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IMPLEMENTATION OF LEAN CONSTRUCTION TOOLS AND THEIR CONTRIBUTION TO SITE MANAGEMENT PROCESS

Master of Science Thesis

Examiner: Professor Kalle Kähkönen
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ABSTRACT

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The objectives of this thesis were to study for Fira Oy, what takt planning process is like in an interior work stage of an apartment building, and what kind of problems appear in its implementation. Because takt production is different from traditional procedures, the demands it sets for site management process were studied. Contributions of several digital tools to a site management process were estimated. Research methods were literature review and a case study, which contained semi-structured interviews and production monitoring.

Theoretical part introduces lean construction and its background. Takt planning and takt control were studied, and the concept of flow was researched from both production and knowledge management point of view. The case study focused on a case site, in which takt planning and several digital tools were implemented. Interviewed people were chosen to represent different work groups, and they were asked questions related to the takt schedule and digital tools. Production was observed by monitoring, if the works were completed due the schedule, and if the data collected by digital tools met the expectations. If there appeared to be differences, their causes were found out.

Takt schedule problems in production were drying times, logistics, incentives and conflicting revenue logic, faults in the schedule, partial implementation, education and communication, contracts, resources, faults in structural design and accidents, absences and other unpredictable factors. Earlier integration into plans and contracts, better planning, education and communication, risk analysis and co-operation with subcontractors and suppliers are recommended solutions for these problems. Traditional site management processes were noticed to be inappropriate for takt production in cases of meetings, model work timing and frequency of work area acceptances and inspections. They should be developed by both contents and frequencies. Digital tools were experienced mostly useful, and they are recommended to be a part of site management. Some shortages were found in digital systems and their features, and they are proposed to be developed.

TIIVISTELMÄ

IINA MUSTONEN: Lean construction -työkalujen käyttöönotto ja niiden vaikutukset työmaan johtamisprosessissa
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Avainsanat: lean construction, tahtiaika, digitaaliset työkalut, työnjohto

Tämän diplomityön tavoitteena oli selvittää Fira Oy:lle, millainen tahtiaikatauluprosessi on asuntorakentamisen sisävalmistusvaiheessa, ja millaisia ongelmia sen käyttöönotossa ilmenee. Koska tahtiaikaan perustuva tuotanto eroaa perinteisestä mallista, sen asettamia vaatimuksia työmaan johtamisprosesseille selvitettiin. Digitaalisten työkalujen kontribuutiota osana työnjohtoprosessia arvioitiin. Tutkimusmenetelminä käytettiin kirjallisuusselvitystä ja tapaustutkimusta, johon sisältyivät puolistrukturoidut haastattelut ja tuotannon havainnointi.

Aluksi teoriaosuudessa tutustuttiin lean construction -tuotantotapaan ja sen taustoihin, jonka jälkeen tutkittiin tahtiaikataulun suunnittelua ja tahtituotannon johtamista. Virtauksen käsitettä tarkasteltiin sekä tuotannon että tietojohtamisen näkökulmasta. Tapaustutkimuksessa seurattiin kohdetyömaata, jossa tahtiaikataulu ja useita digitaalisia työkaluja otettiin käyttöön. Työmaan henkilöstöstä valittiin eri työntekijäryhmiä edustavia henkilöitä, ja heitä haastateltiin tahtiaikatauluun ja digitaalisiin järjestelmiin liittyen. Lisäksi sisävalmistusvaiheen etenemistä seurattiin, ja tarkasteltiin, pysyvätkö työt aikataulussa ja saadaanko digitaalisilla työkaluilla kerättyä ennustettu määrä dataa. Mikäli poikkeamia ilmeni, niiden syyt selvitettiin.

Tahtiaikataulun ongelmiksi nousivat kuivumisajat, logistiikka, ristiriidat ansaintalogiikassa, virheet aikataulussa, osittainen implementointi, koulutus ja viestintä, sopimukset, resurssit, virheet rakennesuunnitelmissa ja sattumanvaraisten riskien realisoituminen. Tahtiaikataulun integrointi hankkeen suunnitelmiin ja sopimuksiin aikaisemmassa vaiheessa, parempi suunnittelu, koulutus ja viestintä, riskien analysointi sekä yhteistyö aliurakoitsijoiden ja toimittajien kanssa ovat ehdotettuja ratkaisuja ilmenneisiin ongelmiin. Perinteisten työnjohtoprosessien havaittiin olevan yhteensopimattomia mallityön ajoituksen, mestan vastaanottojen ja tarkastusten tiheyden ja palaverien osalta, ja niitä tulisi kehittää vastaamaan tahtituotannon tarpeita sekä sisällöltään että frekvenssiltään. Digitaaliset työkalut koettiin enimmäkseen hyödyllisiksi, ja niitä suositellaan soveltuvin osin osaksi työnjohtoprosessia. Joistakin digitaalisista järjestelmistä löydettiin tahtituotannon näkökulmasta puutteita, ja niitä ehdotetaan korjattaviksi.

PREFACE

I want to thank Fira Oy for providing an opportunity for such an interesting research and inspiring atmosphere. Project team in the case site was very warm and welcoming, and there were many spontaneous and interesting conversations about the state of construction. Thanks to everyone who took part in the interviews and helped to understand the topic from different perspectives. Especially I am grateful to my instructors Otto Alhava and Ville Sireni, who have given valuable insights during this research. Thanks for the guidance to my examiner professor Kalle Kähkönen and Tampere University of Technology.

My thesis project was nothing I could have expected. When stumbling through it I learned many valuable lessons, of course through the hard way, even though I had heard people talking about these issues. Thanks to all my friends for providing peer support and encouragement, along with the greatest and most fun years as a student. It has been a privilege to know such lovely people. And lastly, my dear Ville, thank you for everything!

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LIST OF SYMBOLS AND ABBREVIATIONS

Bliot	A condition monitoring system
Congrid	A quality documentation software
Flow	Lean metaphor for a product moving smoothly in a production line, or in construction crews, materials, information etc. factors moving through locations
Haltian	A motion detection system
Insite	Business intelligence view, which combines data from ODP and visualizes the information
JIT	Just-In-Time
Kaltiot	A condition monitoring and location tracking system
Lean	Production philosophy, that aims reducing waste and adding customer value
Lean construction	Lean application developed for construction industry
LPDS	Lean Project Delivery System
LPS	The Last Planner System
ODP	Open Data Platform
PPC	Percent Plan Complete
PPO	Portfolio, Process and Operations model
SiteDrive	A scheduling software
Site Manager	An access control and license management system
SSU	Standard Room Unit
Takt	Constant time period
Takt area	Area, in which tasks need to be completed within a takt
Takt control	Management of takt production
Takt planning	Scheduling method based on takts and takt areas
TFV	Transformation-Flow-Value-theory
Train	Sequenced works or wagons in a takt schedule
Wagon	A set of tasks completed in one takt
WIP	Work in progress

1. INTRODUCTION

1.1 Background and motivation

Construction productivity has been a long-lasting and serious concern, because it has not been improving during the last decades. As one of the most traditional and broad industries construction has a significant impact on public economy. Statistics Finland has surveyed productivity in industries since 1976 and rates in figure 1 indicate that construction productivity remains low, while manufacturing has improved considerably.

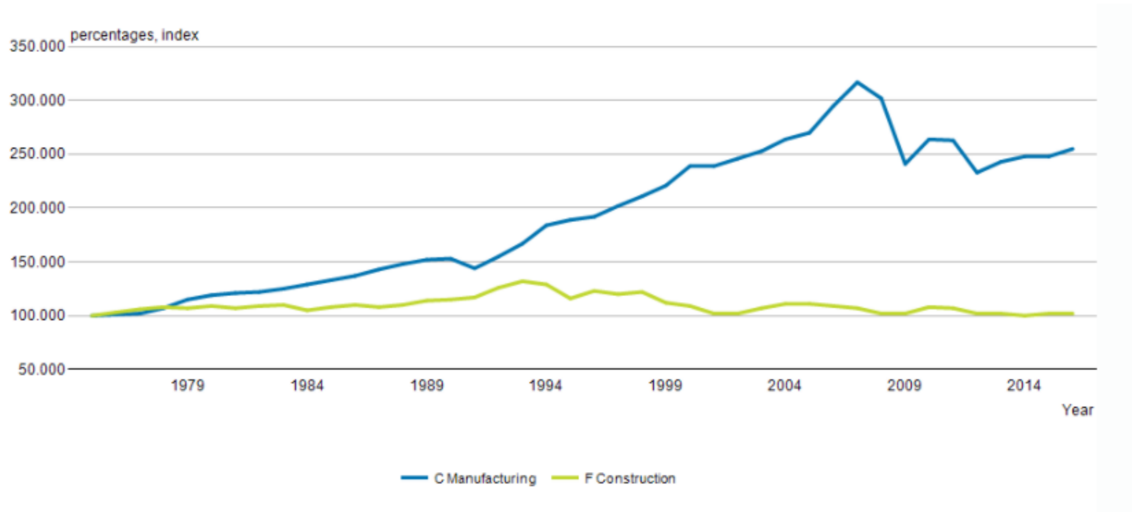

Figure 1: *Multi-factor productivity by industry, value added by industry, sector, type and year. Index 1975=100 including labor composition (Statistics Finland)*

Some significant factors explain the difference between the industries. In construction every product is a big unique on-site project with architectural design aspects and labor-intensive methods. Complexity and uncertainty of projects has been growing because of the customers growing demands and detailed requirements. Contracts has been distributed into numerous subcontracts, which makes projects very complicated. Organizations and supply chains have become dynamic by nature. (Ballard and Howell 1998, Koskela et al. 2002, Salem et al. 2006, Park et al. 2005) Construction productivity has also been considered as a very difficult industry to evaluate, and there has not been a standard measurement system. This may explain some of the numbers. (Park et al. 2005)

There are still signs of a great saving potential in construction. Many researches evidence, that productivity can be improved with better management (Shehata and El-Gohary 2011, Arditi 1985, Koskela 2000) The Business Roundtable found out that more than half of the time wasted was because of poor management (1983). Because of disruptions and constant changes, labor performance may lose 25-50% of its efficiency. (Thomas and Napolitan 1995) Situation in these days has not been improved. One practical example of this is a Finnish pipe renovation company, which noticed that bathrooms are empty 80% of the renovation time (Kauppalehti 2016). Construction seems to struggle with project management year after year.

In search of ways to improve productivity, lean ideology has been one of the great interests. Lean is a production philosophy that aims to reduce waste and add value with some clear principles and methods. Lean has origins in car industry and it has been successful in manufacturing. Because of the differences between manufacturing and construction, all the methods are not applicable as such. Lean construction is an application developed for construction special needs. (Alarcón 1997) According to studies, productivity of whole project can be improved by eliminating waste and variability, which is one basic principle in the ideology. (Ballard and Howell 1998) Lead time of the project can be reduced, when unnecessary movement, waiting time, rework and other types of waste are reduced. Because of better control of the production, lean could also be a solution to quality and safety problems, that have been discussed in the media lately. (Koskela 2000)

When pursuing shorter lead time, takt planning has been proved to be a beneficial tool. It complies with lean basic principles, but additionally it provides a practical way to schedule and organize works. Significant time savings has been reported, and takt planning seems to stabilize the work flow, by setting clear objectives for short time performance. Variability, which appears to be one type of waste, can be reduced by means of takt planning. (Binninger et al. 2018, Haghsheno et al. 2016, Frandson et al. 2014) Takt planning sets different demands for site management, because work stages follow each other more frequently, and there are more simultaneous works going on. Information technology could be one kind of solution to improve the management, because it helps to acquire, organize, storage and distribute information and hence situational awareness. (Cooper 2016)

1.2 Objectives

This research is a part of a bigger development project, which aims to improve construction productivity. The research was made for Fira Oy, which from now on is referenced as a case company. The case company has decided to implement takt planning in their construction projects, and by implementing takt planning, the case company seeks for time savings and hence better productivity.

Objectives of this research are to find out, what the takt planning process is like, and what kind of challenges and problems appear when implementing it. Takt planning sets demands for conventional procedures, so the changes in the interior works process are researched, and it is studied, if site management processes need to be adapted to the new kind of production. Along with takt planning, several digital tools were implemented to try, if they enhance the site management in takt production context. Only interior works in an apartment building are considered, because takt planning was not implemented in other work stages yet.

Based on these objectives, the research questions are:

1. What takt planning process is like in an apartment building's interior work stage?
2. What are the main problems in takt planning implementation?
3. What kind of demands takt planning sets for traditional site management?
4. How could digital tools contribute in the takt management processes?

1.3 Research methods

Research methods were literature review and a case study. The theoretical background for takt planning was studied by literature review, and the main aspects of information flow and its management were studied, to find out how digitalization could affect in management processes. A construction site of a 7-floored apartment building in Helsinki served as a case site, in which takt planning and several digital tools were implemented. The implementation was monitored by observing the data that implemented digital tools provided, and by monitoring, whether the tasks were done due the schedule. If there appeared to be shortages in data, or the works were late, the causes were found out and reported. Disruptions in the schedule revealed some issues that the case company needs to focus on in takt planning and takt management. Monitoring period started jointly with interior works, and it ended after the fixtures. Most of the work stages in interior works were included; only the finishing stage was entirely excluded.

Along with observation, there were 10 semi-structured interviews made in co-operation with case company's user-experience specialist. The purpose of the interviews was to find explanations for the findings of the observation and have some different perspective. Different roles in the case site were identified and the interviewees were chosen to represent each group. Six different groups were found altogether; 1) contractor's management, 2) contractor's supervisors, 3) agency workers, 4) subcontractors' management, 5) subcontractors' supervisors and 6) subcontractors' workers. Because both management groups seemed to fit poorly in this framework, they were left out from this research. The numbers of the interviews in each studied group were: contractor's supervisors 3, agency workers 2, subcontractors' supervisors 3, and subcontractors' workers 2. Interview questions were related to takt planning and piloted digital systems, and they can be found in appendix 1. The case company's management processes were introduced and the conflicts with takt planning were studied.

1.4 Structure of the research report

The research starts with introduction, in which the background and motivation are introduced, along with the objectives, research questions and methods, and structure of the research. Second chapter is a literature review focusing on lean construction, which provides the theoretical background for the study. Conventional project problems are reviewed, lean origins and principles are introduced, and the application in construction is studied. Effects of partnering and subcontracting are estimated. After this, the takt planning and takt control are researched. The role of information flow and basics of knowledge management are introduced in lean construction context.

After the literature review, third chapter introduces the case study. The case site, and the pilots of takt planning and digital tools are introduced, and their findings are discussed. The case company's site management processes are studied, and their adaptability with takt production is estimated. Fourth chapter is a discussion, in which the main findings are introduced, their contribution is estimated, they are compared to the previous research and the limitations of the study are discussed. Fifth chapter is a conclusion with recommendations for the case company and further research.

