achieved by centralizing the purchasing function (Brandon-Jones & Knoppen, 2018). With more strategic approach to the purchasing comes also deeper understanding and commitment to organizational targets (Nair et al., 2015). Organizational procurement is structured to be decentralized, centralized or a hybrid structure between decentralized and centralized structure (Weele, 2010, pp. 283).

3.1.1 Decentralized procurement

In decentralized procurement structure responsibility on financial performance is fully on business unit (Weele, 2010, pp. 283-284). Hence, decision making takes place primarily in the business unit thus is responsible for all its purchasing activities.

Advantage of decentralized structure is its agility and its strong impact direct to the business unit (Weele, 2010, pp. 290). In addition, this structure reduce bureaucracy within the company. However, within decentralized procurement structure may occur as duplicated work because of different business units negotiating with same supplier for the same products and services (Weele, 2010, pp. 283-284). Decentralized procurement structure limits the benefits of economies of scale, and steering of suppliers (Weele, 2010, pp. 290). Also, information regarding prices of materials etc. becomes more scattered.

3.1.2 Centralized procurement

Centralized procurement unifies company's purchasing operations to increase scale of each purchase (Yunna & Ping, 2012). In centralized procurement structure, decision making of purchasing decisions and supplier selection are implemented centrally (Weele, 2010, pp. 284). Increased scale of purchase aims to reduce the unit costs of materials and resources, and because of reduced unit costs, the overall procurement costs are also reduced. Higher volume in purchasing also increases the leverage of the purchaser in negotiations with the supplier (Rothkopf & Pibernik, 2016). Centralization is the most suitable for generic purchasing such as bulk products (Brandon-Jones & Knoppen, 2018), but also for strategically important components and resources and high value materials (Yunna & Ping, 2012).

Advantages of the centralized procurement comes from the supplier selection and management, process standardization and increased transparency within the process (Yunna & Ping, 2012). By standardizing the process and increased transparency, variation of the process between different business units is reduced. Disadvantage of centralized procurement is its more rigid structure (Weele, 2010, pp. 287-289). Within different business unit may occur dramatic differences that one centralized structure is not able serve properly.

3.1.3 Hybrid structure

Hybrid procurement structure combines characteristics of decentralized and centralized procurement structure (Weele, 2010, pp. 285-286). Most companies use the hybrid procurement structure in which selected purchasing categories are centralized and project or business unit specific purchases are made as decentral (Weele, 2010, pp. 279-280).

Critique of the hybrid procurement structure is directed to off-contract purchasing of goods and services, which is called as “maverick buying” (Rothkopf & Pibernik, 2016). Maverick buying bypasses pre-negotiated contracts with selected suppliers and contractors (Karjalainen & Raaij, 2011; Weele, 2010, pp. 46). Off-contract purchasing occurs in every organization, but probability to realization of risk increases if the share of maverick buying is significant (Bozarth & Handfield, 2008, pp. 348). Risks may realize e.g., as higher unit prices and increasing process costs (Karjalainen & Raaij, 2011).

3.2 Procurement process

Procurement process involves required actions to obtain a product or service from outside the organization (Bozarth & Handfield, 2008, pp. 346). Procurement process is one of the more complex processes in a company (Bildsten & Manley, 2015). The complexity of the process stems from the large number of different stakeholders involved (Ruparathna & Hewage, 2013) and high requirements of knowledge for technical aspects of each purchase (Sabolová & Tkáč, 2015) and long-term commitment in uncertain environment (Bildsten & Manley, 2015). Weele (2010, pp. 29) divides purchasing process to six different steps: define specification, select supplier, contracting, ordering, expediting and evaluation, and follow-up and evaluation.

Despite the complexity of procurement as an organizational process (Bildsten & Manley, 2015), there are only rarely situations in which the whole six-step purchasing process is completely occupied (Weele, 2010, pp. 31). Different purchasing situations are a new-task situation, a modified rebuy, and a straight rebuy.

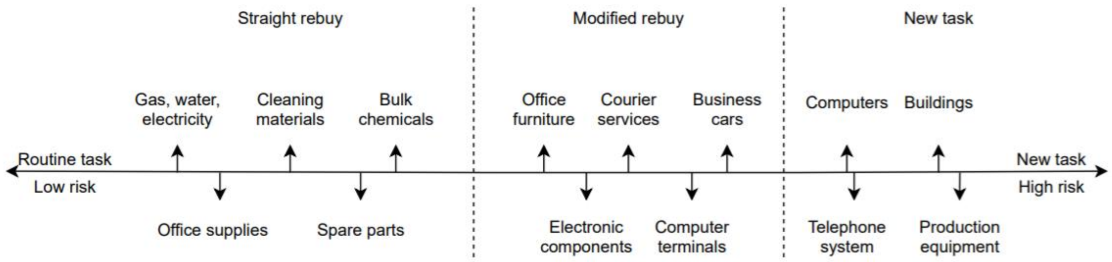

Figure 7. New-task situation, modified rebuy and straight rebuy illustrated by some examples (Weele, 2010, pp. 32).

In the new-task situation, completely new product is bought from a supplier that is unknown for the buying organization (Weele, 2010, pp. 31). The new-task situation is the only purchasing situation that occupies every step of the purchasing process. This type of purchasing involves a highest risk of the purchasing situations. When organization purchases a new product or service from a known supplier, or a familiar product from unknown supplier is called the modified rebuy. The modified rebuy focuses primarily to last four steps of the presented purchasing process. The straight rebuy or i.e. routine buy is the most common purchasing situation in which known product or service is bought from known supplier. There is low risk in the straight rebuy situations due to clear terms and conditions that are previously negotiated. Although purchases can be defined with different purchasing situations, these situations are affected also by the overall effect of each purchase (Bozarth & Handfield, 2008, pp. 346). Effort invested to the purchasing situation is also affected by e.g., financial, and strategic impact of the purchase.

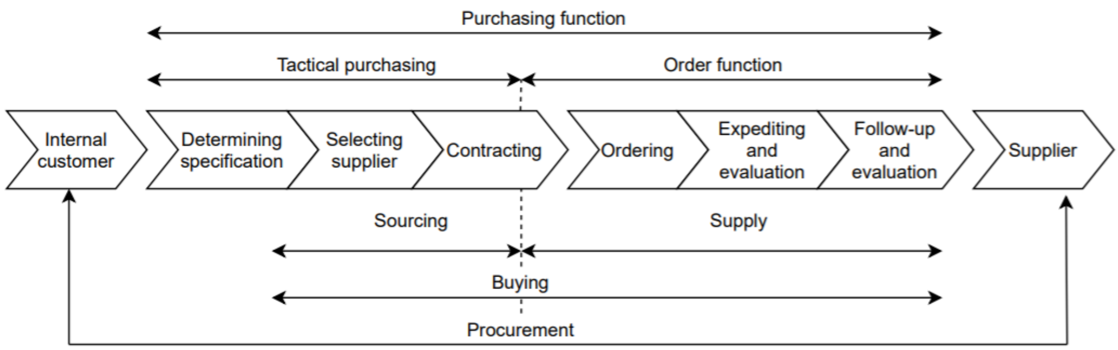

Figure 8. Purchasing process model and some related concepts (Weele, 2010, pp. 9).

3.2.1 Determining specification

After need for required product or service is identified, procurement process begins with defining requirements and specification for the purchase (Weele, 2010, pp. 32-33). Requirements consists of technical and functional specification. Technical specification sets a detailed description of the characteristics of the product or service and, activities required to be performed by the supplier. Functional specification focuses more on the buying organization's expectations for the product or service outcomes (Bozarth & Handfield, 2008, pp. 347-348).

Technical and functional specification together create a wider concept of purchase order specification (Weele, 2010, pp. 32-33). In purchase order specification, all specification is described to select the supplier. These specifications also include specification for quality, transportation, maintenance, legal requirements, and estimation for budget.

3.2.2 Supplier selection

Supplier selection is the next step in the purchasing process after specifications for acquired product or service are clarified (Bozarth & Handfield, 2008, pp. 348-350). Based on the purchasing situation described by Weele (2010, pp. 31), the supplier is selected from known prequalified suppliers or if necessary, completely new supplier is selected (Bozarth & Handfield, 2008, pp. 348-350).

Supplier selection consists of four individual phases: (1) assessment of supplier's responsibilities on assignment, (2) preliminary analysis of possible suppliers for the assignment, (3) preparation of request for quotation and analysing tenders from suppliers, and (4) selecting the supplier (Weele, 2010, pp. 33-37). In the first phase, decision regarding type of subcontracting is defined. Turnkey and partial subcontracting are the two types of subcontracting. In turnkey subcontracting, assignment is fully assigned to the supplier and in partial subcontracting, the assignment is divided to separate parts and each selected supplier is contracted for certain parts of the assignment. The supplier selection phase is also dependent on supplier relationship and acquired product or service, and it can vary significantly based on these factors (Bozarth & Handfield, 2008, pp. 348-350). Selection of supplier is executed after all required evaluation of suppliers are completed.

3.2.3 Contracting

Contract formalizes the relationship with buyer and selected supplier (Bozarth & Handfield, 2008, pp. 350). Contract includes detailed agreement on prices, delivery, terms of payment, warranties, legal terms, and other industry specific refinements (Weele, 2010, pp. 37-40). In addition, technical requirements for the purchase influences on the nature of the contract.

Prices and terms of payment are important aspects of contract (Weele, 2010, pp. 37-40). Most common purchasing contract is a fixed-price contract in which price is agreed in advance (Bozarth & Handfield, 2008, pp. 350). The fixed-price contract is not affected by e.g., fluctuations in raw material prices or by overall the state of economics. This contract type is also rewarding for the supplier (Weele, 2010, pp. 37-40). The supplier receives better margins for the assignment if work exceeds what is agreed in the contract. Better margins form e.g., from less resources used. The supplier may have large upfront investments in order to fulfil customer's order. Hence, terms of payment are preferred to be linked to the performance of supplier.