2. LEAN CONSTRUCTION

2.1 Review of the conventional project management

Construction is a very traditional business controlled by considerable amount of laws and regulations. Production management systems in different companies are often settled upon similar procedures over the years. This makes things easier when working with subcontractors, because both sides are familiar with the process. Bureaucracy, either regulated or proved its worth with conventional management processes, is strongly implemented to the process. The whole construction system has been growing more complex along with buildings. Even though there are good aspects in conventional project management, there are many downsides too.

Conventional production planning procedure starts with dividing the project into small activities and needed time and money to complete each are estimated. Schedule is made by putting those activities in order and release of work from one crew to another is ignored. Contracts are made with existing knowledge, and commercial terms define each task. This causes push for work to begin on the earliest start date, even though there would be no real prerequisites for completing the work. (Koskela et al. 2002)

Controlling projects is loose tracking of costs and schedules, and actions are rarely taken. Start dates are well controlled, but tasks last longer than planned, because of discontinuities and delays. When one subcontractor ends up working in the same location with another one, interruption usually appears. There is a significant delay if a subcontractor needs to demobilize the crew, because of lacking available work on the site. (Seppänen 2009) Frequent interruptions have been widely accepted, and they are dealt with buffering schedules. Time buffers allow inaccurate planning, and hence even more variation and risks in projects. Poor control equates low reliability. (Koskela and Ballard 2006)

Productivity of a single task is often measured by costs, unit rates, time and total work hours. Labor productivity is directly related to the costs and performance, so the measures do matter. The problem is that demands are often set for the whole result, and not for gradual progress. Because of this, variability of daily work performance can be high, and there are no consequences because of generous time buffers. High variability in productivity rates is an indicator of a poor practice, but it also can derive from conditions, design errors, accidents of changes. (Thomas, 2014)

2.2 Lean ideology

Lean is a production management ideology that has its origin in car industry. Toyota succeeded to develop the world-famous Toyota Production System which is commonly considered as a precursor of lean. Similar ideas were introduced earlier, for example by Henry Ford in early 1900s, but the real breakthrough was because of Toyota. Few basic writings serve as a foundation for the later studies. Lean principles are often derived from Toyota Production System: Beyond Large-Scale Production by Taiichi Ohno (1988) and The Machine that Changed the World by James P. Womack, Daniel T. Jones and Daniel Roos (1990). One of the later important releases is Lean thinking: Banish Waste and Create Wealth in Your Corporation by James P. Womack and Daniel T. Jones (2003).

The word "lean" represents the idea of keeping only the vital parts of the process, and reducing everything unnecessary, so-called waste. To identify waste, process must be studied, and transformations that create customer value must be identified. Waste consist of three types; unnecessary work, overburden and unevenness. Besides value stream, there is also work that is non-value-adding but necessary, for example cleaning and logistics, so the process may be difficult to define. (Womack and Jones 2003)

Transformation processes should be simplified as far as possible by dividing them into small and simple subsequent tasks. Well organized workplace makes working more effective, safe and simple. When the process and its requirements are known, organized and trimmed, flow needs to be created. Flow is a self-explaining word for the subsequent tasks following smoothly each other. In the ideal situation waste would have been removed and all the work would create value. Overproduction is one type of waste, so flow must be fitted into customer demand. This happens by avoiding pushing the production and using the idea of pull flow. Because situation hardly reaches ideal, one of the main lean principles is continuous improvement. (Womack and Jones 2003)

Lean is very well known by its techniques and it is often considered as a tool set to improve productivity. This approach often includes Japanese names for the techniques and very precise descriptions, how to implement and utilize them. Another approach is to consider lean primarily as a cultural cause, which creates viable conditions for change and improvement. Organization, that is ready for change, can utilize tools to achieve its internal goals. In lean culture all the people are respected, and the whole organization pursues for improvement. It is discussed, that cultural aspects are more important, and much more difficult thing to implement. (Atkinson 2010) Pekuri et al. identified three different layers of lean (2012);

1) principles and culture
    - customer first
    - continuous improvement
    - respect for people

2) practices
    - eliminating waste, unevenness and overburdening
    - standardization
    - visual management
3) tools and methods
    - lean production
    - lean product development
    - lean construction.

These layers help to understand the structure of different approaches. The model specifies the traditional division into lean thinking and lean production. It is argued, whether it is better to start implementation with outer (principles and culture), or inner (tools and methods) layers first. Philip Atkinson blames in his article Lean is a cultural issue (2010), that most organizations are focusing too much attention on the technical aspects of lean, when more important angle would be creating a culture, that will sustain it. He points out, that lean cannot be implemented upon organization, which does not have a change-welcoming culture. No amount of training in tools and techniques compensates the changes in culture and behavior. (Atkinson, 2010) Others prefer implementing lean tools, like Last Planner System first, because it quickly gives notable improvements and motivates to carry on with change. (Dave et al. 2015) Some even advise to seize or create a crisis to use as a lever in implementation process, but there are more moderate approaches in implementation processes too. Advices of using a change agent, getting the knowledge, visible activity with immediate and measurable results and utilizing the momentum are more widely acknowledged. (Howell and Ballard 1998)

2.3 Applications in construction

Because there had been difficulties with implementing lean into construction field, lean construction started to diverge from the original manufacturing context. Ballard and Howell granted in their article “What kind of production is construction?” (1998) that some constructions characteristics are “apparently lean-resistant”, and should only be changed when appropriate. They categorized construction as a project-type business, with very jumbled flow, loosely linked process segments and relative uniqueness. Later opinions of the type are more diverse; work stages are rather repetitive, and from subcontractors’ point of view, the volume of repetitive production is so high, that their work could be categorized as line flow. The production flows are different between work stages, so the challenge is to match the flows compatible, and improve the interfaces between them. (Sacks, 2016)

To enhance lean implementation to construction, Koskela created the TFV theory of production that combines views of transformation, flow and value (2000). Transformation from inputs into outputs is divided into tasks, that need to be carried out as efficiently as possible. Flow includes transformations, but additionally waiting, moving and inspecting are part of the concept. Aim is to maximize the transformation by minimizing the amount of waste. Value means the fulfillment of customer needs, and it defines which transformations are valuable. (Koskela 2000) TFV theory's main contribution is to provide different views in modelling, structuring, controlling and improving production, and transfer manufacturing ideology to construction context. (Koskela et al. 2002)

Another important milestone in applying lean into construction was Lean Project Delivery System (LPDS), which is pictured in figure 2. The contribution of the model is to picture the whole construction project from its definition to use and point out that the change cannot be made in site alone, if the other parts are not supporting lean. Maximizing value and minimizing waste starts with studying, what a customer wants. Design, supply and assembly should support these objectives. (Ballard 2008)

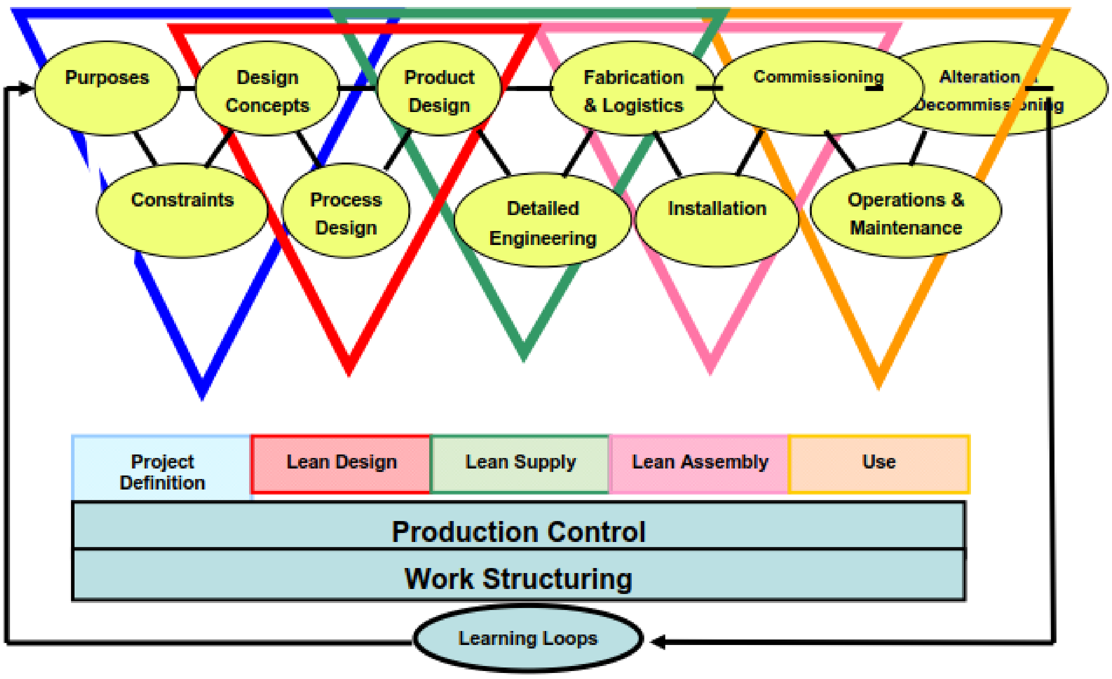

Figure 2: *Lean Project Delivery System (LPDS) (Ballard 2008)*

Concept of waste is relatively similar in construction and manufacturing, but their distributions and appearance are different. Traditional lean management identifies seven types of waste, which are overproduction, correction, material movement, processing, inventory, waiting and motion. (Ohno 1988). Some of these waste types can be easily found in construction, but some seem not to be major problems. In project business for example the concepts of overproduction and inventory are fundamentally different, but they both exist. Overproduction can come up in construction, if for example the structures are unnecessarily solid, or the features overrun the customer demands. According to the lean ideology these situations can be categorized as waste because they do not add customer value. Inventory is another example of the complexity in identifying the waste. Among unsold apartments, there can be numerous inventories of tools, materials and components in every link of the supply chain. Because of the versatile nature of waste, identifying should start with studying the production process; what are the actions, that really provide additional value to the customer? It is a simple question, but the answer rarely is as straightforward as it seems.

Lee et al. (1999) listed the main issues in construction, and they ended up in seven wastes: delay times, rework and quality costs, unnecessary transportation and long distances, lack of work safety and on the top of these poor project management. Koskela (2000) mentions defects, re-work, machine break downs, accidents and layout as waste, and points out, that especially variability leads to additional waste. In modern subcontracted projects contracts are often relatively small by contents but highly specialized. Interestingly, Koskela (2000) identified, that waste increases, when a task is divided into subtasks. This creates more inspecting, moving and waiting. When work-in-progress (WIP) accumulates, lead time increases. This often derives from variability and the lack of maturity of the tasks. They prevent completing tasks at once, which leads to several locations started but not finished. (Koskela, 2000)

2.4 Subcontracting and partnering

Discontinuous and project-based nature of the industry has been disturbing lean implementation. Because of the big number of suppliers and subcontractors, implementation process seems to start from the beginning in every individual project, with different people and different companies. Per Erik Eriksson (2010) emphasizes supply chain improvement by implementing lean in all activities during the whole buying process. If contractors are chosen based on lowest tender price, their attitude will be self-protecting, rather than favourable to change and customer satisfaction. Partnering ensures the possibilities for continuous improvement and for change of conventional procedures. (Eriksson 2010) Frandson and Tommelein ended up in good results, when involving the partners at early stage in planning. (2014) The accuracy of the takt schedule improved, and some work packages were re-arranged to create a better flow.

Sacks introduces in his Portfolio, process and operations (PPO) model the idea of continuity of work flow between projects (2016). This brings in the perspective of a subcontractor. Partnering enables main contractor to provide a continuous portfolio of projects to a subcontractor, which benefits both sides and unifies their objectives. Conflicting interests of a main contractor and subcontractors appear to be problematic.

Multiple projects enable subcontractors to let available work accumulate in each project, so there would be no obstacles, when trying to reach maximum productivity. This can be called buffering of locations, and it causes major disruptions in projects. The situation can be called overbooking, because the subcontractors cannot supply all the sites simultaneously, if there appears to be more work available than expected. Traditional approach is to use large time buffers between subcontractors, so the work availability would be higher, and it would enhance the productivity of a single subcontractor. This sub-optimization leads to high amounts of WIP, and hence longer duration of the whole project. Unreliable schedules can make the situation worse, and lead subcontractors to buffer their production even further. (Sacks 2016, Sacks and Harel 2016)

Partnering, or more precisely project portfolio, is one of the suggested remedies. Its objectives are to align long-term interests and increase trust between contractors. But partnering alone is not the answer to improve performance; if the variability remains high, there is still risk of low productivity. Reducing variability benefits subcontractors and encourages them to allocate their resources relying on a main contractor's estimation. The economic risk should be equally shared, and the production planning should be transparent. When the subcontractors do not have enough information of the production, they choose to leave the site when it seems that losses occur from their point of view. (Sacks 2016, Sacks and Harel 2016) Frandson and Tommelein noticed that subcontractors needed more top-down management than partners, when controlling the work flow. (2014)

2.5 Takt planning

Takt planning is a scheduling method, that is based on setting a working period that always has a constant duration (takt). Workflow is adapted to match the takt by dividing project into appropriate sequenced packages of tasks (wagons), and by dividing the working area into appropriate subareas (takt areas). The set of sequenced wagons, which move through takt areas, are called trains. (Haghsheno et al. 2016) Takt planning has been adopted in construction, and the results have been very good. Lead times of the projects have been reduced, and time savings up to 55% has been reported. (Binninger et al. 2018) Among shortened lead times, overproduction is prevented, and work processes are stabilized. (Haghsheno et al. 2016) Takt planning increases the common understanding by developing a daily goal for workers to meet, and work is being released at even intervals. It increases focus on lookahead planning and make ready analysis. (Frandson et al. 2014)

In construction customers rarely have productivity rate demands for tasks, so the demands can be set to match the takt. (Frandson et al. 2014) The takt planning follows next steps:

1) Identify the standard room unit (SSU). SSU is the smallest replicable area with similar work stages. If there are areas that contain different work stages, they can be divided into their own trains, like apartments and bathrooms.
2) Determine the takt area, which can be one or more SSUs, for example if an apartment is considered as an SSU, the takt area can be one apartment or one floor.
3) Create appropriate sequenced work packages, which contain all the tasks in one SSU. Many work stages in construction have a natural sequence. There is still slight variability and the packages can be composed differently.