Within the contract, the supplier must guarantee that offered product or service is as requested (Weele, 2010, pp. 37-40). Penalty clauses and warranties are applied to the contract to ensure that supplier is obligated to meet the specification of the product or service. Legal terms are to subject what laws are applied to the contract. Commonly the applied laws are the ones from a country of the supplier.

3.2.4 Ordering

Ordering phase takes place in the process after supplier is selected and once contract and its terms and conditions are clear to both parties (Weele, 2010, pp. 42-43). Order cycle begins after buying organization sends purchasing order to the supplier and ends after money transactions and receiving of goods (Bozarth & Handfield, 2008, pp. 351).

Purchasing order is a permission for the supplier to deliver requested service or product (Bozarth & Handfield, 2008, pp. 351). To ensure delivery without defects, supplier must be informed on a specific level (Weele, 2010, pp. 42-43). Purchasing order includes order number, requested product details, delivery information, prices, and invoicing address.

3.2.5 Expediting and evaluation

Expediting in the purchasing process refers to ensuring delivery on time (Weele, 2010, pp. 42-43). Expediting requires purchaser to monitor purchase orders and act if necessary, to avoid any delay. Recommended method of expediting is a proactive in which purchaser contacts the supplier in advance. Effort invested to expediting can be minimized by picking the most reliable suppliers and with an effective monitoring system for purchases (Bozarth & Handfield, 2008, pp. 351).

3.2.6 Follow-up and evaluation

Purchasing process continues in its final phase after products are received or service executed (Weele, 2010, pp. 43). Follow-up and evaluation phase require purchaser to manage possible claims for penalty clauses and questions regarding warranties, the supplier is evaluated, and documentation of the process is finished.

The supplier evaluation is important to be recorded (Weele, 2010, pp. 43). Evaluation is targeted to supplier’s quality, delivery, and factors of innovation and competitiveness. For the future purchasing situations, this data can be utilized to select the best performing supplier (Bozarth & Handfield, 2008, pp. 352).

3.2.7 Summary

The purpose of procurement is to acquire required products or services (Weele, 2010, pp. 6) and select the supplier to fulfil the order (Bozarth & Handfield, 2008, pp. 14). Procurement is also responsible for management of the suppliers. Strategic approach to procurement strives to support organization to achieve its long-term goals (Carr & Smeltzer, 1997) by improving procurement performance that leads to lower costs of procurement and by improving quality (Nair et al., 2015). These improvements are achieved through economies of scale, whereby organizations negotiation leverage increases (Rothkopf & Pibernik, 2016).

Procurement process is one of the more complex processes within the organization (Bildsten & Manley, 2015). The procurement process activities consist of determining specification, supplier selection, contracting, ordering, expediting and evaluation, and follow-up and evaluation (Weele, 2010, pp. 9). All the activities that are connected to the procurement process are the activities of the procurement (Weele, 2010, pp. 6).

4 Methodology

In this chapter, research methodology of the thesis is presented. This chapter covers research approach and design, data collection and sample following with description of reliability and validity of the methodology.

4.1 Research approach and design

This thesis is executed as an exploratory case study which consists of multiple case projects in the Case Company. Exploratory studies are suitable for research that is aiming to build overall understanding of the object to be examined (Saunders et al., 2000, pp. 97). Exploratory studies seek to find out what is happening and to develop new insights. Advantage of exploratory research is its flexibility and adaptability to occurring change. In this approach, a researcher is also required to be willing to change direction of the research as new results and insights occurs.

Data of the research is collected through semi-structured interviews and the data is principally qualitative. Collected qualitative data and its analysis is approached from a deductive perspective. The deductive research approach seeks to meet the objectives of the research based on existing theory (Saunders et al., 2000, pp. 390). This thesis presents existing theory and concepts in the literature review which has been used as a basis for this qualitative research.

Interviews of this thesis are executed as qualitative one to one semi-structured interviews. One interview made an exception, where two interviewees from different projects participated in the same interview. The frame of the interview used in this study is based on the literature review of this thesis and previous studies. Semi-structured interviews are non-standardised in which the researcher have a list of themes and questions to cover during the interview (Saunders et at., 2000, pp. 243-244). However, the content of the interview may vary from another based-on interviewee's responses and knowledge.

4.2 Case projects

For this research there are five selected case projects. All case projects are in Southern Finland in Helsinki and Vantaa. Three of the projects were finished during 2020 and two of the case projects are still on-going. Client of four case projects were the Case Company and two of the case projects had an external client. Sizes of the project varied from around 3300 m^2 to 7000 m^2 by gross building area (GBA). Number of floors in the projects varied from 4 to 8 floors. An overview of the case projects is presented in Table 3.

The case project D was carried out by utilizing takt production. Other projects were executed with more traditional production controlling methods of the Case Company.

Table 3. Overview of case projects.

Case project	Location	Status	GBA	Number of floors	Duration of the internal phase in weeks	Client
Project A	Vantaa	On-going	4680 m^2	4	36	Internal
Project B	Helsinki	Finished	6941 m^2	5	32	Internal
Project C	Helsinki	Finished	7082 m^2	7	42,8	Internal
Project D	Helsinki	Finished	4042 m^2	7	47,8	External
Project E	Vantaa	On-going	3316 m^2	4	32	External

4.3 Data collection and sample

4.3.1 Method

Interviews as a research method is very flexible and thus it is versatile for various studies (Hirsijärvi & Hurme, 2008, pp. 34). Interviews are one of the most used data collection methods, especially unstructured and semi-structured interviews. Saunders et al. (2000, pp. 243-244) divide interviews into three categories: structured interviews, semi-structured interviews, and unstructured interviews.

In structured interviews, the interviews are standardized and are based on identical set of questions (Saunders et al., 2000, pp. 243-244). An interviewer asks questions and records responses of the interviewee. Within structured interview, social interaction between the participants is limited only to the set of interview questions. Semi-structured and unstructured interviews are non-standardized interviews in which the content of the interviews is not strictly defined in advance. Semi-structured interview is based on list of themes to cover in the interview while unstructured interviews has a topic of which the interviewee can talk without restrictions.

This thesis utilizes semi-structured interviews as a data collection method. Semi-structured interview is selected for this thesis due to its suitability for the nature of this thesis. In this study, the research objectives and questions are complicated and multidimensional and thus structured approach may ignore important aspects to address the research objectives. There may be important aspects to support understanding that have not been considered by the interviewer, but which are raised during the interview by the interviewee (Saunders et al., 2000, pp. 247).

4.3.2 Process

The data for the empirical part of the thesis was gathered from semi-structured interviews. The interviews were divided into two different structures. Aim of the first interview structure was to solve and understand the current state of the interior phase production and focal factors affecting to the lead-time of the interior phase production. Interviewees of this interview structure were site managers and supervisors from different projects of the Case Company. Information regarding interviewees of first interview structure are shown in Table 4. All interviews were conducted through Microsoft Teams.

Table 4. Summary of the interviews of Interview A.

Interviewee	Title	Experience in years	Project	Date	Length of the interview
Manager A	Site Manager	25	Project A	28.4.2021	41 min
Manager B	Site Manager	8	Project E	28.4.2021	41 min
Supervisor A	Senior Supervisor	12	Project B	29.4.2021	1 h 01 min
Supervisor B	Senior Supervisor	44	Project C	4.5.2021	57 min
Supervisor C	Senior Supervisor	3	Project D	5.5.2021	53 min

The second interview structure was implemented with the subcontractors. Interviewees are shown in Table 5. Aim of these interviews was to understand factors affecting to their production and lead-time and how these factors should be addressed. In addition, the purpose was to gain understanding on how subcontractors have experienced takt production and how it can be implemented to the benefit of all participants in the construction site.

Table 5. Summary of the interviews of Interview B.

Interviewee	Title	Experience in years	Category/service	Date	Length of the interview
Subcontractor A	Chief Executive Officer	30	Wall levelling and painting	18.5.2021	1 h 02 min
Subcontractor B	Chief Executive Officer	42	Flooring	28.5.2021	53 min
Subcontractor C	Installation Manager	20+	Cabinetry	21.5.2021	59 min
Subcontractor D	Departmental Manager	29	HVAC	24.5.2021	58 min

4.4 Reliability and validity

4.4.1 Reliability

Reliability of the study in deductive approach can be assessed by reviewing its consistency and repeatability (Saunders et al., 2000, pp. 100-101; Hirsijärvi & Hurme, 2008, pp. 186). Reliable study is implemented in a way that any researcher can execute the method with similar results (Saunders et al., 2000, pp. 100-101). This is a disadvantage and a problem in non-standardized research methods as non-standardized methods are not always suitable to be repeated (Saunders et al., 2000, pp. 251). In addition, Saunders et al. (2000, pp. 101) presents four threats to reliability of this research method: subject error, subject bias, observer error, and observer bias.

Subject error refers to a factor that may cause unwanted variance to interviewee's responses (Saunders et al., 2000, pp. 101). In this research, the interviewees are informed well in advance with required information to ensure their readiness for the interview to avoid subject error. Subject bias refers to a situation in which interviewees responses are skewed. The interviewees answers as they consider they should answer and not as things really are. To avoid subject bias, all interviews are executed as anonymous.

Observer error refers to interviewer and one's misunderstanding and misinterpretation of responses. To minimize this threat, frame of the interview is semi-structured with themes and questions which are based on the literature review. Observer bias is the greatest threat to research reliability (Saunders et al., 2000, pp. 228). Observer bias refers to researchers unwanted influence on research outcome. Conclusion of the study may be influenced by researcher's own beliefs and subjectivity. To avoid observer bias, frames of the interviews are peer-reviewed by the supervisor and instructors of this thesis.

4.4.2 Validity

Hirsijärvi and Hurme (2008, pp. 186-187) divides validity into four types: statistical validity, construct validity, internal validity, and external validity. Statistical validity is associated with manipulation of statistical data and thus in qualitative semi-structured interviews it is not the most essential in this study. Construct of validity refers to structure of the study and its objectives: whether the study addresses what it is supposed to address. In this thesis, construct of validity is supported by building the empirical part based on the literature review, previous studies, and the research questions.

Internal validity refers to causation of different factors and the outcome is really the result of these factors and is not caused due to another unknown factor (Hirsijärvi & Hurme, 2008, pp. 188). Internal validity is supported in this thesis by establishing findings on only to quotations of the interviewees. External validity refers to generalisation of findings and results in different occasions or subjects. Saunders et al., (2000, pp. 102) states that external validity is a relative issue in a single organisation case study. However, in such cases purpose is not to produce an outcome that is as such generalisable to all occasions. In this thesis aim is to understand what is happening in this research scope and situation.

5 Results

5.1 Interview A – current statue of interior phase production at site

In this section, results of the interviews are overviewed. This interview focused on the current statue of the interior phase production at site. Interviewees of this interview were Case Company's site managers and supervisors from five different projects in Southern Finland. For closer examination, interview structure used for these interviews can be found from appendices.

5.1.1 Focal factors affecting to lead-time of interior phase production

Although the responses considering focal factors affecting to lead-time of interior phase production were partially scattered, three major factors were raised: production schedule, structural engineering, and people.

Every interviewee raised production schedule as a crucial factor for successful interior phase production. Supervisor B stated production schedule as the most important factor to execute interior phase production successfully. The interviewee also argued that the production schedule must include all the minor work phases as well and that the more precise the production schedule, the better. Other interviewees stressed the importance of realistic schedules which are feasible. Supervisor A emphasised that with realistic schedules each work phase can be completed at once and thus avoid re-entries to workplaces. Each re-entry will cause additional unnecessary costs, wasted time, or both. Managers A and B underlined the importance of pay special attention on work phases that are pacing the whole interior phase production e.g., wall levelling and painting. These work phases must be scheduled accurately due to the large impact on other work phases.

To conclude the importance of production schedule:

> *the better the schedule is made, the easier it is to work at site. – Supervisor B*

Structural engineering is referred in this thesis to describe all production design: architectural, structural, and building engineering. There was no clear consensus of views on the structural engineering's effects on interior phase production lead-time. However, in every interview the topic was mentioned as an affecting factor.

Manager A stated that if structural engineering is really flawed, it affects the overall lead-time, but in such scale deficiencies occurs rarely. Supervisor A stressed that it is important that all structural engineering is finished before starting the interior phase production. Thus, interferences of production can be avoided. Also, Supervisor C stated that flaws in structural engineering affects to the interior phase production and its lead-time and there is always flaws in production design but, the overall effect to the lead-time is minor. However, these flaws cause unnecessary work and stress for the site supervisors.

During the interviews, people and their skills and knowledge was highlighted as a crucial factor to the interior phase production lead-time. This factor includes both project management and workers. Produced work in the construction site is performed primarily by workers, thus pace of each work phase is not constant (cf. production line in manufacturing industry), and pace can vary between different workers. However, Supervisor C noted that the subcontractors are committed to the production schedule. Manager B stated that in project management experienced employees are important and often inexperienced employees in project management leads to uneven workload between the management. Supervisor B argued that competence of project management comes back to the production schedule. To create realistic production schedules, experienced project management employees are a necessity.

5.1.2 Disturbances and interruptions in production

In the construction site disturbances and interruptions in production emerge from many different factors. Disturbances and interruptions in interior phase production typically cause a "domino effect" in which one interruption will affect to every next phases. During the interviews, the interviewees identified the factors behind the disruption and interruptions. Identified factors were extended drying times, lack of communication, poor production scheduling, material logistics, quality issues, absences, and unfinished work phases.

Drying times were underlined in every interview. Supervisor C stated that slow concrete drying and variation in drying times is mostly a consequence of seasonal weather changes. Supervisor A argued that drying times are affecting to production and it is not at all times considered thoroughly in the production scheduling. Extended drying times causes delays in certain work phases which affect then to the whole production schedule. Based on the views of Supervisor B, by controlling drying times, often the project's interior phase stays on the production schedule.

Supervisor B stated that lack of communication between different participants leads to overlap of different work phases. As the overlap occurs and multiple contractors cannot work simultaneously, one subcontractor must halt and if there is no other workplace as a buffer it causes idling. Also, a root cause for these overlaps in the first hand is poor production scheduling.

Material logistics were also identified as the factors of production interruption. It is essential to have materials at right place to ensure production flow. Supervisor C underlined that if materials are not at right place at right time, again idle time appears. Supervisor B added to material logistics as interrupter that if materials are moved the risk of breakage of materials increases.

Quality issues that interviewees raised were e.g., incorrectly installed drywalls, concrete related quality issues such as poor concrete post-processing and misplaced power sockets or heating pipes, and painting. Manager B stated that typically these quality issues have a minor impact to the lead-time but causes re-entries and therefore unnecessary work. Supervisor A however had an opinion that if work is completed fully at once, time savings can be achieved.

Absences were mentioned by all interviewees. Interviewees described absence as time when worker or workers was not working on the site as agreed. Supervisor A stated that typical reasons for absences are e.g., illness or if subcontractor is behind the schedule in another construction site, they tend to prioritize their resources to this site. Manager A and B emphasized the significant impact of absences to production in cases where replacement labour resources are not available.

Unfinished work phases were recognized as a reason for interruption in production. Views for its overall impact to the production were scattered in the interviews. Supervisors A and B experienced that unfinished work phases are affecting to next work phases and even the lead-time. On the contrary Supervisor C experienced that unfinished work occurred rarely in Project D and hence its impact is relatively low for lead-times. Managers A and B stated that unfinished work occurs at their projects, but the impact is minor due to time buffers. However, based on the interviews unfinished work phases are one of the most common disruptor and reason for production interruptions although its overall effects were perceived differently.

5.1.3 Anticipation to production disturbances and interruptions

Anticipation to production disturbances and interruption starts from production planning. Supervisor A stated that production planning is required to be implemented in a manner that ensures workflow. The workflow is ensured by securing each workplace for subcontractor at the time. Supervisor B stressed that in production planning the sufficient time for each work phase must be ensured and thus work can be done with high quality and on time.

> *Work must be completed fully and avoid any re-entries. This way production runs like a train. – Supervisor A*

Every interviewee underlined the importance of supervision of work and its progress for ensuring workflow. Manager A argued that with active supervision of work, disturbances and interruptions can be avoided. Supervisor A stated that with active supervision if interruption however occurs in interior phase production, corrective actions to interruption can be done faster and thus avoid major disturbance. Also, Supervisor C emphasized the importance of supervision. The realistic view of work and its progress for project management is ensured with active supervision.

Self-inspection process is a practice in construction site production in which each subcontractor inspects results of their own work before the handover of the workplace for the next subcontractor. Aim is to ensure that work phase is completed fully as agreed and thus avoid disturbance and interruption at the start of the next work phase. This practice of self-inspection is applied also to interior phase production. However, all interviewees considered that its realization varies by subcontractor.

Manager A and B with Supervisor A and C experienced that as self-inspection process is not always done properly, it again increases the workload of the project management. Manager B also added that it is important that each subcontractor inspect and receive next workplace in advance to ensure that they can start and complete their work phase without interruptions. Supervisor A stated that the process of self-inspection and committing to it by subcontractors should be developed for it to work as intended. One option presented by Supervisor A was to make negligence of self-inspection process possible to financially fined by main contractor. Supervisor B did not experience realization as a problem and stated that in Project C, supervisors at site obliged subcontractors to participate and execute the process together with supervisors. However, self-inspection process is the responsibility of the subcontractor. Supervisor A described one implementation of setting quality requirements for the self-inspection process. In this implementation, one apartment is completed and used as a model of quality standard and each subcontractor commits to its quality level.

During the interviews buffer times were underlined as a crucial factor to ensure workflow. Time in production to which there is no scheduled any work and is independent to any variables in production is called as a buffer time (Dlouhy et al., 2019). Buffer times are intended to prepare for changes and disturbances in production e.g., in cases where one work phase requires more time than scheduled, the buffer time can be utilized. Supervisor B argued that the production schedule is facing unexpected changes in all projects and therefore buffer times must be included to the production schedule. Also, Manager B, Supervisor A and C underlined that every realistic production schedule must include buffer times.

Time buffers were stressed in the interviews to avoid disruption and interruptions in the production caused by possible extended drying times. Even if weather conditions affect to the drying times, drying times can be controlled. Supervisor B argued that drying times can be controlled and that it is possible to have similar drying times despite the weather conditions by protecting and sealing windows and doors, by heating, and by striving to get building's heating systems on as quickly as possible. Supervisor C also stated that by using right concrete materials, and by heating, drying times can be optimized but can lead to cost increase.

The importance of communication was also stressed during the interviews to ensure workflow. Supervisor B stated that it is important to communicate between different parties at site and the importance is extremely important in cases in which there is an error which has led to the interruption in the production to tackle issues as effectively as possible. Implementation practices of communication varied by project. Supervisor C argued that weekly meetings are the most effective way to inform all parties. Also, Managers A and B supported the importance of weekly meetings. However, communication also takes place in other ways as well. There are unformal daily conversations at site with subcontractor's workers, emails between supervisors etc. The most important is that there is communication between different parties to ensure the workflow.