4) Decide the takt. Takt length should be appropriate, so the all the tasks can be done on time. Resources can be considered as variables and they can be added to match the performance into takt.
5) Level the work packages (figure 3) and buffer the production. (Haghsheno et al. 2016)
6) Plan the release of work and continuation of flow. (Frandson et al. 2014)

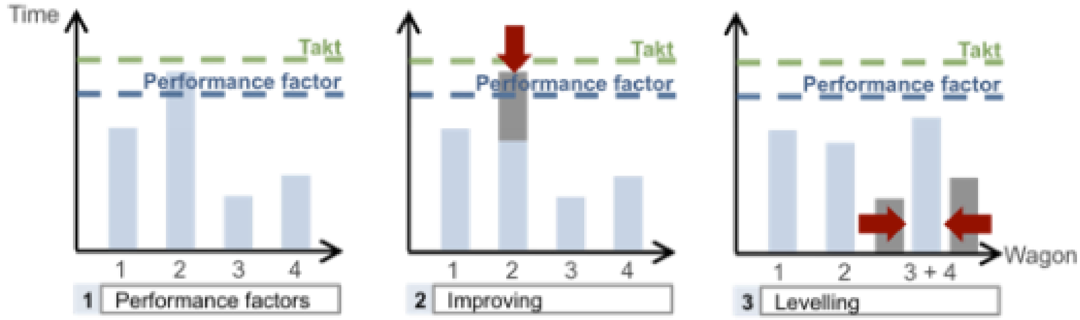

Figure 3: *Levelling the work packages (Haghsheno et al. 2016)*

Studies show that lead time decreases when using shorter takt. Lead time of the project can be calculated by the equation:

$$Lead\ time = (Number\ of\ Takt\ Areas + Number\ of\ Wagons - 1) \times Takt.$$

Takt and the size of takt areas are directly related if the capacity remains the same. Hence the number of the takt areas is related to takt. Takt has significantly higher effect in lead time than other factors, so using short takt has its advantages. One week is a commonly used length for a takt, but even 15-minute takt has been used in cruise ship cabin refurbishment and the applicability of it to construction has been discussed. (Binninger et al. 2018)

2.5.1 Reducing variability

Common sense is that construction productivity can be improved by increasing resource utilization. Studies indicate that the common sense is wrong; instead of improving productivity, the high utilization rates of the resources seem to lead increasing variability. Variability increases the whole project time, and effect is similar than rush hour in traffic; when the density of traffic increases, even a small perturbation can cause the speed to drop to zero. Constant accelerating and braking make the situation worse, than it would be when driving slower but uniform speed. (Howell et al. 2001) One good measure for work flow reliability is Percent Plan Complete (PPC) which indicates how many of the planned assignments can be completed in time. (Ballard 1999) Howell et al. concluded that with the same target wait time the higher PPC increases the capacity utilization. (2001) The effect of PPC is shown in figure 4.

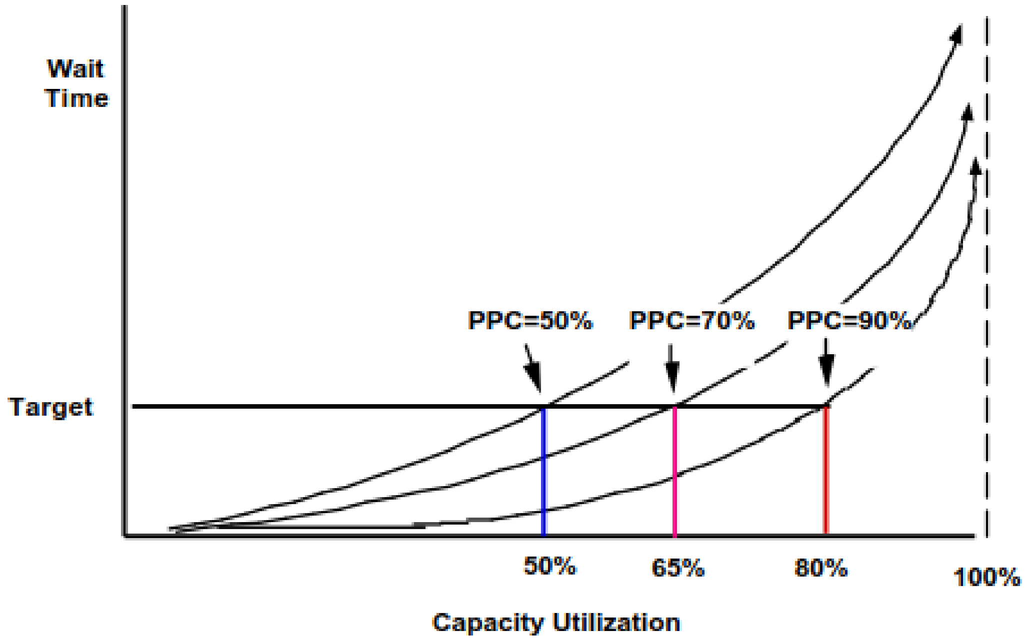

Figure 4: *Capacity utilization, wait time and the effect of PPC (Howell et al. 2001)*

High utilization rates benefit the subcontractor, because their earning is not depending on the outcomes of the whole project. They choose to work when there is plenty of work available, and they can make the best out of their contract. (Howell et al. 2001) One way to improve the utilization rate are sound assignments, from which all constraints have been removed. If design information is current and requirements are clear, resources are easily available and work space has been allocated, the productivity of the crew improves. (Ballard 1999)

Variability causes the release of work getting uncertain. The variability in a single task duration is presented in figure 5. When the time of the task varies between time A and time B, there are few options to plan the continuous work flow. The duration of the tasks can be set to the time B, which is longest possible time it might take. This way the next crew has work available, and they do not have to wait. One option is to set the duration to the time A, which is the earliest moment the task can be ready. The following crew probably need to wait for the prerequisite task to get finished, but the method leads to the quickest progress in the project. Another option is that the prerequisite crew informs the following crew when the task is finished. (Howell et al. 2001) This may be problematic if the crew is working elsewhere or they are otherwise unavailable.

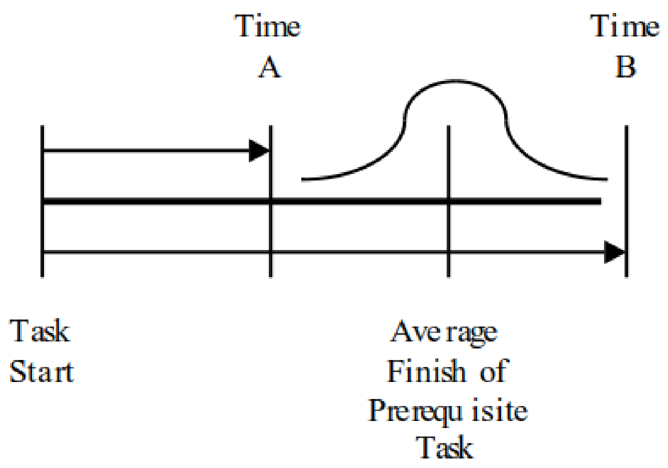

Figure 5: *Variability in task finishing time (Howell et al. 2001)*

It must be noticed, that overtime causes decrease in labor productivity compared to typical 40-hour week. Such factors as shift work and overmanning have similar effect. (Hanna et al. 2005) These factors must be considered when planning the resources, because doubling the crew or working hours may not double the performance.

Real schedule variance appears when a task moves into another takt sequence, not when varying within its own takt. Frandson et al. called this smaller non-affecting variance as a schedule noise. (Frandson et al. 2014) Variance in working areas, for example between apartments and public areas, can be dealt with using separate task forces for the public areas or part of it and keep them out of takt schedule. If some apartments are considerably bigger than others, they can be scheduled last in the sequence with longer takt, or they can be treated like public areas. (Heinonen and Seppänen, 2016)

Takt plan is not a fixed concept, and it is more likely constantly evolving. (Haghsheno et al. 2016) Updating the schedule might be difficult because of the complexity of it. Same reason compromises the visuality. Dlouhy et al. suggest a three-level model to master the complexity of the takt schedule without additional buffers. (2018) Dividing the schedule into macro, norm and micro levels enables appropriate view in different use cases. Visuality and understandability remain good, and even all the smaller tasks can be added to the same schedule. Division is demonstrated in figure 6. Importance of the visuality of the schedule has been proved, so the model offers a welcome solution for improving it. (Frandson and Tommelein 2014, Salem et al. 2006)

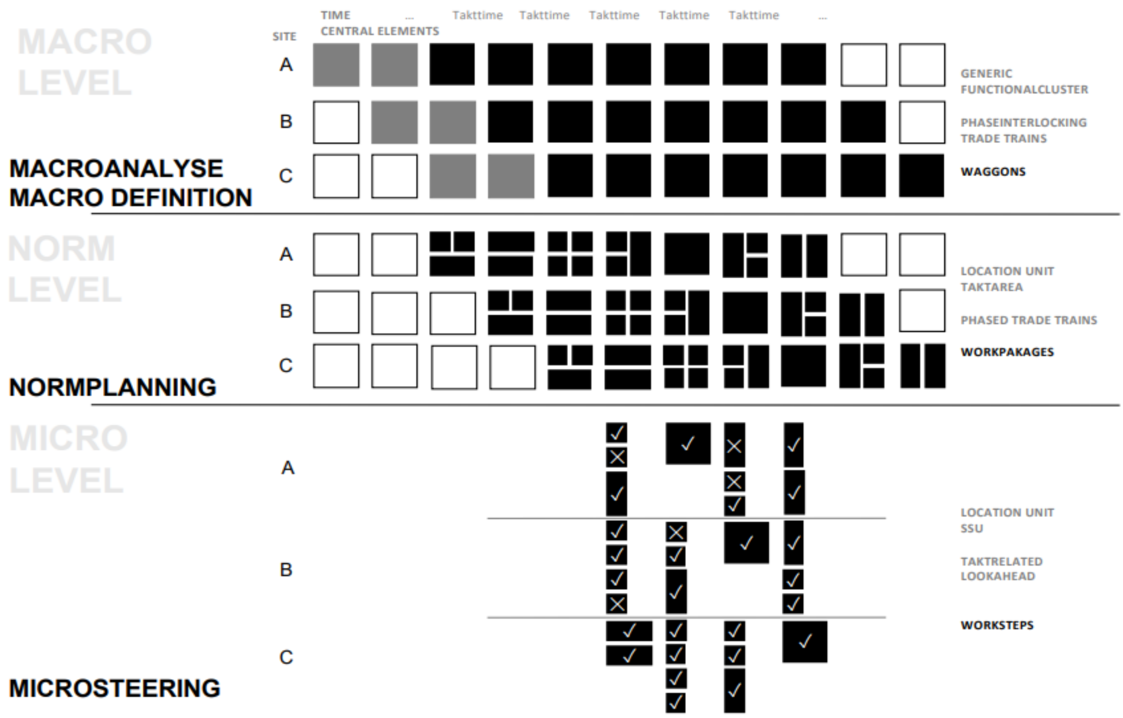

Figure 6: *The three-level model of the takt schedule (Dlouhy et al. 2018)*

There are several principles that help to reduce variability. Complex systems are inherently less reliable than simple systems, and human ability to deal with complexity is bounded. Simplification and organization of the process should be done as far as it is possible. (Koskela 2000) Standardizing may reduce the number of tasks on site, it increases repetitive work. If there are areas that do not fit into SSUs, they cannot be proceeded in takt schedule. Even the process should be standardized. The most important things when improving site assembly are planning and control. They need to be standardized at the meta-level by developing systematic procedures. (Ballard and Howell 1998) Takt time planning should begin in the early project definition phase, because it is a work structuring method, that sets demands on constructability, procurement and contracts. (Ballard 2008)

2.5.2 Buffering the schedule

Even the most carefully made schedule should be buffered, even though lean thinking considers buffers as waste. Buffers protect the production by preventing normal variance to affect the whole schedule, and it helps to prepare for unexpected situations. The trick is to avoid overrating the necessary buffer size, and place buffers in the right places. For example, the tasks that have the biggest variance, the tasks that are unusual or include high risk of failure, or the tasks that require cleaning, drying time or large-scale logistics, are worth buffering.

Time is the best-known buffer. Russell et al. studied time buffers in construction projects and they identified 12 most frequent and 12 most severe causes for setting time buffers. (2014) Top 12 most frequent causes of setting time buffers were project complexity, complexity of the trade task, quality of documents, project size, required coordination with other trades, contract period, design constructability, tendency of scope changes, material transfer distance, material transfer method, work area access, and weather or climate. The top 12 most severe causes of time buffers were quality of documents, project complexity, complexity of trade task, tendency for scope changes, weather/climate, design constructability, project size, work area access, strict specification requirements, quality control requirements, low degree of repetition, and late materials. They noticed, that the causes that seemed to be both frequent and severe need to be targeted first. Most of these causes were found to be related to poor communication and information flow. (Russell et al. 2014) Drying times may require time buffers between tasks. Overnight drying time can only be easily utilized, if takt is one working day. If takt is shorter, the drying times remain the same, and they cause additional waiting time in production. Logistics require time buffers especially if material deliveries or garbage collection outlast takt time considerably. (Heinonen and Seppänen 2016) Time buffers in takt schedule can be seen as empty columns in takt schedule shown in figure 7.

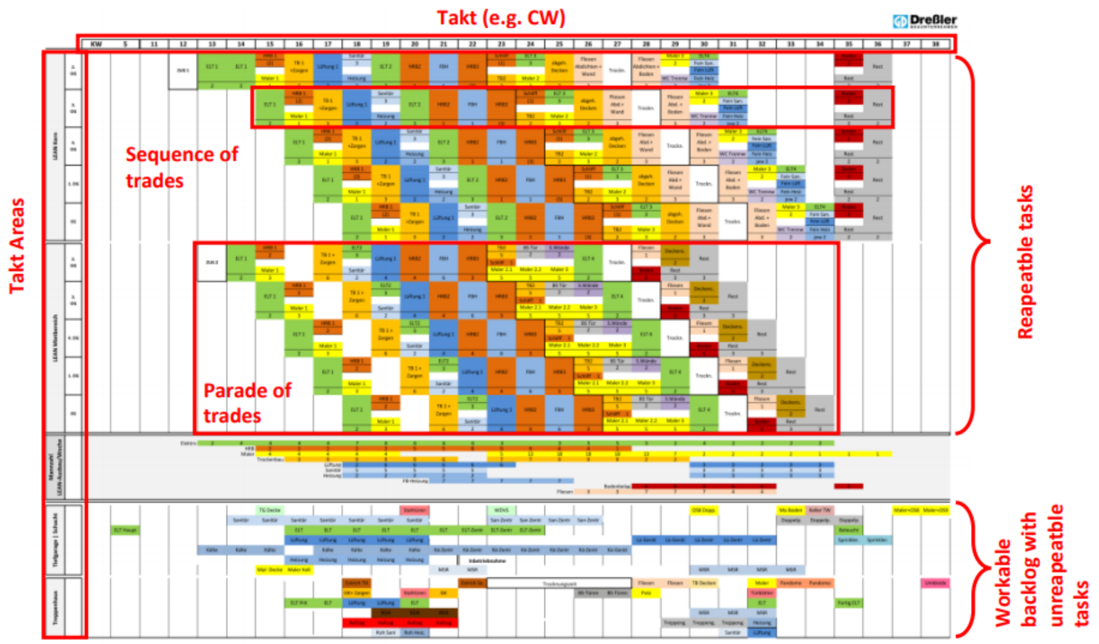

Figure 7: *Takt schedule (Haghsheno et al. 2016)*

Among time, also capacity, space and plans can be considered as buffers. (Frandson et al. 2015) Glenn Ballard suggests that capacity should not be fully loaded. (1999) This improves the reliability of the work flow, because underloading allows the variability without affecting the lead time of the whole project. Loading 100% of capacity is acceptable only if the capacity can be certainly predicted. (Ballard 1999) Construction industry traditionally strives to fully load the resources, and the production system relies on it with its contracts, incentives and conventional scheduling methods, so buffering the capacity may turn out difficult to implement.