5.1.4 Production control and scheduling

Production controlling of Project D was implemented utilizing takt production. Other projects were utilizing more traditional production controlling method of the Case Company. However, there were project-specific differences in production controlling practices in every project.

In Project D, the takt production was implemented with one-week takt times and each floor was defined as the takt area. Production schedule planning was executed primarily by the Case Company. HVAC subcontractors were the only ones to participate in production schedule planning. Supervisor C stated that subcontractors should have involved more to the production schedule planning.

Production schedule faced issues from the beginning of the interior phase production. Wall levelling and painting were incorrectly scheduled which led to extension of the schedule. There were two buffer weeks (colour white in Figure 9) included in the takt schedule which had to be used due to more time required in wall levelling and painting. Delay affected also to next work phases e.g., cabinetry and ordered materials for it had to be stored temporarily. Supervisor C also stated that due to these delays, rest of the interior phase production had to be carried out without any buffers.

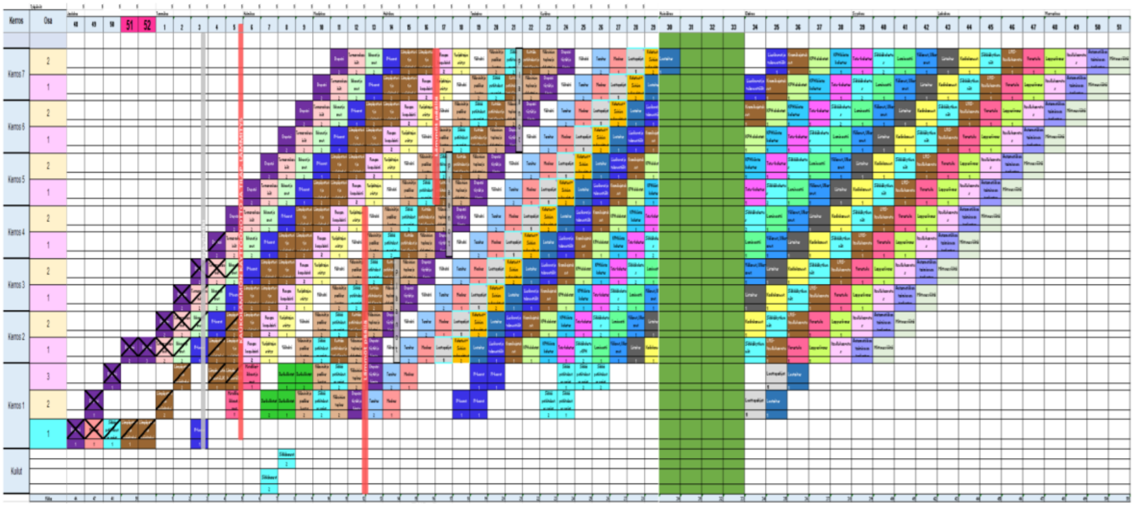

Figure 9. Takt production schedule from Project D.

In other case projects, the production scheduling was also primarily done by the project management. In Projects B and E subcontractor responsible for wall levelling and painting was involved to the production schedule planning due to its high impact to the overall interior phase production pacing. Manager A from Project A stated that the project was relatively simple hence involvement of subcontractors was low but in more complex projects involvement of subcontractors in production schedule planning is required. Supervisor A stated that in Project B, all subcontractors were involved to production schedule planning during the production by using reverse phase scheduling. In the reverse phase scheduling, the schedule is reviewed from scheduled finish to current state.

5.1.5 Committing to production schedule and its changes

As stated earlier, staying on production schedule is crucial for undisturbed production. Hence, committing to production schedule is a key to its success. Committing to production schedule experienced important especially in Project D in which takt production was implemented and buffer times were limited.

Supervisor C stated that there were issues in balancing work to takt schedule. From the start there were problems with wall levelling and painting which required almost twice the time what was originally scheduled. Issues in balancing were not only from extensions of required time but also because of there was not enough work to be done from the perspective of the subcontractor. For example, there were scheduled one week for each takt area (one floor). This included work phase of baseboard installation which not required whole week to complete. Supervisor C stated that this led to a situation in which the subcontractor refuses to fully commit to the takt schedule.

The most common practice of committing subcontractors in case projects was contracting. There have been set sub-goals, which are accepted by the subcontractors. Sub-goals also can be set to be financially fined. Supervisor B argued that the problem of committing the subcontractors to the production schedule is that each participant within the interior phase production typically focuses only their own work phase and ignores other parties and added that every participant should adapt to mindset of collaboration. Possible disturbances in production could be typically resolved more effectively with closer collaboration. Supervisor A stated that effective way to commit subcontractors the production schedule in addition to contracting is to involve subcontractors to production scheduling process.

During the interviews there were differences on the importance of the commitment to the production schedule but in Project D the importance was extremely important because of the strict schedule with limited time buffers. Other case projects were implemented with looser schedule, with time buffers typically from one week to two weeks between each work phases. Time buffers scheduled in Project B can be seen in Figure 10 (empty spaces between work phases) that presents the master schedule of the project. Compared to the takt schedule of Project E, the production schedule of the traditional production controlling method is not as sensitive to interruptions because there are always time buffers to solve any occurring disruptor.

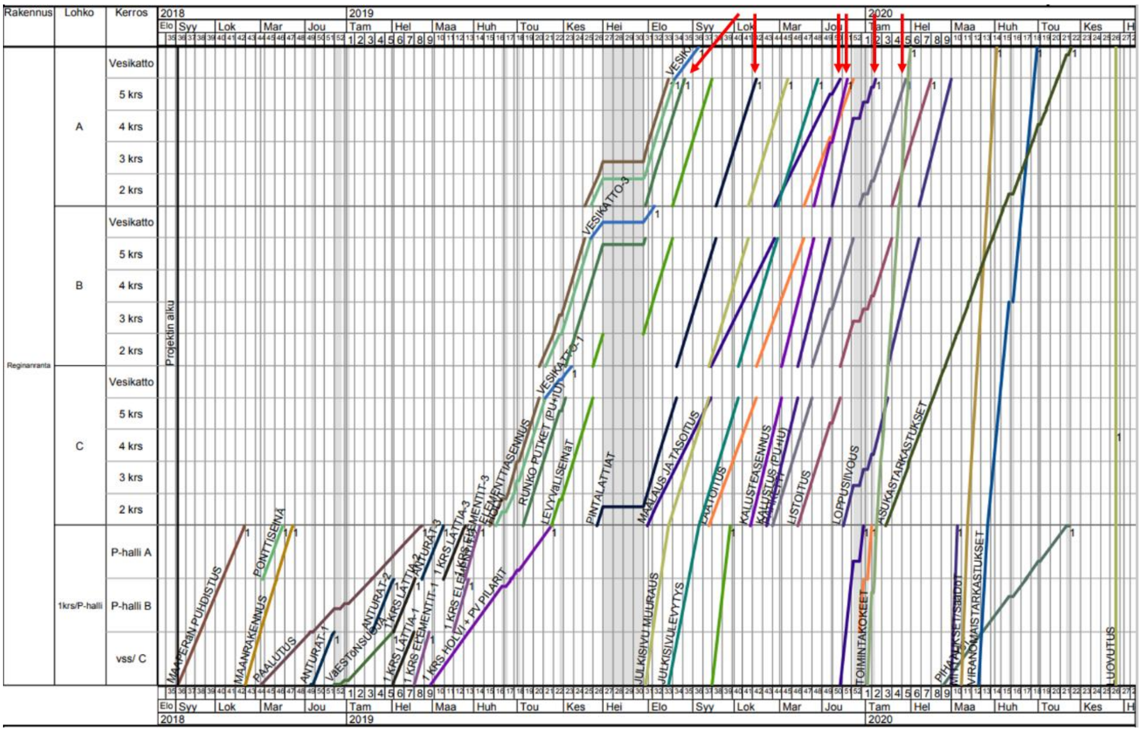

Figure 10. Master schedule of Project B and work phases to be studied.

5.1.6 Support of procurement and takt production in shortening lead-times

Supervisor C experienced that the takt production as an enabler in shortening of lead-time of the interior phase production is possible but it requires more experience and more matured takt production model.

> *I believe that after takt production model matures and experience is gained from its utilization, lead-time of interior phase production can be reduced. – Supervisor C*

Based on the views of Supervisor C, in takt production more attention should be paid to production scheduling process i.e. takt planning. Particular attention should be paid making the production schedule realistic. To a more realistic outcome subcontractors should be involved more to production planning. In addition, takt production should include some sort of time buffers for possible interruptions. Support of procurement to takt production should come from contracting. Supervisor C stated that in contracts, subcontractors should be committed more strictly to takt production and more precise to takt times and areas. Committing to takt production requires also that subcontractors ensures required resources to production scheduling and to the actual production phase. Supervisor A also stressed that procurement should be better understood of events of the construction site. This is achieved by participating more.

During the interviews, takt production was raised as a topic of the discussion. In other case projects, takt production was not implemented and none of the interviewees had previous experience from takt production in practice. The takt production as a concept was familiar to the interviewees. All the interviewees experienced takt production has a potential to reduce lead-times. In particularly, the more precise production schedule was experienced as an enabler to improve the interior phase production. Supervisor B stated that possible issues of the production schedule can be identified and tackled in advance due to more detailed production scheduling. Manager A stated that more detailed production schedule would probably improve forecasting of the production schedule if all contractors commit to the takt production.

The interviews considered that takt production does not cause significant changes to the contracting. Manager B stated that if contracts are changed to suit takt production the risk is that the focus is on too small details. Supervisor C argued that e.g., even if the subcontractor is required to execute the self-inspection process is in contract, it does not guarantee its realization at site. However, based on the interviews, in takt production securing labour resources should be agreed by subcontractor in the contracts.