Space buffers are areas between trades and they can be identified in takt schedule as empty rows in figure 7. Space buffers may come in question if the trade requires empty space around it rather than time. Workable backlogs are planned buffers; if starvation of the workflow, or other obstacles, prevent working according to the schedule, there is some work available outside the takt production. This ensures the subcontractors productivity, and it improves trust to continuous work and enhances commitment to the schedule. (Haghsheno et al. 2016) Because of the conflicting interests, the main contractor tends to build buffers of capacity and materials, because this ensures the continuous work in the project. Subcontractors rather buffer locations in different construction sites. (Sacks 2016)

2.5.3 Just-in-time deliveries

One of the lean principles is Just-in-Time (JIT). It points that inventories are not valuable and should be regarded as waste. Production should be pulled by a customer to avoid overproduction, rather than pushed to the inventory. In construction, inventories especially occur when materials or components are stored in site for later use. (Salem et al. 2006) Normally inventories are placed in the unfinished building, where they consume lots of space and increase fire load. (Heinonen and Seppänen 2016) Additionally, stored materials are constantly blocking work stages, when they need to be moved. They also affect in tidiness of the site. (Eriksson 2010)

Because space is one important resource in a construction site, inventories should be avoided by using JIT deliveries. Long delivery times and reluctance of suppliers can appear to be challenging to deal with. Cost efficiency of bigger batches is usually better in long haul logistics because of fewer trucks. A good compromise is to ship long haul items in batches and to pick the materials to be delivered Just in Time closer the site. (Heinonen and Seppänen 2016)

2.5.4 The Last Planner System

One way to reduce variability and improve reliability of the work flow is the Last Planner System. It is a production planning method tailored for construction. It was originally developed in United States and many researchers and companies have noticed its advantages. Productivity increase 10-40% has been measured and lead time reductions and safety benefits are reported because of Last Planner System. (Koskela and Howell 2002) It is one of the most popular lean construction tools. Last Planner is also said to be the best place to start introduction of lean construction. (Dave et al. 2015, Koskela et al. 2000)

The Last Planner System provides controlling mechanism and facilitates planning and adaptation, when continuous flow is not possible, or interruptions appear. (Frandson et al. 2014) The Last Planner System increases reliability of plans by dividing planning into distinct processes that focus on different levels of detail. Plans become more precise as the project goes on, and the ones making the most detailed plans are the ones acting as interface to execution. The Last Planner System enhances collaboration, because workers plan the work together, and it allows two-way communication between supervisors and workers. As plan unfolds it is easier to make alternative plans, and knowledge among the workers increases. Along with engaging workers, The Last Planner system facilitates variation and provides control system. (Frandson et al. 2014)

Idea of the Last Planner is simple. Every plan period, which is typically 1 week, starts with a meeting. At first tasks that *should* be done are pushed from the master schedules. Then the *should*-tasks are evaluated and pulled into tasks that *can* be done, if the preconditions are ready. There are different categorizations for pre-conditions, and one very clear and construction site-friendly is provided by Koskela (1999): design, components, materials, workers, space, connecting work and external conditions. Prerequisite work is included into weekly plans, if there is work that should but cannot be done in upcoming weeks. Actual weekly plan is based on tasks that can be done. Tasks that *will* be done are decided among these. Also, tasks that someone *did* are documented and feedback gathered. (Frandson et al. 2014) If previous plans have failed, it is vital to find root causes for the interruptions. (Koskela et al. 2002) This can be done for example by using one of the lean tools, 5 Whys. It means asking "why" five times, using each answer as a basis for next question. It helps with finding the real root cause and not just fixing the visible problem. (Womack and Jones 2003)

Dave et al. found out in their research in 2015 that there have been many problems in implementation of Last Planner System. To mention few of them, there seems to be a shortage of lookahead planning, supply chain integration and clear division of responsibilities. Implementation is often partial, and it causes lack of information flow between short-term and long-term plans. System is not working, if master plans are neglected. Weekly meetings may easily slip into gathering information rather than planning upcoming tasks, and it compromises the original idea of the system. Other problem is inability to deploy the collaborative aspects in meetings. (Dave et al. 2015) Takt schedule fits well with the Last Planner System, because it clarifies the definition, size and sequence for each task. The meetings can focus on identifying the prerequisite work, materials, design and other demands. (Frandson and Tommelein 2014)

2.6 Takt control

Planning alone is not enough to manage any construction project. Takt control has lately emerged as an interest in construction, because the production seems to lack effective controlling. Some factories may stop the whole production if problems appear, but the situation in construction is different. The production control processes seem to be non-systematic and different from the model process. (Seppänen 2009) Appearing problems often lead to confusion and suboptimal performance, but there seems to be no severe consequences. Monetary penalties after completing the contract may appear, but they have no enhancing effect in ongoing project. (Dave et al. 2015) Lack of control was noticed to derive from ignorance, lack of tools or lack of commitment, and different causes of waste seemed acting jointly accumulating to the end of the project. (Koskela 2000)

Project control can be defined as a process, which contains planning, monitoring, correcting and re-planning for each manageable work packages. (Morris 2013) Specified plans are communicated to each worker, for example in meetings. Many researchers have ended up recommending short cycled and systematic control. For example, Haghsheno et al. found it as a significant success factor in construction projects. (2016) Conventional construction meetings tend to be a weekly occasion, but because of takt schedule the tasks follow each other faster. This creates a need for more frequent meetings as well. Daily takt status meetings that last approximately 15 minutes were used in the case study Dlouhy et al. made in 2018. Its main purpose was to document the actual project status and measure if the resultant fulfils the requirements of the norm level. The three-level model, that was presented by Dlouhy et al. (2018) and introduced above, had the micro level meant for takt controlling. Each work step and their completing can be controlled, because the parts of the tasks and preparing works are listed in detail. Detailed plan for the prerequisite work, logistics and cleaning is necessary when ensuring smooth release of work. Pull flow can be only achieved when the previous work stages are carefully done and the requirements for execution are fulfilled.

2.7 Creating flow

Word “flow” can be understood in different ways. Womack and Jones (2003) defined flow as movement of resources, like materials, information, and equipment through a system. Koskela (2000) identified flow in construction site to consist of material flow, task flow, location flow and assembly flow. Later (2016) Sacks discusses that flow can be defined as trade flow, location flow and additionally, project flow, which has been discussed above when studying the impact of partnering. Understanding of trade flow has evolved from separate means of production into flow of work packages that contain crew, product, work method, design information and equipment. Work packages flow through locations, which are perceived as components of the product. (Sacks 2016) Because the sequence of the trades can vary, and they can be done simultaneously in one location (it reduces productivity though), and because the division of the locations is not necessarily fixed, the trades can be thought as “work stations”, which location flows through. (Kenley and Seppänen 2009) Achieving both good trade flow and good location flow simultaneously is very difficult. Re-entrant flow means that a trade is required to return to the same work area for a different work stage. Re-entrant flow causes a big number of handovers, compared to the number of trades. If unplanned work appears, the trades may need to prioritize, if they choose to open up new locations or close out the other ones. (Sacks 2016)

Another lean principle is that production flow should be pulled. It means that work is released from the previous stage to the next one, rather than a work stage starting date is scheduled and it pushes the previous task ready. Pull systems release the work based on system status, and push systems schedule the release of work. Construction has traditionally been pushing tasks. (Koskela 2000, Koskela et al. 2002) Seppänen found all the case projects using push methodology in his thesis (2009). Because of this, there were long time buffers in the end of the projects, and they ended up being fully spent after accumulation of the problems. Worst problems were resources and their reliability, along with out-of-sequence work. (Seppänen 2009) Koskela et al. (2002) suggest making tasks ready to be performed, but this requires explicit commitment of the crews, and it may be difficult to achieve if the objectives are not consistent. The Last Planner System is one option to transform the push system into pull system, when fully utilized. (Koskela et al. 2002)

2.8 Information flow

The role of information in production has been varying; others consider information flow as its own (Womack and Jones 2003) and others define it as a part of trades (Sacks 2016). In this thesis information flow is discussed as a separate flow, because it has dynamic and various nature. Traditionally construction projects have been considered to have five major life cycle phases: 1) initiation, 2) planning, 3) execution, 4) performance and monitoring and 5) closure. (The Constructor 2018) This model fits well in the idea of trade flow; information has been produced before the execution phase and it remains quite stable. Real situation rarely is so simple: the plans are incomplete, incorrect, constantly changing and becoming more accurate. Availability and utilization of information varies, and the interpretations of it are different. Combined with individuals' knowledge, skills and perception, the same information can result in several applications. It is necessary to understand, what is information, how the information flow can be created and how it can be converted into value.

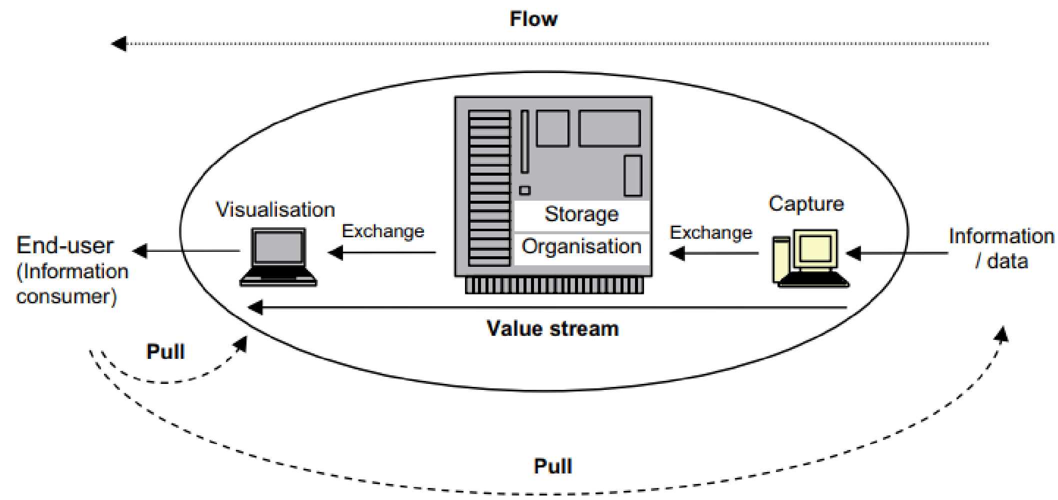

Figure 8: *Information flow (Hicks 2007)*

Hicks presented the value-flow model applied to information management (2007), and it is shown in the figure 8. It has similar principles than any of the other flow types; the only difference is that the end-user pulling the flow is not necessarily the customer. Anyone who needs the information can pull it through the system. When comparing information flow to other flow types, it is not parallel with any of those. It is more complicated network, which combines several sources. To understand the value stream of information, basics of the knowledge management are reviewed.

Information flow and its value creation can be managed by the means of knowledge management. Knowledge management is the systematic process and strategy for creating, gathering, organizing, refining, sharing and using knowledge in an organization. Its objective is to create value and leverage by getting the right knowledge to the right person at the right time. (Cooper 2016, Gajzler 2016) An organization should be able to base their decisions on explicit and correct information. First, it is necessary to define, what are data, information, knowledge and wisdom, and how are they related. They are shown in the figure 9. Data is raw material which carries information but is not very useful as it is. It has no meaning without a context. When data is given a context, it becomes information. Information is structured and organized, and there are both manual and automated method to refine data into information. Knowledge is a result of cognitive processing and validation of the information. Human experiences, values, contextual information and expertise affect knowledge. Wisdom is the highest form, and it includes moral and ethical framework. (Gajzler 2016, Cooper 2016)

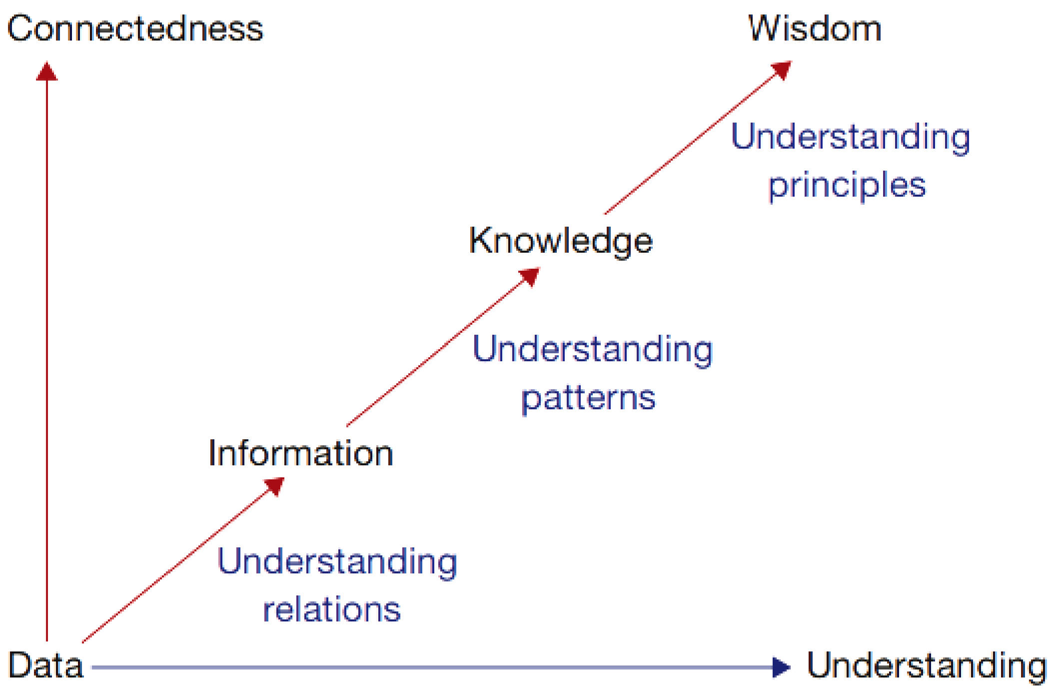

Figure 9: *Data - information - knowledge - wisdom (Cooper 2016)*

When connectedness and understanding grow, transferring gets more difficult. Information is still quite transferable, but knowledge is more complicated. Knowledge can be tacit or explicit. Tacit knowledge is difficult to transfer to another person and it contains aspects that are hard to explain, for example riding a bike. Explicit knowledge is transferable, because it can be written or articulated somehow and accessed and understood. SECI-model by Nonaka and Takeuchi (1995) which explains the relation between tacit and explicit knowledge and how they can be converted into organization knowledge, is shown in the figure 10. SECI-model underlines the value of tacit knowledge of workers as a part of company's intellectual capital. When there is a system for converting tacit knowledge into explicit knowledge, which becomes gathered, part of the individuals' intellectual capital can be transferred into company's knowledge.

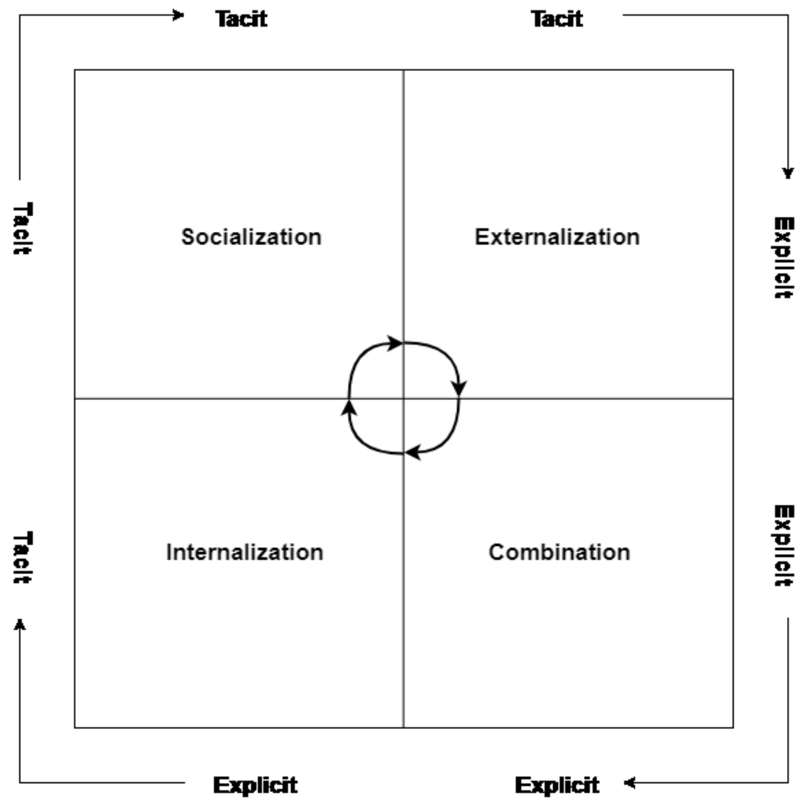

Figure 10: *SECI-model: (Nonaka & Takeuchi 1995)*

In organizations the process of knowledge management starts with identifying the information needs. Information needs are not easy to define; they are changing over time along with organization, industry and environment. This is very important stage of the process, because it defines what kind of information should be acquired. The needed information is acquired as a nonrecurring or a recurring process, and the gathered information can be either organized and stored or distributed. Information can be used from the storage or straight from distribution, and it can be utilized in decision making. The steps of the process are shown in the figure 11. (Choo 2002)

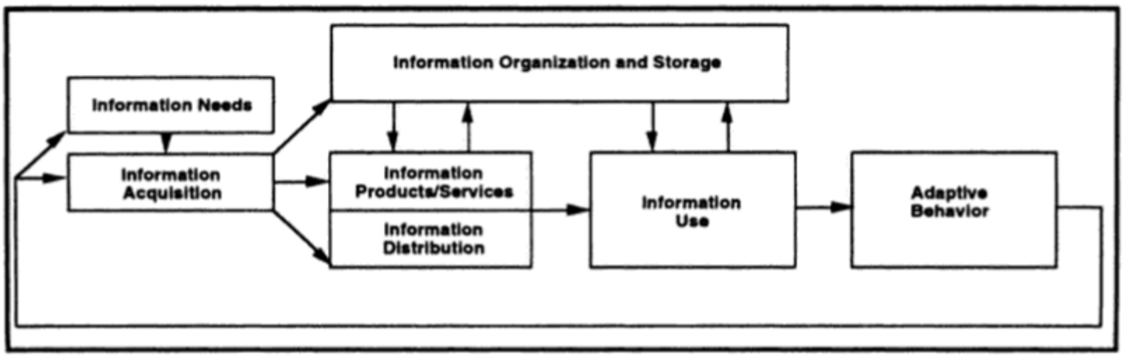

Figure 11: *Knowledge management process model (Choo 2002)*

Information technology has a major role in information acquisition, organization, storage and distribution. Information systems' outputs are dependent on accurate and relevant input data. (Cooper 2016)

When evaluating information flow in LPDS, it can be noticed that information flows through the whole project from the definition to the lean assembly and use. The same information gets enriched along the project, and it can be pulled from the information storage or distributed when necessary. In takt production work stages follow each other faster than in conventionally scheduled projects, so the information should be up-to-date and easily available. Usually there are different people producing, consuming and enriching the information in different phases of the project, which points out the importance of SECI-model and externalization of knowledge. When people leave the project, their tacit knowledge will become inaccessible. If the LPDS process takes information flow into account, most of the knowledge can be converted into explicit and utilized later.

3. CASE STUDY

This chapter first introduces the case site. The takt schedule implementation is studied from the planning process to the execution. Based on the interviews and monitoring, takt schedule implementation and experiences of it are reported. Disruptions and problems that appeared during the monitoring period are gathered, and the possible causes for them are discussed. After this the digital tools implemented in the case site are introduced and their utility is estimated from the takt production point of view. The site supervisors' management process is studied, and the compatibility with the takt schedule is estimated.

Relatively big percentage of scheduled tasks were late, and the reasons for delays are better introduced later. Monitoring revealed that there were difficulties with some digital systems implementation because there was not much data or users. In some cases, overlapping systems, like Excel or WhatsApp, have replaced the implemented systems, which was because of poor usability or other shortages. In some systems data was very incoherent, which is also an indicator of shortages in usability or education. Interviews indicate that better education and communication is necessary, because knowledge of takt schedule and digital systems was inadequate. Additionally, some digital tools were not providing enough benefits to maintain the motivation in resilient usage.

3.1 Introduction of the case site

Case site is an apartment building that consists of 42 apartments and some common rooms, like storages and staircases. It can be divided into lower part with three floors and higher part with seven floors. Total area of the apartments is 2350 m^2 and apartment size varies from 42 m^2 to 83 m^2. Case site was selected to be a pilot for implementation process, because it is relatively small and ordinary building, and the production and the main features of it were quite well known before attempting to implement new systems. The case site building plan can be seen in figure 12.

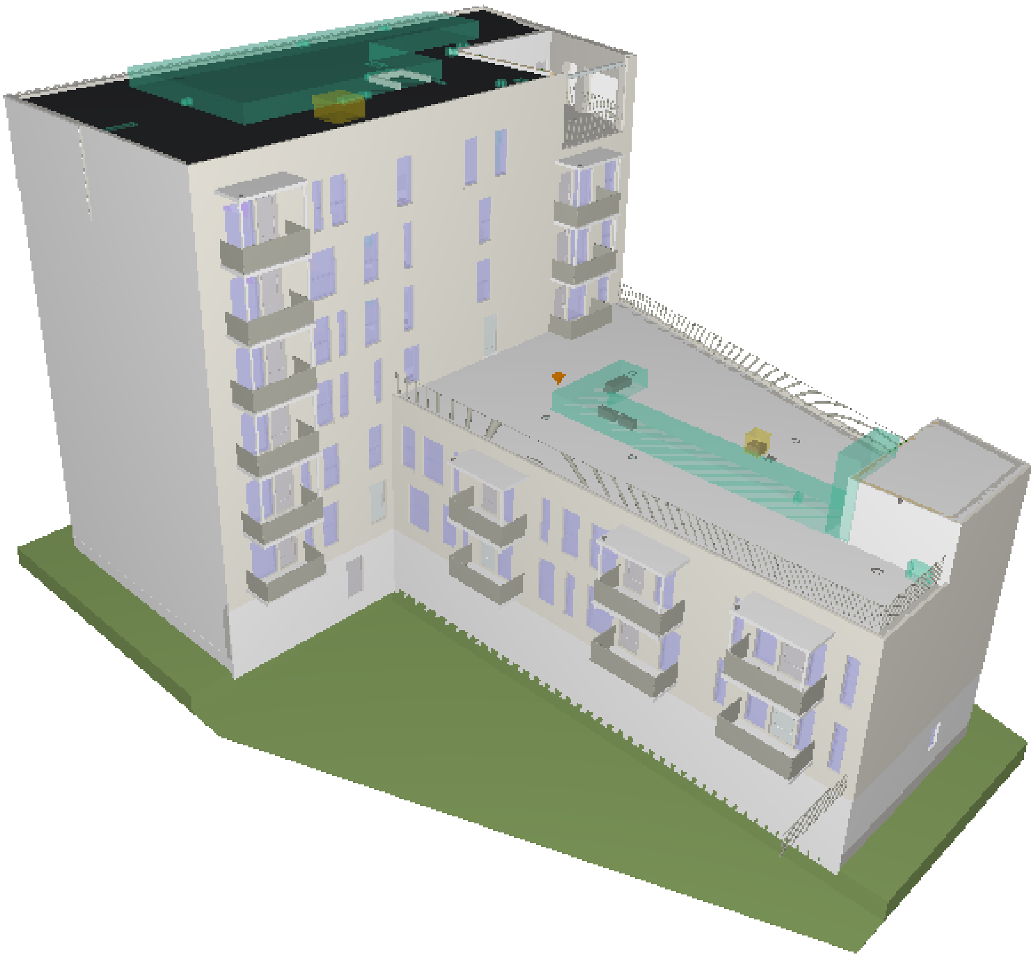

Figure 12: *3D-Model of the case site*

Site management organization appeared to be more variable, than expected. Changes in site supervisors and engineers were mainly because of holidays and other leaves of absence, and they complicated the piloting project. Learning curve was not as steep as it would have been with more stable organization. Site management had more resources than conventional construction sites, but the high number of trainees compensated it a little.

Objective of the case company's piloting project was to gather more information about takt planning, takt control and the support that digital tools could provide for these kinds of projects. Hence, takt schedule was implementation was partial, and not fully applicated in the work stages like painting, which traditionally have demanded a whole floor as a work area. Digital tools had many levels of implementation. Some of those had been already in daily use, but the data was utilized differently, and others were only lightly tested, without further data utilization. Each system and the use of them will be introduced later in this chapter.

3.2 Takt planning pilot

Takt planning was piloted for the first time in the case company in apartment construction context. Takt schedule was not included in production plans or subcontracts. Implementation was done anyway, because the given durations of the work stages did not dramatically change, and because the subcontractors' reactions were positive, and they seemed to commit to it. Takt was only implemented in interior works, because it fits well with takt scheduling. Apartments formulate a clear set of areas with similar work stages, and the crews, materials and information can flow through them. SSU's identified were apartments and bathrooms, so there were two trains in the takt schedule.

Common areas were not included in takt, and they served as workable backlog. This was because there were fewer work stages, which of them HVAC works were nearly done. Only exception were some work stages that were scheduled to whole floors, so they included common areas. Some work stages were not fitted in the takt. For example, leveling and painting were scheduled in a traditional way (approximately one floor per one week), because spraying needs clean environment, and the works are done also in the common areas, which were left out from the actual takt schedule. This way the implementation was estimated to be easier, and these work stages could be fitted to takt in later projects.

Planning continued by dividing interior works into different work stages. Work stages are rather similar in conventional apartment buildings, so they were identified relying on previous experiences and some model schedules. Work stages were divided into subsequent tasks, and their durations were estimated. Some of the durations were calculated from Ratu-database (2018), some were based on previous experiences and some were inquired from subcontractors. The duration of the takt ended up being two apartments per one work day. This seemed to fit well with most tasks, and the subcontractors committed to the schedule in the negotiations before starting their work. The planned schedule differed from theoretical takt schedule a little, because there was plenty of additional buffer time between the tasks. Buffers were added just in case if the durations of the tasks appear to be incorrect and for smaller work stages, like logistics, cleaning and quality controlling. Part of the takt schedule is shown in figure 13, in which time buffers can be seen as empty space, and work stages that were not fitted into takt as bigger boxes.

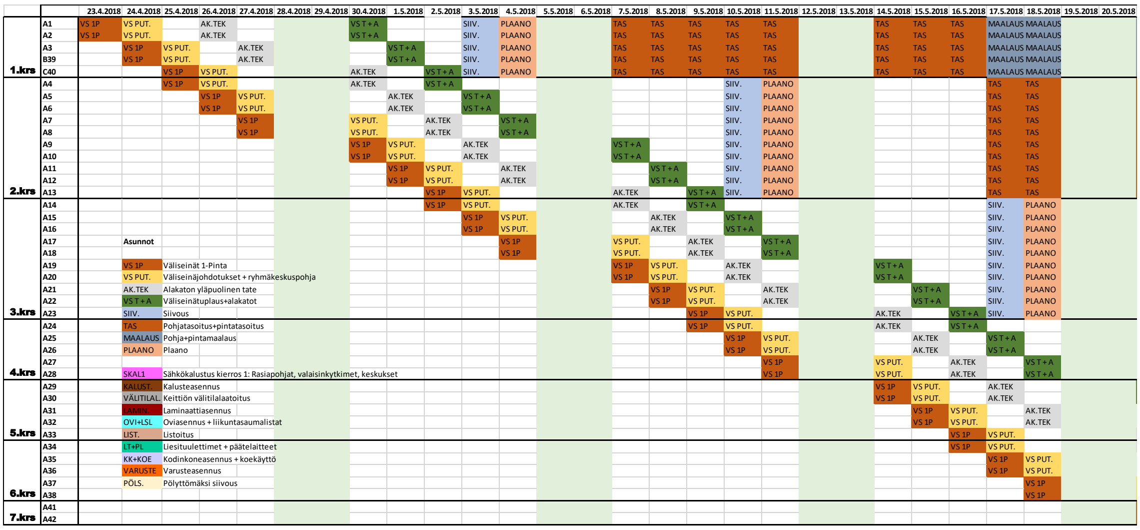

***Figure 13:** Part of takt schedule*

Executing the tasks from takt schedule started in 23.4.2018. Shortly after starting the execution it was noticed that the takt schedule faced some difficulties. Tasks did not keep to the schedule and the work stages strived to proceed in conventional ways. Despite of time buffers, when single tasks did not proceed as it should have proceeded, subsequent work stages disrupted each other, and the schedule needed to be updated. Several causes for disruptions were found by monitoring the tasks proceeding and investigating the reasons for the tasks delaying. They were:

1) *Drying times*. Some concrete castings in hollow slabs, especially the ones connected to Schöck-balconies, were not dry enough for coating on planned time. The problem appeared mainly only in dry areas in the apartment, because the castings were rather small and irregularly located, and hence not considered in scheduling. Bathrooms contain bigger hollow slab castings, but their drying times were carefully planned, and the floor was waterproofed later. Other smaller drying problems appeared also whenever the work was not planned beforehand, for example with glue or filler in preparing works.