The interviewees experienced also issues in the concept of takt production. Supervisor A experienced that the problem of takt production is its fragility to interferences and added that there are always factors affecting to the production that cannot be scheduled in advance.

> *If the production schedule is fully optimised, it takes only one mistake and the production schedule is threatened to go awry. – Supervisor A*

Also, other interviewees raised the issue regarding takt production being fragile for any occurring changes. As a solution, the interviewees all stated that in takt production time buffers cannot be completely left out and to succeed in takt production there must be time buffers included.

5.2 Interview B – subcontractors

In this section, results of the second interviews are overviewed. These interviews were implemented together with subcontractors from selected categories: wall levelling and painting, HVAC, cabinetry, and flooring. Interviewees were well experienced professionals from their field. The interviews focused on the current production and factors affecting to its lead-times and the experience of subcontractors in takt production and its implementation.

5.2.1 Factors affecting to lead-time of subcontractors and its shortening

Subcontractors experienced that shortening lead-times is difficult in current production. Shortening lead-times requires significant changes to the production model. For example, Subcontractor C stated that current lead-times can be shortened by a couple of days, but to shorten lead-times significantly, it requires change to whole scheduling of interior phase production.

During the interviews, there were multiple factors identified affecting to the lead-time of studied work phases. Factors identified by the subcontractors were primarily similar to the ones identified by the Case Company's project management. Identified factors were unfinished work phases, production scheduling, quality issues, material logistics, and differences in the management of projects.

Based on the views of the interviewees, the start and progress of the work was most affected by unfinished work phases. Subcontractor C stated that from the perspective of subcontractor it is the most important thing that previous work phases are completed before starting the work phase. Subcontractor A stressed that each work phase is required to be fully completed but the quality of the work must also be in line with the quality requirements to ensure the workflow of the next work phases, and the problem typically spring from self-inspection process that is not executed properly. Also, Subcontractors B and D emphasized unfinished work as one of the most common factors affecting to their production lead-time.

Production scheduling was raised as a factor that affects subcontractors starting of the work. Issues related to starting of work is often linked to the unfinished work. Subcontractor D stressed the importance of timeliness. Scheduling and its resourcing should be implemented as balanced from start to finish to complete work as agreed within the schedule. Also, Subcontractor A stated that staying in schedule is a significant problem in the construction industry and based on their own data, starting of work as agreed is delayed by at least one to two weeks in 80 per cent of all projects they are working. Subcontractor B argued that issues in production scheduling are repeatedly related to drying times. Moisture and its control are neglected in production scheduling that causes delays in starting of work. Subcontractor B added that drying times are major bottlenecks in construction production that requires more attention.

> *Drying times can be controlled with using right concrete materials, and with ventilation and by heating. – Subcontractor B*

Quality issues were raised by Subcontractor A. Problems observed were targeted to concrete surfaces and installation of concrete elements. Variation in quality disrupts forecasting the duration of time required for working. As an example, Subcontractor A mentioned wall levelling that is affected especially from the quality of concrete surfaces. Hence, time and materials required can vary between projects. Subcontractor D stated that quality issues e.g., missing HVAC pipe reservations affects to their work.

Material logistics were also identified as a factor affecting to subcontractor's lead-times. In categories cabinetry and wall levelling and painting, subcontractor's experienced that on-site material logistics affects to the lead-time. Subcontractor C stressed that materials should be delivered to the workplace well before starting the work to avoid any unnecessary waiting in installation of cabinetry. Subcontractor A argued that in current production system, often material logistics related to their work phase at the construction site is performed by e.g., painters that is not cost efficient in every situation and is skill misuse that can be identified as a waste. In addition, material logistics causes traffic at site that can affect to the other ones working. Subcontractor A stated that in takt production working free of interruptions is essential and thus material logistics should be executed in a "night shift" by external logistic worker when there is no other traffic at site.

Significant project-specific differences in project management were considered as a factor affecting to production and its lead-time. However, views on the overall impact to the lead-time was scattered. Subcontractors A and C argued that project and its management is heavily dependent by its people and thus production flow varies between projects. Subcontractor B stated that with bigger companies as the Case Company, the project management is such standardized that changes between projects are minor and affects to their production are small.

5.2.2 Avoiding production disruptions and ensuring the continuity of work

All subcontractors stressed the importance of communication in the construction site. With sufficient communication, all project participants are aware of possible changes in the production scheduling and thus production interruptions can be avoided by anticipating. Subcontractor D stated that project weekly meetings are in key position in effective communication. Subcontractor A argued that communication regarding changes in production schedule is not effective and suggested online platform i.e. subcontractor portal where the main contractor uploads the production schedules and updates these schedules regularly if changes occurs. Interviewees also raised the importance of informal communication. It is important that communication takes place via daily conversations between supervisors and subcontractors. Subcontractor B suggested that the construction site's informal communication can be implemented also other ways e.g., in a group messaging mobile app.

Interviewees stressed collaboration as particularly important in the production scheduling. Subcontractor D argued that if subcontractors are involved to the production schedule planning process, the schedule is more realistic, and the reliability of its forecasting improves. Based on the views of Subcontractor C, collaboration is crucial in problem solving to address problems effectively.

For ensuring the continuity of subcontractor's work, main contractor must ensure workplace to the subcontractor that is free of distraction in which work phase can begin on-time as agreed. Subcontractor A argued that the most important thing is that each subcontractor can complete their work phase fully on schedule.

> *Each delay affects to every following work phases. – Subcontractor A*

Finished work phases requires active supervision of work and effective self-inspection process according to the interviewees. Subcontractor D argued that the self-inspection process is not standardized enough and should be developed to in a more standardized direction. Subcontractor A stated that with standardized self-inspection process it can be ensured that each work phase is fully completed, and next work phase can be executed with free of interruptions.

5.2.3 Previous experience from takt production

All subcontractors had previous experience from takt production implementations from different main contractors in different projects. Views on how utilization of takt production have worked in previous projects were mixed. The concept of takt production was generally considered as a positive development to the construction industry. More precise production scheduling, increasing involvement to the production planning process, and mindset of collaboration was considered as positive aspects of takt production by the subcontractors. However, problems in takt production implementation were also identified. Problems of the previous takt production implementations were balancing of work, missing time buffers, variation in takt production implementation, fragmentation of workload and consequent decline in productivity, and the sensitivity of takt schedule to any changes or disturbances.

In concept of takt production aim is to balance production rates of different work phases. Interviewees considered previous implementations of balancing problematic. In projects where takt areas were divided to much smaller areas compared to traditional production this led to decrease in productivity of subcontractors. Loss of productivity was caused by increasing waiting time (due to lack of space to work with), and from transportation. For example, Subcontractor B described their operations in floor levelling in which significant share of the working time is used to transportation and preparation of machinery and this used time is constant. In takt production working areas for floor levelling has become smaller, and the distribution in working time usage is weighted even more to preparation and transport. Suggestion to this issue was that more machine-oriented work phases are executed outside of the takt schedule. Also, other interviewees stressed the importance of reasonable size of the takt areas.

Takt production models implemented varied from project to project. Differences occurred e.g., in production planning, which work phases were included to takt production, and involvement of subcontractors to the planning process. Subcontractor D stated that in production in which takt production and traditional production models are combined is problematic. If takt production is implemented, all subcontractors should be committed to it. All interviewees considered that it is crucial for successful takt production implementation to be involved to the production planning process.

Major problem of previous takt production implementations was the sensitiveness of takt schedule to occurring changes. Subcontractor A stated that none of the takt production project they have participated has realised as scheduled originally. As the schedules are not realised as planned, difficulties arise from the lack of time buffers. All the interviewees considered that even if takt production contains less time buffers, it cannot be implemented without time buffers. Subcontractor A argued that as long as unfinished work appears in the construction site, takt production is impossible to execute without time buffers and successful takt production will be difficult. Lehtovaara et al. (2019) suggested softer start for takt production. Subcontractors had no experience on soft start in takt production but considered it as a positive concept that should be piloted.

Positive experiences on takt production focused on collaboration and to project production planning. Subcontractor C stated that collaboration is the key for successful takt production and stressed the importance especially in current situation in which takt production is in its early stage. Collaboration and possibility to influence to the production plans considered as a workable mean for subcontractor commitment. Collaboration also was considered to increase the level of improvement. Possible increase in required resources to planning phase of takt production was not considered as a problem. Subcontractors experienced that as more effort is used in the project's early stage the less it is required at during the production phase and at final stages. Subcontractors also considered that with takt production, reducing lead-times is possible after production system matures, and its flaws are tackled.

5.2.4 Shortcomings and questions regarding takt production for the subcontractor

In the interviews, interviewees were asked about shortcomings of takt production from subcontractor's perspective. The subcontractors emphasized that if takt production is utilized in a project, information on its implementation should be available at an early stage of the project. Preferably in the tendering phase of the project. When the information is obtained early, the subcontractors can direct their resources for the project correctly and possibility to the involved to the production planning process. Other foreknowledge was not considered necessary for takt production implementation.

One of the concerns to takt production for subcontractors were that in previous implementations, it is focusing too much on main contractor. Subcontractor B stressed that even if the overall lead-time of the interior phase production is reduced, it may not benefit the subcontractor due to decrease in productivity (e.g., increased waiting). Subcontractor D also argued that it is not always clear for the subcontractor how takt production support their current revenue model and thus committing to takt production may become more difficult. Also, as takt production reduces time buffers, any possible additional work added to original contract is required to plan with consideration on how the additional work is possible to execute without compromising the subcontractor's original responsibilities to the takt schedule.

5.2.5 Committing to takt production

The commitment of subcontractors to takt production requires possibility to get involved to the production planning, collaboration, clarity of the earning model, and continuity for subcontractor. The most important factor for committing to takt production was based on the interviews to get involved to the production planning. Involvement as such is not enough to interviewed subcontractors. There must be an opportunity to influence to the production schedule and thus create the mindset of collaboration.