2) *Logistics.* Especially bigger items, like gypsum boards and fixtures, caused some special arrangements. Contracts usually instruct vertical transfers to belong to the main contractor and horizontal transfers to subcontractors. Some horizontal transfers were so troublesome that they needed to be re-allocated, because otherwise they would have taken too much time. Just-in-time deliveries were not properly implemented, and materials were often delivered for at least one floor or more at the time. This caused problems when items needed to be stored in the apartments. Additional storage or smaller delivery batches would have been necessary. Some

delivery times were not considered, so there were tasks that delayed because of shortage of materials. Better planning would have prevented these delays.

3) *Incentives and conflicting revenue logic.* The work stages that had workers who were paid for performance were noticed to have more problems with takt schedule than the others. Interviews indicate several conventions that conflict with takt schedule objectives. Workers usually get paid for a square meter of completed structure, but in the takt schedule for example drywalls and tiling are divided into parts. These subtasks are continuous and originally planned to a single worker. Another reason for one worker to complete the whole work stage in one area is that this way no one should fix some other's faults and it is fair if everyone is required the same overall quality. Working conventions also may vary between the workers. When performing a work assignment from beginning to end, there is possibility to design one's own working routine. The equity of the division of the areas is also one major reason to object the takt schedule. In an apartment building there are often similar floors. If one floor belongs to one worker and second floor belongs to other worker, they get equal jobs and are equally paid. If the areas are divided without considering the earnings, workers may protest. Lastly, the basic earning logic when paid for performance is that the faster you work the more you will earn. In takt schedule it is essential to stick to the schedule, and not work as fast as possible.

4) *Faults in the schedule.* Some lesser work stages were missing from the schedule, and it appeared to cause disruption, or at least to complicate the allocation of resources. On the other hand, if all the smaller works are marked in the schedule, it may reduce the clarity and visuality of the plan. One solution for this could be using The Three-level Model introduced in chapter 2. The durations of the tasks varied from planned. One reason for this can be that their estimation was based on conventional production, and it differs a little from takt production. Some subcontractors seemed to overstate the durations of the tasks. They may be extra careful trying not to commit to anything that might fail and have negative consequences. Others seemed not to have a realistic perception of their abilities, and they just agreed with any schedule. Impacts of overtime, working in shifts or overmanning, all of which reduce productivity, were not considered. Some subcontractors worked significant amount of overtime, and the schedule was sometimes tried to catch up with overmanning. In these cases, the correcting operations did not reach the desired outcome, because the performance was not increased as it was planned. Still most of the subcontractors estimated the durations very well and gave valuable recommendations. Inquiring from subcontractors alone appears not to be reliable way to estimate the schedule, but it can be used with caution. Varying size of the apartments caused some variation in the durations, but it was considered when placing the time buffers and the situation was explained to the

subcontractors. If the sizes of the apartments would have varied more, the division of the areas should have been reconsidered. Some work stages in the schedule appeared to be too inaccurate from the perspective of controlling, because they included an unconsidered chain of subcontractors. This did not lead to any disruptions in this case, but it should be considered in the next project. Work ergonomics was one of the factors that was not considered before the pilot. Monotonous work with bad ergonomics, like floor tiling in the bathrooms, should not be planned for a single worker continuously.

5) *Partial implementation.* Theoretically thinking, the takt schedule was only partially implemented because of the big amount of time buffers and some work stages outside from the takt. Other feature that differs from the theoretical takt production is that the whole train was never stopped if there appeared to be obstacles. This led to spending time buffers, and in some cases changing the plan in a way that caused series of additional changes in the schedule, confusion and frustration. It remains unclear if stopping the production would have been better from the workers point of view, because there are no comparable experiences. Either way the plan would have been more stable if the subcontractors would not have continued their work in disorder.

6) *Education and communication.* It became clear in the interviews that additional education and training would have been necessary. None of the interviewees had previous experiences in takt production. Only the main contractor's supervisors and one subcontractor's supervisor from all the interviewed persons knew the takt schedule and its objectives and principles well (4/10). It seemed like the ones knowing the idea of the takt schedule also considered the takt system as a promising and a positive thing. Others had rather negative attitude towards it. The objectives of the takt production were not clear enough either among the workers or the supervisors. If workers understand the idea of the takt, they know their goals and it would be easier to explain why they should depart from the usual conventions they strived to keep. Commitment was poor in some cases and it seems to derive from lack of knowledge. Supervisors should have been better educated into takt planning too. Updating took the schedule constantly further from the theoretical takt ideology and it usually lead to confusion and defects in planning. Supervisors and management would have needed instructions, means and processes to control the new kind of production. Communication in case of organizational responsibilities and changes in plans could have been better. Lack of appropriate view in scheduling software caused some problems. There were two schedules; one in SiteDrive and other in Excel, which was regularly printed. All the interviewed supervisors considered Excel better, because it provided clear image of the whole situation, and it was easy to use. On the other hand, communication and

transparency were weaker with Excel, when the updated schedule was not available to everyone, like it was with SiteDrive. Multiple versions of the schedule were noticed to cause confusion and extra work.

7) *Contracts.* As mentioned above, takt schedule was not included in contracts. In most cases it did not cause any harm, because subcontractors were committed to the schedule. Only negative influence was that if there appeared to be problems, the contract did not support the objectives well enough, and there was no use to plead to it. Contracts could have included some incentives to support the subcontractors' commitment to the takt schedule. There were not many works that were left out of the subcontracts, but some boundaries should be planned more carefully. For example, bathroom thresholds can be interpreted to belong in many subcontracts in both bathrooms and other parts of apartment, but they were meant to be done by agency workers. Because these kinds of "no-one's" works were often left out of the plan too, it depended on supervisor's abilities to remember, predict and arrange them.

8) *Resources.* Success of takt production requires adequate availability of resources. Sometimes availability of resources seemed to be a problem with some smaller subcontractors that did not have any worker reserves. Many of the interviewees mentioned that it is difficult to find and hire capable workers. Ministry of Economic Affairs and Employment published a report of hiring labor, and it shows that in year 2017 about 47% of all the construction companies had difficulties in recruiting. Lack of employees concerned 21% of companies. Construction workers were one of the most wanted professionals and increasing workforce was the reason for recruiting in construction in 66% of cases. Lack of workforce seems to be a bottleneck in the industry. (Maunu, 2018) In this case study subcontractors' overbooking to simultaneous construction sites did not seem to be a problem. In bigger companies it enabled to regulate the resources by choosing the workers whose performance naturally match the takt. If there were not enough work available, subcontractors allocated their workers to other sites, but this was rather a consequence than a cause. Other under-resourced group was agency workers. Because of the compressed schedule, the agency workers' tasks were appearing more frequent than normally. They were allocated to many important work stages that were vital to enable subcontractors' work. Because of this, some less urgent tasks like clearing were often delayed and it affected to the site functionality and work safety.

9) *Faults in structural design.* Planning faults and imperfections were a rare problem, but they had major consequences in production. Some tasks in certain locations could not be finished because additional tasks needed to be planned and

completed first. This caused a need of re-routing the works and the changes disturbed the production. For example, the amount of pipe casings was surprisingly big, and they were missing from both plans and consequently contracts. Constructability of the building should be carefully planned, and there were several places that needed extra work because of unconsidered joints or structures. These details are rarely taken into account when planning contains of contracts so their costs and consequences in production are rather unpredicted.

10) *Accidents, absences and other unpredictable factors.* Some unpredictable things like water leaks and sick leaves caused disturbances in production. These factors cannot be completely prevented, but through proper risk analysis and preparing the consequences can be minimized.

Despite these problems, those who understood the takt schedule principles, considered it as a promising new practice, which helped to plan the production much earlier than in conventionally scheduled projects. Especially contractor's supervisors felt the takt schedule useful, because it was clearer and more accurate. It helps for example planning the deliveries. Delivery times can be several weeks in some cases, and some factories even close during July to have summer holidays. The materials and components need to be booked so early, that in conventional production the appropriate delivery day should be guessed, or additional time buffers should be added to make sure the timing is not too early. One of the subcontractors' supervisors said the accurate schedule to help allocating their resources between multiple construction sites.

Other good sides of the takt schedule were reduced lead time, clarity and visuality of the schedule. Reduced lead time reduces costs rapidly, and the lead time seemed to decrease about two months, even with tentative implementation. Printed takt schedule was considered as a good tool for planning and meetings, because it clearly provided a look for the current situation, along with planned and completed tasks. The schedule presents the sequence and dependencies between the tasks, so changing the plan rarely caused faults.

3.3 Digital tools pilot

Among takt schedule, there were several digital tools implemented in the case site. As mentioned above, their implementation level varied; some tools had already been in use for years, but their data was utilized in a new way, others were only tested to find an appropriate technical system for further development. Each digital system is introduced in this chapter. Their implementation and contribution to takt management is estimated, and some problems and deficiencies were found. Takt schedule provided plenty of rather accurate information to share, and on the other hand, it demanded sticking to the plan, rapid actions when necessary and careful planning. It was essential for supervisors to know the real-time situation and identify if there was something that needed further actions.

3.3.1 Insite

Main driver for piloting a set of different digital tools was development of an open data platform (ODP) and business intelligence view Insite. Objective of the case company is to create an ODP, which combines data gathered by digital tools on site. Data itself may not be useful, but it can be refined into information when combining and presenting it in an appropriate way. In the case site the objectives were to develop views that provide situational awareness for the site management, and to test how data of different digital systems could be combined. The working principle of Insite is shown in the figure 14.

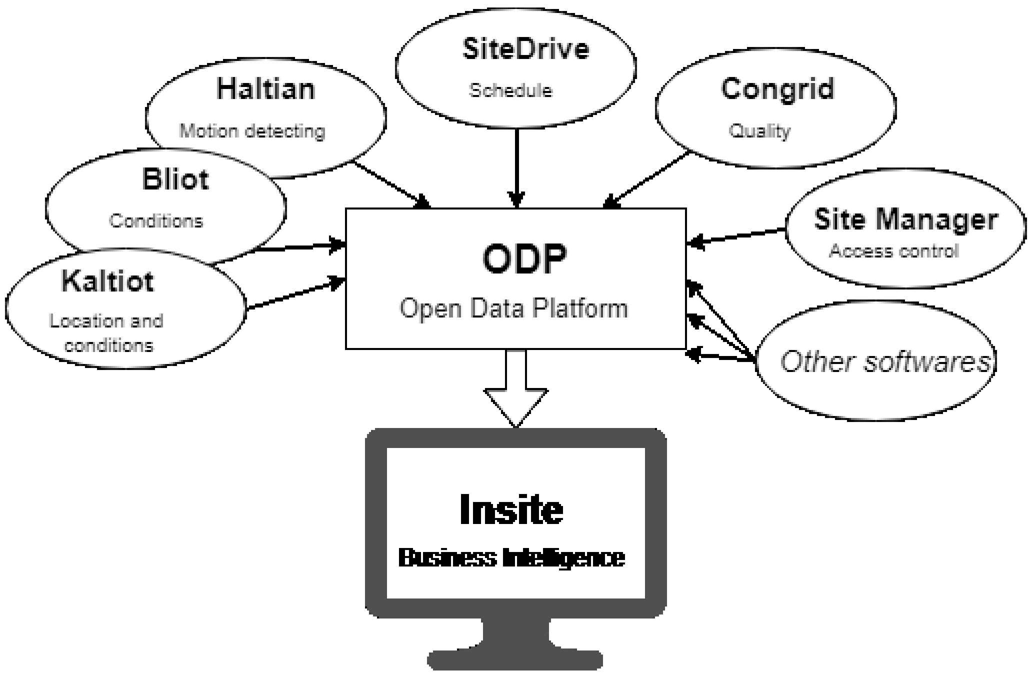

Figure 14: *Working principle of Insite*

Data combined in ODP from different systems is displayed in business intelligence view Insite. When giving data a context it becomes information, and it can be easily distributed with visual interface. Situational picture is provided by choosing the main issues, like proceeding of the works, obstacles and quality faults, to the front page. Insite front page is demonstrated in the figure 15.

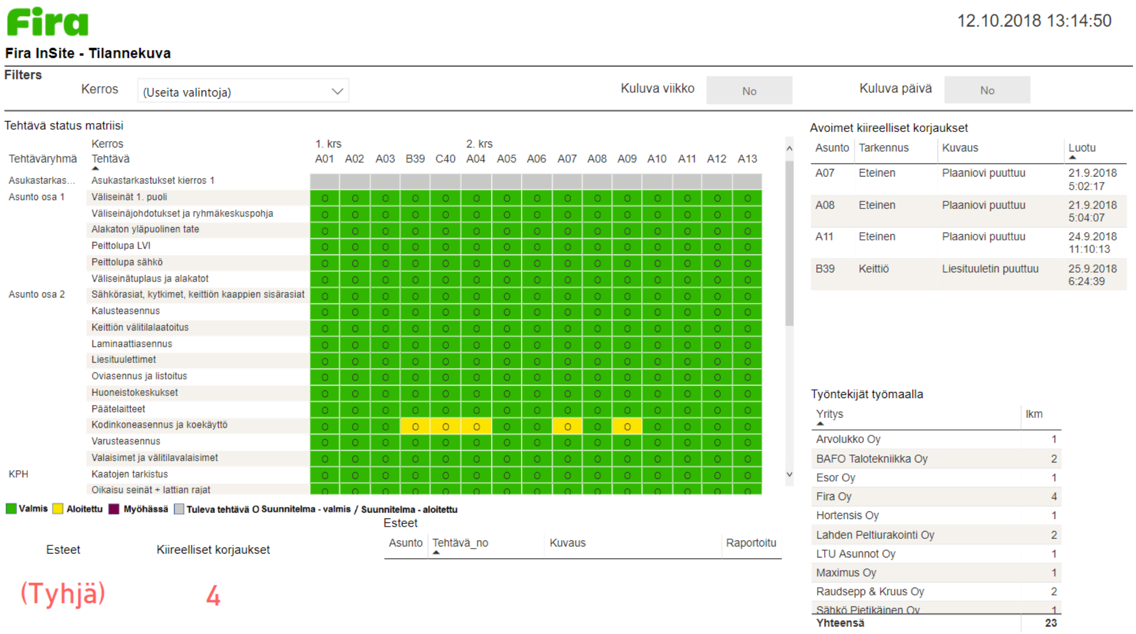

Figure 15: *Insite Business Intelligence view*

Data from different systems is not automatically compatible, so the congruences need to be identified and implemented before gathering the data. For example, the division into areas or the names of the subcontractors need to be similar in every subsystem. These kinds of rough guidelines were not enough for some systems. A four-numbered tag was implemented for each work stage, to make sure that different spelling will not cause problems. Some digital systems turned out to allow very variable uses, so an appropriate use needed to be created and instructed. Development of Insite was agile, which means that it was continuously improving and changing based on users' feedback.

Interviews indicate, that Insite was considered as a promising tool to control the site. Main issues were the structure, quality and reliability of the data, but they seemed to concern more likely the subsystems and their data. Other shortage was a one-way nature of the information flow; all the changes and updates needed to be done in the subsystems, even though it could have been easier to modify them in Insite. For example, the schedule view was more appropriate in Insite than in SiteDrive, but it could not be updated. As a result, it was decided to lean on Excel version of the schedule in the meetings. Insite was not yet utilized among other stakeholders than the main contractor's supervisors.

3.3.2 Site Manager

Site Manager is an access control and license management system for construction sites. (Takamäki 2018) It has been developed by Takamäki Group and the case company has been using it for years. The reason for Site Manager introduction in this thesis is that its information can be utilized in a new way when combining it in Open Data Platform. Site

Manager provides several features. Most important for the case company are work safety related features, working hours monitoring, automatic information verification and reports to the authorities. Every worker in construction sites has a Valtti smart card which includes worker’s name, picture, tax number, company details and a unique bar code and number. The card can be electronically identified with its NFC-chip. (Tilaajavastuu 2018) There are card readers usually in every bigger construction site in Finland and workers are required to register themselves with the card every time they are entering or leaving the site. With Site Manager working hours for each employee and each company can be checked.

Even though the convention is very general, there are some problems with getting correct information. Lacking registering seem to accumulate for a small group of people, so constant oblivion or technical issues can hardly explain the deficiencies. Convention should be considered from human point of view; why some people do not obey the rules. Attitude towards the system can be negative for several reasons. Workers may not achieve anything that motivates them, and they may feel uncomfortable because of monitoring of their working hours. They may consider, whether the consequences are more severe with no registering or being provably late or leaving early.

Registering to the site tells only whether the workers are on site. It does not indicate at all what they are doing and in which location, so some additional information for production management is needed. Site Manager can still provide very valuable information. Because the implementation of the card readers has already been done and the use of it is very easy and the system is well-known, data should be utilized further. For example, when comparing the numbers of present workers on the site with the numbers planned, it indicates if the production is running the way it should be. If there are significant differences, the plan may be imprecise, and the actual outcomes cannot be predicted.

3.3.3 SiteDrive

SiteDrive is an online-based scheduling software that case company has utilized in several projects. It can be used in a browser or in a mobile application. All the changes are automatically updated so the same version of the schedule is available for all users. There are different access rights: project admins can edit, and update and project users can view the schedule. (SiteDrive 2018) In this case project the admin rights were granted for the main contractor’s engineers and supervisors, and the user rights for subcontractor’s supervisors, foremen and workers.

Scheduling process is similar with conventional scheduling software: a project can be divided into appropriate subtasks and after this the starting dates, durations and sequences are planned for each. Resource, which in this case is subcontractor, is allocated for each task and assignees can be allocated for each resource. Schedule can be viewed from different perspectives like location, resource or assignee. Assignees can see their upcoming tasks and mark them started and completed. If a scheduled task cannot be done, an assignee can mark an obstacle which must be acknowledged. SiteDrive offers possibility to easily monitor the real-time progress. This requires though precise scheduling and disciplined usage.

In the case study there were several problems found. Most of them are schedule-related and discussed above in the takt time planning context. At first, the structure of areas and work stages needed to be standardized across the separate systems. Because some work stages were divided into smaller subtasks, a four-numbered tag compatible with Congrid quality matrix was added to each task to combine the information for Insite. For example, drywalls and tiling were marked as one work stage in Congrid, but in SiteDrive drywalls include one task for both sides and tiling is divided into several subtasks for walls and floors separately. This way it was possible to name the subtasks differently. Tasks were divided by the area into either apartments or floors. This kind of partition appeared to be confusing and it would have been better to use the same hierarchy of places with all the tasks.

SiteDrive was found to lack a practical view that easily visualizes the takt schedule. Because of this, the schedule was originally planned in Excel and the sheet was printed. SiteDrive could not fully replace the Excel-sheet in production stage either so there were two parallel scheduling systems. It caused additional work and there were some conflicts with the schedules because often only one of them was updated. Printed version of excel did not help with the updating problem: printing a big colorful table on roll-paper was rarely done and hence the visual and handy schedule in meetings was often out of date. Some improvements were suggested to SiteDrive developers to get rid of the two schedules problem.

In the beginning there seemed to be uncertainty within the organization, who's responsibility it was to update the schedule. Updating it was irregular and interviews indicate that if the schedule did not match the agreed plan, workers easily gave up with trying to follow it. When supervisors were encouraged to edit the schedule, it remained better updated and the transparency of the arrangement improved. On the other hand, in some cases the freedom to update the schedule seemed to result in constantly changing plan that diverged from takt schedule considerably. Interviews indicate that also the frequent changes lower the motivation to stick to the plan. Updating the schedule was seen as a troublesome extra task. Conventions were taking shape for some time and some ways appeared to be better than the others. For example, if the task cannot be finished for some reason, it can be marked completed and a new task can be created for the rest of the work in more appropriate time. Like that the unfinished task is not disturbing the monitoring if it does not require any additional attention.

In the beginning of the implementation process the communication failed and there was some uncertainty if the application was intended only to the supervisors or to workers too. It was first introduced only to the supervisors. When this appeared to be inadequate way to get tasks and obstacles marked, introduction was gradually made among the workers too. When it comes to using SiteDrive in the site, there were many kinds of user experiences. Some users seemed to refuse learning to use the application. They had negative attitude towards the system and the results remained poor even when additional education was provided. Others found the application very handy and easy to use. They suggested that the usability or skills can hardly be the reason for neglecting the use.

The idea of collecting information about actual durations of tasks worked only if the tasks were marked both started and completed on time. If only the supervisors updated the progress of the work stage, usually they only marked completed tasks every now and then. Workers were not very motivated to mark the progress of the tasks, but when they did so the results were more accurate than when only supervisors marked them. Workers felt they did not benefit from marking the progress, but they marked obstacles very well instead. At first workers felt like there was too long reaction time for the obstacles they reported. Because of this, the case company set a 4-hour time limit to react the obstacles and inform the workers about the solution. This worked very well, and the obstacles were widely and accurately marked. They help the case company to identify repetitive problems and to fix their processes to prevent them. To help the analysis of the obstacles, certain obstacle types were created to organize them.

It was argued if the works of the agency workers were more practical to add to SiteDrive schedule or to leave out from it. Agency workers' work was mainly cleaning, clearing, logistics, work safety and preparing, and some other tasks that were left out from the subcontracts. Work includes constant prioritizing because of small resources and suddenly appearing urgent needs. Interviews indicate high consensus among both supervisors and workers that WhatsApp is the best digital tool for allocating the tasks for agency workers among other communication. It overcame SiteDrive because of several reasons; 1) notifications helped with rapidly changing plans and urgent tasks, 2) all the important stakeholders were informed at the same time, 3) the agency worker who is nearest and has time can sign up for tasks, 4) pictures and additional information was easy to attach and 5) the progress and completion of the task or problems can be informed and discussed. WhatsApp application is also widely known and does not require additional applications or user accounts if it has already been downloaded.

Because of low rate of users, all the possible benefits were not reached. Partial implementation leads to more inaccurate information and additional work for supervisors who need to patch the progress monitoring. When the benefits did not reach the level they could have reached, it lowered the motivation to use the system. That is why the implementation may be better when done all at once and not gradually. Despite some problems, SiteDrive was experienced as the most beneficial digital tool and it was the most used system in the case site after WhatsApp.

3.3.4 Congrid

Congrid is a digital quality tool that is used for documentation and inspections. Congrid software package consist of Congrid Live Portal and Congrid Mobile application. Additionally, there is a simpler Congrid Lite application that is meant for subcontractors. With them main contractors, subcontractors and developers can manage construction site by having access to necessary files, making inspections and taking photographs on site and monitoring defects and fault correlations in real time. (Congrid 2018)

From the perspective of getting the production situational picture, there were two important features: 1) planned quality inspections for work stages and 2) the notices of the defects found. First mentioned is precautionary by nature and it must be done on time. It depends on work stage how comprehensible set of inspections will be made. Particularly briefer inspections are not necessarily including any defects, so they might only securely indicate if the quality control actions are done. Second use case gives valuable information about the completion of the work stages. Defects that have eluded the inspections or result from later actions can be documented separately. Congrid has some other features too, like reclamation and site diary, but they are not relevant in this research and hence bypassed.

In the case study it was noticed that Congrid can be used in many ways and most users have their own habits. In the case company there were no common instructions for the documentation, so some users apply Congrid as a checklist with no organized structure and some use only certain features. Defects can be allocated to a certain place and a certain company, and to a list or an inspection, but there was no common way to do so.

Because of the lack of systematic conventions, the data structure was too incoherent to process and to automatically produce information. Inspections for different work stages were displayed in a quality matrix that was based on outdated Talo80 nomenclature. Because of this, the same nomenclature needed to be implemented in other systems to integrate the information gathered. Another problem was that precautionary inspections and noticed defects were not identified as different kinds of cases. This created confusion, because inspections were processed as faults that needed fixing. To correct the situation, a common instruction for Congrid was created. It is shown in the figure 15. Urgent repairs were decided to separate from others by creating additional list, because it was not possible to filter the notes by urgency.

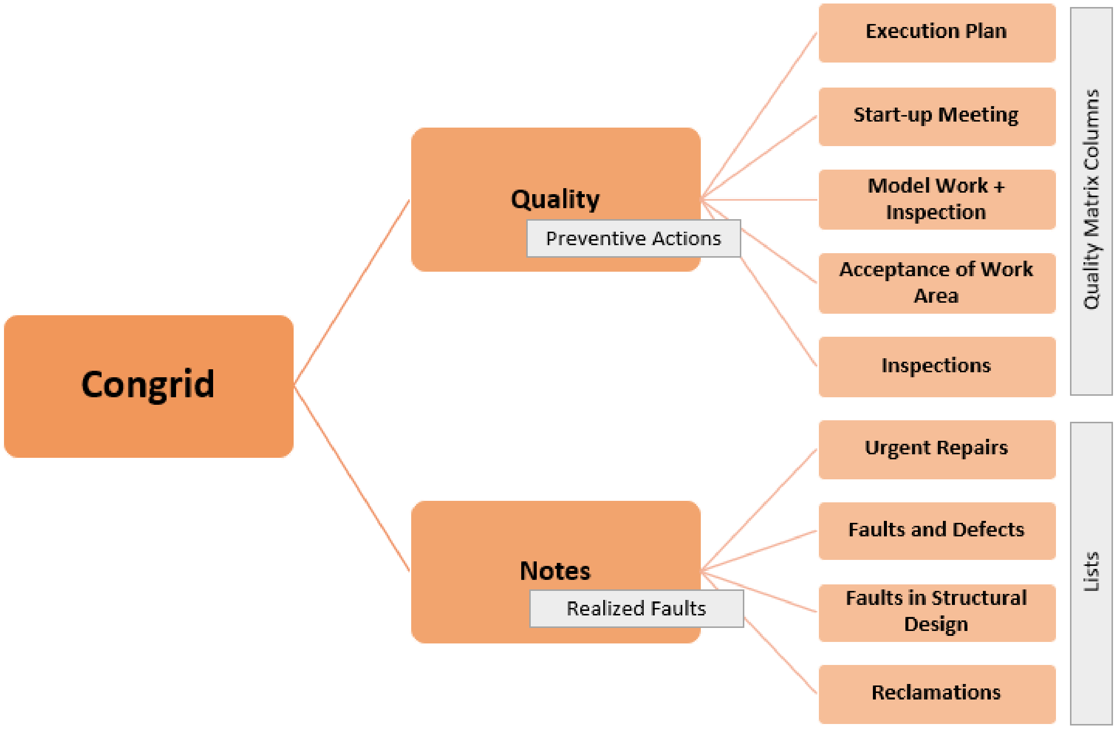

Figure 16: *Basic principles of organization of quality documentation*

WhatsApp appeared to be a competitor for not only SiteDrive but for Congrid too. Notifications and common groups ease fluent communication, especially in cases that need fast reactions. Congrid's usability was estimated to be rather poor, but it was well known software among both main contractor's and subcontractors' supervisors, and especially the defect list in finishing state was considered as a very good tool. Some improvements need to be done. Demands for the frequency of the inspections, and all the quality documents, including execution plans, should be included into Congrid, so the documentation would not be in different systems. Inspections can only be done by mobile application, and execution plan and start-up meeting transcript usually contain so much text, that they need to be written by some appropriate software. Documents can be uploaded in Congrid, but quality matrix does not recognize them as completed quality actions. This shortage makes quality control more difficult, if Congrid is the only tool to monitor the quality documentation. Congrid was noticed to lack one important feature; the documentation could not be electrically signed. Because of this, reports needed to be printed or e-mailed to get an acceptance, and the signed documents were saved somewhere else. Despite of some difficulties, Congrid manages to convert tacit knowledge into explicit, by providing an opportunity to create instructions and guidelines for each inspection and quality-related action. Instructions have been created by a group of professionals and they are updated when knowledge increases. Knowledge gets distributed in the organization when an employee uses Congrid.