Interviewees described that collaboration in takt production requires in addition to the involvement to the production planning, an effective communication. In the effective communication, the subcontractors are informed in every stage from the planning phase to the handover. Also, variation in terms of communication should be kept to minimum and strive to more standardized communication models.

Finally, for subcontractors committing to takt production clarity of the earning model is required to be clear. In takt production, ensuring continuous workflow is essential for the subcontractor’s productivity. Subcontractor B suggested that takt production should include financial incentives that motivates subcontractors for committing to takt production. Current practice within the industry is to set penalty clauses from delays but based on subcontractor’s view it may motivate better to commit if the pricing is implemented with bonuses instead of the negative approach. Subcontractor C stated that if subcontractors are committed to development of takt production, also -main contractor should commit to the subcontractors especially in current situation in which takt production is relatively a new production model. Subcontractor C also argued that thus continuous improvement in takt production occurs and collaboration is realised.

5.3 Summary of the results

As broader concepts, factors influencing to the lead-time of interior phase production were identified three factors: production schedule, structural engineering, and people. Disturbances in these factors leads to interruptions and delays of the production. Disturbances and interruptions are result of lack of communication, poor production scheduling, material logistics, quality issues, absences, or due to extended drying times, and unfinished work phases. A key role in anticipating production disruptions is high-quality production planning and active supervision to ensure the workflow without interruptions. Also, for ensuring the workflow, the importance of the self-inspection process and its shortcomings were highlighted by the interviewees. Identified factors and corrective actions raised during the interviews are listed in Table 6.

One of the projects studied was implemented by utilizing takt production in the interior production phase. The utilization of takt production was considered as an enabler for shortening the lead-time. However, the implementation faced issues right from the start of the production due to lack of proper execution of the takt production. The interviewed subcontractors considered the general concept of takt production as a positive development for the industry, but in its current form incomplete. Previous implementations of takt production, subcontractors considered that commitment to takt production requires transparency and effective communication, strong involvement to production planning, and clarity in the earning models.

Table 6. Identified factors as a waste, and corrective actions.

Factor	***Waste***	***Corrective action***
Unfinished work phases	Inventory	Self-inspection process; contracting
Production scheduling	Inappropriate processing	Involvement of subcontractors; subcontractor portal; standardized takt production model; soft start
Quality issues	Defects	Self-inspection process
Material logistics	Transportation, skill misuse	External logistics workers
Extended drying times	Inappropriate processing, waiting	Involvement of subcontractors; production planning
Lack of communication	Motion	Takt control meeting; subcontractor meeting; standardized communication practices
Absences	Waiting	Supplier selection; contracting

6 Conclusions

Poor development of the productivity of the construction industry is widely recognised (Fulford & Standing, 2014). Location-based production controlling method takt production developed from lean construction has shown great potential in reducing the lead-times of construction and thus increasing the overall productivity of the construction industry (Lehtovaara et al., 2019). Procurement also plays a significant role in the industry due to high percentage of outsourced work (Zeng et al., 2018). This thesis examined interior phase production in residential construction. Focus of the thesis was to identify focal factors affecting to the interior phase production and how to address these findings with takt production and procurement.

6.1 Answers to the research questions

Two research questions were defined for the thesis:

1. What are the focal factors affecting to the lead-time of the interior phase production?

2. How procurement process and takt production can support shortening lead-times of the interior phase production?

These research questions are answered in this section of the thesis based on the interviews and the literature review.

The focal factors affecting to the lead-time of the interior phase production are production schedule, structural engineering, and people. These factors are broad concepts that are enabling continuous workflow that is free of interruptions and disruptions. In turn, disruption in these factors results as interruptions and disruptions in the production and as possible delay in the overall lead-time of the interior phase production. In addition, these factors interact with each other and can be partially overlapping especially in situations in which problems occurs in the production. The interruptions and disturbances identified in this thesis that follows from the disturbance in the three focal factors were lack of communication, poor production scheduling, material logistics, quality issues, absences, or due to extended drying times, and unfinished work phases. Identified disruptors of the production were almost identical between the Case Company's interviewees and subcontractors. However, subcontractor's opinions on which are the most crucial factors varied from the Case Company's interviewees opinions.

To answer second research question, it is necessary to discuss it by considering the findings of the first research question. One of the major factors identified was production planning and its importance and impact to the interior phase production lead-time. Takt production and scheduling aims to more detailed production planning and thus less time buffers are required. Hence, lead-time can be reduced. However, as stated in the previous paragraph, identified factors are in interaction with each other and thus to implement takt production successfully other two factors: structural engineering and people must be at the level required for takt production.

Takt production requires strong commitment to succeed. Due to requirement for strong commitment, the importance of procurement increases. As Bozarth and Handfield (2008, pp. 14) stated, the main purpose of the procurement is to select the supplier. In addition, procurement is responsible for supplier management. Procurement and procurement process can support shortening lead-time of the interior phase production in takt production by selecting suppliers that are willing to commit and improve in collaboration. Rose and Manley (2011) argued that to commit subcontractor's procurement must strive for equality between different parties. Hence, trust should be highlighted instead of current practice of financial incentives which by their nature signals for untrust between the main contractor and subcontractors. Selected subcontractor for takt production is required to be able to work in more intense work environment e.g., small subcontractors may not be able to secure the labour resources. There should also be a focus on contracting which supports the commitment of subcontractors to takt production. Although, based on the interviews, no significant changes to the contracts are required for takt production. Finally, in takt production implementation projects the importance of involvement of procurement is important.

6.2 Comparison between results, literature review, and previous studies

Issues identified in the results of this thesis similar in many respects with the previous studies and literature review. Previous papers on takt production have identified barriers and enablers that were similar to the factors affecting to the lead-time of the interior phase production identified in this thesis. Especially disruptors and interrupters identified can be examined from the lean perspective. Most of these identified factors can be interpreted as wastes of production which were presented in Table 1 by Liker (2004, pp. 28-29). From a procurement perspective, the findings were not as obvious. However, the literature review of the thesis supports the conclusions regarding procurement in support of takt production.

Bajjou et al. (2017) argued that over 50 per cent of work in construction industry is equal to waste. Bajjou and Chafi (2020) stated that most common wastes in construction industry are delay in start of activity, rework, skill misuse, long approval process, and unfinished work. Although this thesis does not take a position in waste ratios of production, waiting, transportation, inappropriate processing, inventory (work in progress), motion, defects, and skill misuse were identified from Liker's (2008, pp. 28-29) wastes.

Based on previous studies (e.g., Frandson et al., 2013; Binninger et al., 2018) takt production as an enabler to shorten lead-times is evident. Also, shortening lead-time with current production models was considered challenging by the interviewees. Ahonen et al. (2020) stated that productivity of construction industry has been almost non-existent from 2000s, which confirms the argument that it is challenging to shorten lead-times and thus improve the productivity with the current production models.

Barriers for takt production were identified in this thesis that were also observed in previous studies and in the literature review. For example, buffer times was highlighted in the interviews. Time buffers are addressed in previous studies and Dlouhy et al. (2019) have presented different implementation methods for takt production. Need for buffer times comes from disruptors of the production which were identified in the results section. From these identified factors e.g., drying times and unfinished work were identified as barriers for takt production in the previous studies. Drying times were addressed in studies of Lehtovaara et al. (2019) and Binninger et al. (2018). As in the interviews, Lehtovaara et al. (2019) stated that drying times are not planned in required level. In the interviews, the subcontractors emphasized the importance of fully completed work to ensure continuity of work. Keskiniva et al. (2020) argued that it is crucial to complete each work phase before the start of the next activity. Also, Lehtovaara et al. (2021) identified unfinished work phases in their study case projects.

Literature focusing on procurement in takt production is scarce. Lehtovaara et al. (2019) argued that procurement process plays an important role in committing subcontractors and suppliers to takt production. During the interview's subcontractors considered that the earning model is not clear in takt production cases. Issues regarding the earning model from the perspective of subcontractor was noticed also by Lehtovaara et al. (2019) and by Vatne and Drevland (2016). Albeit literature on procurement in takt production is scarce, procurement and the procurement process theory presented in the literature review of this thesis, responds to many of the issues posed in the results. As Bozarth and Handfield (2008, pp. 14) stated that the main purpose of the procurement is to select the right supplier. The key role of the supplier selection together with contracting and supplier management remains in takt production.

7 Discussion

In this section objectives and practical implications of the thesis are evaluated. Also, the limitations of the thesis are considered. Finally, recommendations for the Case Company are presented following with proposal for the future research.

7.1 Objectives and practical implications of the thesis

The objective of this thesis was to study the current state of interior phase production in residential construction. The thesis aimed to identify the focal factors that are affecting to the lead-time of interior phase production and to address these findings by means of procurement process and takt production to reduce lead-times in the future projects.

In this thesis, focal factors that are affecting to the lead-time of the interior phase production was successfully identified. Based on interviews, previous studies, and the literature review solutions were presented. The findings of this thesis can be utilized in the future projects and thus implement takt production successfully with support of the procurement process to shorten lead-time of interior phase production.

7.2 Limitations of the thesis

This thesis was implemented as a qualitative study. Guidelines of qualitative study were followed but there are also limitations concerning this thesis. Sample size of the projects and interviews were acceptable. However, the views of each case projects were limited to one interviewee. Wider sample size from each project may have affected to the results. In addition, the subcontractors were interviewed from overall perspective. Subcontractors were participating in many of the case projects, but the interviews focused to the wider picture. Interviewees were managers, supervisors, and CEOs and thus their viewpoints may vary for example from the workers perspective.

Interviews were conducted remotely via Microsoft Teams and each interview were recorded. Working remotely change the nature interaction and affects to the conversation and this may impact to the results. Interviews were anonymous but the aspect of recording may also influence to the interviewee's responses. As the study was implemented as multiple case study, the generalisation of the responses is more challenging compared to a single case study.

Limitations considering the literature of the thesis is targeted to the literature on takt production. As the concept of takt production is relatively new, the scientific literature is scarce. Current literature is also primarily published by one publisher, IGLC. There are only a few peer-reviewed articles published in scientific journals.

7.3 Recommendations for the Case Company

Development and implementation of takt production should be continued due to promising results documented from the utilization of takt production. However, the studied Project D was not implemented exactly as the theory of takt production models suggests. Thus, it is recommended that the next takt production implementation is carried out as TPP or TPTC model is planned. Special attention should be paid to takt planning and involvement of subcontractors.

During the interviews issues related to the self-inspection process were highlighted. Unfinished work and quality issues could be tackled by developing effective self-inspection process. Current practice is not standardized, or at least it does not realise as planned in the projects. Especially for takt production, it is crucial to have work phases completed to ensure workflow. If unfinished work, and quality issues can be reduced by developing the self-inspection process, also the need for time buffers reduces. One of the options to increase the efficiency of the self-inspection process is to tie the process to terms of payment.

For the procurement and procurement process in takt production main focus should be paid in the supplier selection. Selected suppliers should be ones who are able and willing to commit to takt production and its development. With selected suppliers and subcontractors strive should be on closer collaboration. Closer collaboration also requires commitment to the suppliers and subcontractors to support motivation and continuous improvement. In contracting, attention should be paid to clear earning model that is beneficial to all parties to promote motivation and commitment. In addition, procurement should be more involved in projects in which takt production is utilized.

7.4 Future research

In this thesis issues of takt production implementation were identified to which this thesis did not directly provided answers. Future research is instead suggested for these subjects:

1. Development of the self-inspection process that supports takt production
2. How to promote supplier and subcontractor motivation and commitment to takt production

References

Ahonen, A., Ali-Yrkkö, J., Avela, A., Junnonen, J.M., Kulvik, M., Kuusi, T., Mäkäräinen, K. & Puhto, J. (2020). Rakennusalan kilpailukyky ja rakentamisen laatu Suomessa. Finnish Government's analysis, assessment and research activities. http://urn.fi/URN:ISBN:978-952-287-926-4

Alarcón, L.F., Rivas, R. & Serpell, A. (1999). Evaluation and improvement of the Procurement Process in Construction Projects. In, Proceedings IGLC-7, 26-28 July 1999, University of California, Berkeley, CA, USA.

Alhava, O., Rinne, V., Laine, E. & Koskela, L. (2019). Can a Takt Plan Ever Survive Beyond the First Contact with the Trades On-Site, In: *Proc. 27th Annual Conference of the International Group for Lean Construction* (IGLC), Dublin, Ireland, pp 453-464. https://doi.org/10.24928/2019/0261

Alves, T., Milberg, C. & Walsh, K. (2012). Exploring lean construction practice, research, and education, *Engineering, Construction and Architectural Management,* 19(5), 512-525. https://doi.org/10.1108/09699981211259595

Aziz, R.F. & Hafez, S.M. (2013). Applying lean thinking in construction and performance improvement, *Alexandria engineering journal,* 52(4), 679-695. https://doi.org/10.1016/j.aej.2013.04.008

Bajjou, M.S., Chafi, A. & En-Nadi, A. (2017). A Comparative Study between Lean Construction and the Traditional Production System. *International Journal of Engineering Research in Africa,* 29, 118-132. https://doi.org/10.4028/www.scientific.net/JERA.29.118

Bajjou, M. & Chafi, A. (2020). Identifying and Managing Critical Waste Factors for Lean Construction Projects, *Engineering management journal,* 32(1), 2-13. https://doi.org/10.1080/10429247.2019.1656479

Bemelmans, J., Voordijk, H. & Vos, B. (2012). Supplier-contractor collaboration in the construction industry: A taxonomic approach to the literature of 2000-2009 decade, *Engineering, Construction and Architectural Management,* 19(4), 342-368. https://doi.org/10.1108/09699981211237085

Bildsten, L. & Manley, K. (2015). A framework for understanding purchasing in building construction companies, *Construction management and economics,* 33(11-12), 865-879. https://doi.org/10.1080/01446193.2016.1164325

Bildsten, L. (2013). Purchasing decisions: enablers and barriers to innovation in construction. In S. Kajewski, K. Manley, & K. Hampson (Eds.), *Proceedings of the CIB World Building Congress, 5-9 May,* Brisbane, Australia. http://urn.fi/URN:ISBN:978-0-9875542-1-5

Binninger M., Dlouhy J., and Haghsheno S. (2017). Technical Takt Planning and Takt Control in Construction. In Walsh, K., Sacks, R., Brilakis, I. (Eds.), *LC3 2017 Volume II – Proceedings of the 25th Annual Conference of the International Group for Lean Construction (IGLC),* Heraklion, Greece, pp. 605–612. https://doi.org/10.24928/2017/0297

Binninger M., Dlouhy J., Müller, M., Schattmann, M., and Haghsheno, S. (2018). Short Takt Time in Construction – A Practical Study. In González, V.A. (Ed.), *Proc. 26 th Annual Conference of the International. Group for Lean Construction (IGLC),* Chennai, India, pp. 1133–1143. https://doi.org/10.24928/2018/0472.

Biton, N. & Howell, G. (2013). The Journey of Lean Construction Theory Review and Re-interpretation. In Formoso, C. T. & Tzortzopoulos, P. (Eds.), *21th Annual Conference of the International Group for Lean Construction*. Fortaleza, Brazil, 31-2 Aug 2013. pp 125-132

Bozarth, C.C. & Handfield, R.B. (2008). *Introduction to operations and supply chain management* (2nd edition). Pearson Prentice Hall.

Brandon-Jones, A. & Knoppen, D. (2018). The role of strategic purchasing in dynamic capability development and deployment, *International Journal of Operations & Production Management,* 38(2), 446-473. https://doi.org/10.1108/IJOPM-10-2015-0656

Carr, A. & Smeltzer, L. (1997). An empirically based operational definition of strategic purchasing, *European Journal of Purchasing and Supply Management,* 3(4), 199-207. https://doi.org/10.1016/S0969-7012(97)00014-2

Dlouhy, J., Binninger, M., Oprach, S. & Haghsheno, S. (2016). Three-level Method of Takt Planning and Takt Control – A New Approach For Designing Production System in Construction. In, *Proc. 24th Ann. Conf. of the Int'l. Group for Lean Construction*, Boston, MA, USA, sect.2 pp. 13–22.

Dlouhy, J., Binninger, M. & Haghsheno, S. (2019). Buffer Management in Takt planning – An overview of Buffers in Takt Systems. In, *Proc. 27th Annual Conference of the International Group for Lean Construction,* Dublin, Ireland, pp. 429-440. https://doi.org/10.24928/2019/0226

Fulford, R. & Standing, C. (2014). Construction industry productivity and the potential for collaborative practice, *International Journal of Project Management,* 32(2), 315-326. https://doi.org/10.1016/j.ijproman.2013.05.007

Fiallo, M. & Howell, W.J. (2012). Using production system design and takt time to improve project performance. In, *Proc. 20th Annual Conference of the International Group for Lean Construction* (IGLC 20), San Diego, CA, USA.

Frandson, A,. Berghede, K. & Tommelein, I.D. (2013). Takt time planning for construction of exterior cladding. In, *Proc. 21st Annual Conference of the International Group for Lean Construction* (IGLC 21), Fortaleza, Brazil, 31 July-2 August 2013.

Frandson, A. & Tommelein, I.D. (2014). Development of takt-time plan: A case study. In, *Proceedings of the 2014 Construction Research Congress: Construction in a Global Network, Atlanta, GA, USA, 19-21 May 2014,* 1646-1655. https://doi.org/10.1061/9780784413517.168

Ghanbarizadeh, A., Heydari, J., Razmi, J. & Bozorgi-Amiri, A. (2019). A purchasing portfolio model for commercial construction industry: a case study in a mega mall, *Production planning & control,* 30(15), 1283-1304. https://doi.org/10.1080/09537287.2019.1612110

Haghsheno, S., Binninger, M., Dlouhy, J. & Sterlike, S. (2016). History and theoretical foundations of takt planning and takt control. In, *Proc. 24th Ann. Conf. of the Int'l. Group for Lean Construction*, Boston, MA, USA, sect. 1 pp. 53-62.

Hirsijärvi, S. & Hurme, H. (2008). *Tutkimushaastattelu – teemahaastattelun teoria ja käytäntö.* Gaudeamus Helsinki University Press.

Holweg, M. (2007). The genealogy of lean production, *Journal of operations management,* 25(2), 420-437. https://doi.org/10.1016/j.jom.2006.04.001y

Jasti, N.V.K. & Kodali, R. (2015). Lean production: literature review and trends, *International journal of production research, 53(3), 867-885.* https://doi.org/10.1080/00207543.2014.937508

Hopp, W.J. & Spearman, M.L. (2011). *Factory physics* (3rd edition). Waveland Press Inc.

Johnsen, T. (2018). Purchasing and supply management in an industrial marketing perspective, *Industrial marketing management,* 69, 91-97. https://doi.org/10.1016/j.indmarman.2018.01.017

Karim, K., Marosszeky, M. & Davis, S. (2006). Managing subcontractor supply chain for quality in construction, *Engineering, Construction and Architectural Management,* 13(1), 27-42. https://doi.org/10.1108/09699980610646485

Karjalainen, K. & van Raaij, E.M. (2011). An empirical test of contributing factors to different forms of maverick buying, *Journal of purchasing and supply management,* 17(3), 185-197. https://doi.org/10.1016/j.pursup.2011.05.001

Keskiniva, K., Saari, A. & Junnonen, J.M. (2020). Takt planning in apartment building renovation project, *Buildings (Basel),* 10, 226-244. https://doi.org/10.3390/buildings10120226

Li, S., Fang, Y. & Wu, X. (2020). A systematic review of lean construction in Mainland China, *Journal of cleaner production,* 257, 1-16. https://doi.org/10.1016/j.jclepro.2020.120581

Liker, J.K., (2004). *The Toyota Way: 14 management principles from world's greatest manufacturer,* McGraw-Hill.

Lehtovaara, J., Mustonen, I., Peuronen, P., Seppänen, O., and Peltokorpi, A. (2019). Implementing takt planning and takt control into residential construction. In Pasquire C. and Hamzeh F.R. (Eds.), *Proc. 27 th Annual Conference of the International. Group for Lean Construction (IGLC),* Dublin, Ireland, pp. 417-428. https://doi.org/10.24928/2019/0118

Lehtovaara, J., Seppänen, O., Peltokorpi, A., Kujansuu, P. & Grönvall, M. (2021). How takt production contributes to construction production flow: a theoretical model, *Construction management and economics,* 39(1), 73-95. https://doi.org/10.1080/01446193.2020.1824295

Nair, A., Jayaram, J. & Das, A. (2015). Strategic purchasing participation, supplier selection, supplier evaluation and purchasing performance, *International journal of production research,* 52(20), 6263-6278. https://doi.org/10.1080/00207543.2015.1047983

Pacheco, D., Pergher, I., Antunes, J., Roehe, V. & Guilherme, L. (2019). Exploring the integration between lean and the theory of constraints in operations management, *International Journal of Lean Six Sigma,* 10(3), 718-742. https://doi.org/10.1108/IJLSS-08-2017-0095

Rose, T. & Manley, K. (2011). Motivation toward financial incentive goals on construction projects. *Journal of Business Research,* 64(7), 765-773. https://10.1016/j.jbusres.2010.07.003

Rothkopf, A. & Pibernik, R. (2016). Maverick buying: Eliminate, participate, leverage?, *International journal of production economics,* 179, 77-89. https://doi.org/10.1016/j.ijpe.2016.05.020

Ruparathna, R. & Hewage, K. (2013). Review of Contemporary Construction Procurement Practice, *Journal of Management in Engineering,* 31(3), 1-11. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000279

Rymaszewska, A. (2016). *Rethinking the Applicability of Lean Philosophy: a conceptual and empirical analysis.* [Doctoral thesis, University of Vaasa]. Osuva. http://urn.fi/URN:ISBN:978-952-476-697-5:

Sabolová, M. & Tkáč, M. (2015). Characterization of procurement process in the construction company, *Investment management & financial innovations,* 12(4), 166-170. Received 2021-02-09 from https://businessperspectives.org/images/pdf/applications/publishing/templates/article/assets/7154/imfi_en_2015_04spec.issue_Sabolova.pdf

Sarhan, J., Xia, B., Fawzia, S. & Karim, A. (2017). Lean construction implementation in the Saudi Arabian construction industry, *Construction Economics and Building,* 17(1), 46-69. https://doi.org/10.5130/AJCEB.v17i1.5098

Saunders M., Lewis, P. & Thornhill, A. (2000). *Research Methods for Business Students* (2nd edition). Pearson Prentice Hall.

Shang, G. & Sui Pheng, L. (2014). Barriers to lean implementation in the construction industry in China, *Journal of Technology Management in China*, 9(2), 155-173. https://doi.org/10.1108/JTMC-12-2013-0043

Tommelein, I.D. (2017). Collaborative Takt Time Planning of Non-Repetitive Work. In Walsh, K., Sacks, R., Brilakis, I. (Eds.), *LC3 2017 Volume II – Proceedings of the 25th Annual Conference of the International Group for Lean Construction (IGLC),* Hereklion, Greece, pp. 745-752. https://doi.org/10.24928/2017/0271

Van Weele, A.J. (2010). *Purchasing and Supply Management* (5th edition), Cengage Learning.

Vatne, M. E. & Drevland, F. (2016). Practical Benefits of Using Takt Time Planning: A Case Study. In *Proc. 24th Ann. Conf. of the Int'l. Group for Lean Construction*, Boston, MA, USA, sect.6 pp. 173–182.

Womack, J.P., Jones, D.T. & Roos, D. (1990). *The Machine that Changed the World,* Rawson Associates.

Womack, J.P. & Jones, D.T. (1996). *Lean Thinking,* Simon & Schuster.

Yunna W. & Ping L. (2012). Centralized Procurement of Construction Enterprises Based on SCMS. In: Luo J. (Ed.) Affective Computing and Intelligent Interaction. Advances in Intelligent and Soft Computing, vol 137. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-27866-2_63

Zeng, W., Tse, M. & Tang, M. (2018). Supply chain quality management: An investigation in the Chinese construction industry, *International journal of engineering business management,* 10, 1-16. https://doi.org/10.1177/1847979018810619

Appendices

Haastattelurunko A – nykytilakartoitus työmailla

Teema 1: Sisävaiheen tuotantoon vaikuttavat tekijät

1 Mitkä ovat keskeiset tekijät, jotka vaikuttavat sisävaiheen tuotannon kestoon?
2 Mistä keskeytykset ja häiriöt aiheutuvat sisävaiheen tuotannossa?
3 Keskeytyksiin vaikuttaminen/varautuminen?
4 Miksi mestalle joudutaan palaamaan ja millä toimenpiteillä se saataisiin minimoitua?
5 Millä keinoilla sisävaiheen läpimenoaikaa voidaan lyhentää?

Teema 2: Tuotannonohjaus, aikataulusuunnittelu ja aliurakoitsijoiden sitouttaminen

6 Kuinka tuotannonohjaus ja aikataulusuunnittelu toteutettiin projektilla?
7 Kuinka aliurakoitsijoiden osallistuivat tuotannon suunnitteluun?
8 Kuinka aliurakoitsijat sitoutettiin noudattamaan yleisaikataulua?
9 Miten varmistetaan urakoitsijoiden töiden eteneminen sekä valmistuminen aikataulu- ja laatuvaatimusten mukaisesti?
10 Miten aikatauluista ja mahdollisista muutoksista kommunikoidaan aliurakoitsijoiden kanssa?
11 Kuinka hankinta ja hankintaprosessi voivat tukea työmaan sisävaiheen tuotantoa läpimenoaikojen lyhentämiseksi?

Haastattelurunko B – urakoitsijat

Teema 1: Nykyinen tuotanto ja läpimenoaika

1 Kuinka paljon läpimenoaikaa on mahdollista lyhentää ja mitä toimenpiteitä se edellyttäisi?
2 Mitkä ovat keskeiset tekijät, jotka vaikuttavat sisävaiheen tuotannon kestoon?
3 Mitkä työvaiheet ovat herkimpiä keskeytyksille ja häiriöille?
4 Miten ilmeneviä tuotannon ongelmia/keskeytyksiä ratkotaan tai tulisi ratkoa ja kuinka häiriöihin voidaan varautua ennakoivasti?
5 Millä toimenpiteillä Tapausyritys mahdollistaa urakoitsijan töiden sujuvan etenemisen?

Teema 2: Tahtituotanto ja hankinta

6 Miten Tapausyrityksen hankintaprosessi ja tahtituotanto voivat tukea sisävaiheen läpimenoajan lyhenemistä?
7 Mitä ennakkotietoja tahtikohteesta tarvitaan ja missä vaiheessa prosessia?
8 Mitä epäkohtia/ongelmia tahtituotanto aiheuttaa urakoitsijalle?
9 Miten tahtituotanto projektilla vaikuttaa tarjousvaiheeseen urakoitsijan näkökulmasta?
10 Kuinka tahtituotanto tulisi huomioida sopimuksessa tuotannon sujuvuuden varmistamiseksi?
11 Kuinka laadunvarmistus toteutetaan niin, että työt tehdään kerralla valmiiksi eikä mestalle tarvitse palata?

Interview A – current state of interior phase production at site

Theme 1: Factors affecting to interior phase production

1. What are the focal factors affecting to lead-time of the interior phase production?
2. What causes interruption and disruption in interior phase production?
3. How to prepare and solve interruptions and disruption?
4. What causes re-entries to workplace and how to minimize re-entries?
5. By what means lead-time of interior phase production can be shortened?

Theme 2: Production control, scheduling, and subcontractor commitment

6. How production control and scheduling was implemented in the project?
7. How subcontractors were involved to the production designing process?
8. How subcontractors were committed to follow the master schedule?
9. How to ensure continuation of work of subcontractors within required schedule and quality?
10. How communication about schedule and changes in it is executed with subcontractors?
11. How procurement process and takt production can support shortening lead-times of interior phase production?

<u>Interview B – subcontractors</u>

Theme 1: Factors affecting to lead-time and its shortening

1 How much lead-time can be reduced and what it requires?
2 What are the focal factors affecting to lead-time of the interior phase production?
3 Which work phases are the most sensitive for interruptions and disruption?
4 How problems are/should be addressed and how to prevent? Subcontractors part and Case Company part?
5 How Case Company can assure continuum of subcontractor's work?

Theme 2: Takt production and procurement

6 How Case Company's procurement process and takt production can support shortening lead-times of interior phase production?
7 If project is implemented with takt production, what information is required in advance? And in what stage of the process?
8 What grievances or problems takt production causes for subcontractor?
9 How takt production affects to tendering phase from the subcontractor's perspective?
10 How takt production should be considered in the contract to ensure fluent production?
11 How quality control should be executed to avoid re-entries to workplace?