3.3.5 Location tracking and condition monitoring

Location tracking and condition monitoring are briefly introduced in the same chapter, because both parts of Insite were at the stage of testing in search of right kind of solution. Additionally, one of the tested three solutions gathered both location and condition data. Tested systems were Haltian Kaltiot, and Bliot. Haltian system included only motion detectors, which were tested in fifth and sixth floor of the case site. Both floors had different number of sensors, to find out if data was more applicable with different setups. The objective was to compare, if there is movement in right places. For example, if there appears to be only little of movement in an apartment where a task should have been executed, or plenty of movement in an apartment which should be empty due the schedule, it can be concluded that the worker might not be in the right place. Unlike Kaltiot, this system could not any way identify the character moving in different places, so separating the planned movement from unplanned turned out to be difficult. The data was not yet accomplished to transform into useful information, which could be helpful with managing the project.

Kaltiot contained a fixed beacon in every apartment in the site. They measure temperature, humidity and air pressure, and the data remains stored for approximately two weeks. Additionally, these beacons have their own location data. Additionally, among fixed beacons there are scanner beacons, which can be carried. Other part of Kaltiot Smart Tracker is a mobile application, which collects data from beacons when nearby, and transfers it to a cloud service. There mobile applications are both carried (employees' phones) and fixed. (Kaltiot 2018) Third of the tested solutions was Bliot, which offers real-time concrete moisture and temperature measurement. 18 sensors were placed to measure air temperature and humidity, 5 sensors measured concrete conditions and one was outside. Measurements were done every 30 minutes, and the data was available in real time.

In the case study it was noticed that none of the interviewed people considered the location tracking as a positive thing. The main problem was that workers assimilated location tracking to constant watching or spying, which made them feel uncomfortable. Few were willing to install the app to their phone, and some said it was because of their phone had full data storage or bad battery life. This was corrected by lending phones or using beacons to get some user experiences from the site. None of the interviewees experienced that they would have gained benefits from it. This may be because the case site is relatively small, so it is not so difficult to find lost tools from there. Hence, beacons which could have been attached to tools gained no popularity. Additionally, marking the tools would have demanded the mobile app which tracks the phone and the user, which leads back to the first problem. Only marking the tools was considered as a useful practice.

There were some technical issues concerning the location and condition tracking systems. Beacons and sensors were small, and they needed re-placing when the interior works were proceeding. Finding the lost beacons from the site was rather troublesome. Beacons needed to be protected for example from painting. In Kaltiot system the data was gathered from beacons via mobile applications, so the information was not updated real time. Because of this, for example information of too low temperature may come with a delay. This problem did not appear in Bliot system, which sends the data real time to the cloud. Bliot was considered to have least technical shortages from the two compared condition monitoring systems, and it lacks location tracking and its issues.

3.3.6 Knowledge in the project

When evaluating the data, information and knowledge in the project, it was noticed, that some of it disappears during the proceeding. Firstly, all the tacit knowledge cannot be turned into explicit knowledge, so when employees change, their tacit knowledge leaves the project too. Differentiation of the teams in different phases of the projects emphasizes the situation. On the other hand, if differentiation is places in LPDS concept, it enhances the learning loop of a team. There are many ongoing construction projects, and hence many ongoing learning loops, which provides more frequent feedback in a narrow field. Learning loop may not necessarily last from the beginning to the end of a project, because knowledge cumulates gradually, and some lessons can be learned during projects. Some data gets lost because different teams may use different systems in their processes. Notes and transcripts often contain knowledge that could be valuable, but they are not widely distributed. Other aspect is that there can be so much unnecessary information available, that lean principles and waste elimination should be applicated in information flow field and only relevant things should be distributed. This view supports Hicks' ideology and pull flow through digital systems.

3.4 Management process

This chapter studies management process on site, focusing on the role of the main contractor's supervisors. In search of identifying a site management process, management actions were divided into three different cases; subcontract management, meetings and daily management. Subcontract management contains a conventional process between main contractor and each subcontractor. Meetings are summoned regularly, in this case weekly, and they are concerning the whole project. Daily management was the hardest to identify, because there is no defined process for it. It was considered as daily actions supervisors do to contribute the completion of the project. These three management processes and are introduced and their adequacy with takt planning is evaluate

3.4.1 Subcontract management

Certain model for managing the subcontracts has become common in construction, and it is shown in the figure 18. After the contract has been signed, the main contractor and subcontractor start planning the work with startup meeting. Contract is reviewed and responsibilities, plans and schedules are introduced and specified. The actual work starts with model work, which's purpose is to prove that quality fulfils requirements, and to point out appearing problems. Hence, duplication of the faults and defects can be prevented. Model work is inspected very carefully, and depending on work stage, there might be inspector, designers or other stakeholders involved.

After the model work is inspected and accepted, subcontractor accepts the work area and performs the work, which main contractor inspects. This phase of the subcontract management process can vary greatly. Firstly, this phase can be done for the whole site at once, for each floor or even for each apartment. Secondly, subcontractors may have their own quality management process, which affects the process. For example, some may inspect their own work, and some may have demands on the frequency of the inspections. Usually these procedures derive from economic reasons; subcontractor separates their own faults from others and hence has an estimation of the cost of the repairs. Payments may be divided into parts, and the performed work needs to be inspected before it can be paid. After completing all the works subcontract contains, the closure of the subcontract is made.

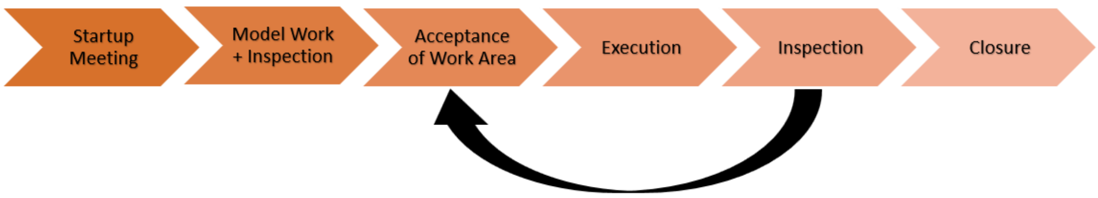

Figure 17: *Subcontract management process*

In the case site, there seemed to be some issues concerning the timing of the model work and its inspection. All the apartments were included into takt schedule, so there was no separate apartment for performing the model work separately. Takt area was two apartments, so the inspection needed to be done in very tight schedule. Because there may be several stakeholders inspecting the model work, the timing should be carefully planned in advance. Frequency of the work area acceptances and inspections of the work were not planned to match the takt schedule. They were attempted to be done in a traditional way, usually floor by floor, but the following work stage was usually already performed in some apartments, and the inspection was too late. The amount and frequency of the inspections was not planned, and the supervisors were uncertain how the process should have been. In the case company it should be decided, whether to do model works in the first takt or separately. Additionally, acceptance of work area, execution and inspection cycle could be established for each takt area after every takt, and not vary the system for each subcontractor. Congrid is the main digital tool to contribute the subcontract management process. All the inspections (model work inspection, acceptance of the work area and work inspections) are done by creating a quality document in Congrid.

3.4.2 Meetings

In the case company there are established meeting practices, which usually contain three different meetings: The Last Planner meeting, contractor meeting and supervisor meeting. The frequency of the meetings may depend on size and type of the site, but in the case site all the meetings were summoned once a week. Meetings were generally noticed to be ineffective, because they had no chairperson, their agenda slipped into free conversation about whatever comes to mind, their duration was usually longer than planned and all the stakeholders were not present. This situation was tried to improve during the case study, by requiring better preparing, naming a chairperson and setting an agenda for the meetings. Still the old habits were not completely overcome. Even though the meetings were not included in the interview questions, three out of six supervisors mentioned that there are too many meetings.

The Last Planner System has been utilized in the case site before the case study. Before the implementation of the takt schedule and digital tools, weekly plan was created in Excel and it included less accurate lookahead planning for the following six weeks. Because the case site utilized takt schedule and digital tool SiteDrive in Last Planner meetings, there was no conflict between weekly plan and the master schedule. Visuality of SiteDrive was noticed to be rather poor for these meetings and the printed version of Excel was often out of date and it did not contain all the lesser work stages. This caused some difficulties whenever the plan needed some changes in the meetings.

In the case study the Last Planner system was noticed to be only partially implemented, because tasks are pushed to weekly plans and division into should, can and will -categories is missing. Because only should-category is regarded, the idea of pull flow is not utilized, and one basic principle of lean disappears. Did-category, which includes both succeeded and failed tasks and search of root causes for failures, was only very briefly discussed. This had both positive and negative sides from this case study and human point of view. Firstly, digital tools could replace the data collection, so in the meetings there should be no need for checking the execution and looking for root causes for the delayed tasks. Secondly, interviews indicate that some people felt pressured when the failed tasks were discussed in the meetings. On the other hand, discussion about bygone tasks provides a chance to speak one’s mind and give feedback.

Contractor meetings were summoned every Wednesday and they were meant for the main contractor, all the subcontractors and inspector. Representatives from each group are introducing the stage of their contracts, and work safety, schedule, plans, complaints and other issues are taken a look. Contractor meeting is an important way to monitor and document the proceeding of the project, and the transcripts can be used to solve possible conflicts afterwards. It provides a chance to communicate with other contractors and make sure that all the issues are known. Hence, it is essential to take part in these meetings and adduce issues concerning the execution of the contracts. Supervisor meetings took place every Friday and all the main contractor's supervisors were present. Agenda of these meetings was to discuss and plan the project. Work safety, schedule, resources and subcontract management are taken a look, and solutions for possible conflicts and problems are decided.

3.4.3 Daily management

Daily management includes all the everyday work supervisors do to contribute the completion of a site. This includes controlling the project; planning, monitoring, reacting on deviations, allocating the resources, materials and deliveries, and taking care of all the prerequisites workers need. It was noticed, that the process for daily management is not defined; it can depend on supervisor's personality, education and routines. Solid recommendations cannot be given, but there are some characteristics that can improve daily management. Supervisors need to be aware, what is happening, and which issues may need attention. Role of digital tools arises especially with situational awareness in complex projects. Supervisors need good communication with workers and other stakeholders.

4. DISCUSSION

The case study revealed several problems in implementation process of takt schedule, and the findings set demands on the case company's policies concerning project management. Main findings are introduced in this chapter. Findings seem to fit well with previous research, and the main problems seem to relate with lack of early integration and planning, as well as lack of education and communication. User experiences from digital tools were gathered, and the main findings are introduced. It is discussed, how digital tools could contribute in the site management process with takt schedule.

4.1 Findings of the research

Takt schedule seemed to shorten the lead time considerably. Project was not finished during this research, so the actual time saving has not yet become clear, but approximately two months seems to be a good estimation. There were both positive and negative experiences. The main contractor's supervisors considered takt schedule helping to plan the whole production, when there is more precise schedule for the whole interior work stage. Workers on the did not have enough knowledge of the schedule and its objectives, and some of them thought it only means they need to work faster. Ten main problems concerning takt schedule were: 1) drying times, 2) logistics, 3) incentives, 4) faults in the schedule, 5) partial implementation, 6) education and communication, 7) contracts, 8) resources, 9) faults in structural design and 10) accidents, absences and other unpredictable factors. These findings seem to conform well to previous research, which state the importance of integrating the whole process. Most of the problems could have been prevented with better planning in early stage of the project. Co-operation or partnering with subcontractors could have been helpful when estimating the performances and their durations, as well as unifying the objectives. Contracts are an important interface to other operators in the project, so it must be ensured that the objectives do not conflict with revenue logic. Pay for performance was noticed to be one of the incentive types that had conflicting objectives with takt schedule. Expectedly, variability seemed to be one of the most important reasons for delays, and from time to time variability was so big, that the whole schedule needed to be changed. Too frequent and major changes decreased the reliability of the schedule, when the supervisors gave up following it. Buffering was done with empty wagons, and this may have been the reason for spending them fully.

Along with takt schedule, seven digital tools were piloted in the case site. User experiences were collected from different systems, and their possible contributions to the site management process were estimated. Piloted systems were Insite, Site Manager, SiteDrive, Congrid, Kaltiot, Haltian and Bliot. Business intelligence view Insite was considered as a useful tool for site management, because it gives a clear situational picture of the complex project and helps to focus on the most critical issues. Insite could also patch some shortages in other systems; if the organization or visuality are poor, the data can be organized and showed in a different way, or it can be combined with additional data to create new information. Development is still in progress though, and the reliability of the data depends on use of the other systems. Combability of the data was a challenge, which caused lots of extra work and iteration of the user applications. Insite works only as a view, so the updates cannot be made through it. Site Manager is a well-known and functional digital system, and the only clear problem concerning the data was that registering to the site is manual and may be forgotten.

SiteDrive had very good usability, and it could provide valuable information about the progress of the project. Lack of users caused some lost benefits; the actual durations of the tasks were not recorded if workers did not mark them started and finished, and the proceeding information was not real time, if only the supervisors were using SiteDrive. This was because they usually did the markings only occasionally, when there were several tasks finished. SiteDrive lacks the right kind of view for a takt schedule, so there was Excel version of the schedule too. Parallel versions cause confusion and additional work. Congrid was noticed to require common instructions, because the usability allows too many ways to use the system, and the data is too incoherent for further use. Another shortage is that the documents cannot be electrically signed, so the reports still need to be printed or emailed. Haltian is a motion detection system, Bliot is a condition monitoring system and Kaltiot includes both location tracking and condition monitoring. Location tracking and motion detectors were considered offending the privacy of the workers, and there were experienced no benefits among the interviewees. Only tracking the tools was considered as a promising idea, along with condition monitoring. Compared to traditional perceptions of the information flow, the mindset could be changed into more modern way, which consider information flow as a complex network rather than a constant and straightforward part of a trade. WhatsApp turned out to be the most popular digital tool in the case site, which indicates that better usability could enhance the use of other digital systems. Additionally, WhatsApp’s common groups created transparency and notifications helped to follow the constantly changing plans.

Takt control is a topic that has not yet been much discussed, so takt schedule implications for the traditional management process should be considered. It was noticed, that some of the traditional management processes should be updated to match the takt schedule. Subcontract management includes a start-up meeting, model work and its inspection, repetitive cycle of accepting the work area, work execution and inspection, and finally the closure of the subcontract. Timing of these procedures seemed to fit poorly to the takt schedule. The start-up meeting could provide valuable information to the scheduling process, if it was done earlier. It should be decided if the model work is done at the same time with first takt or should there be a separate apartment for the model works. The number of work area acceptances and inspections varies greatly, and there are necessarily no demands for the frequency of them. Takt schedule causes rapid progress, so traditional number of inspections may not be enough. There were three kinds of meetings in the case site that were considered to belong to the site management process; The Last Planner meeting, contractor meeting and supervisor meeting, all of which were weekly. Even though literature recommends frequent, even daily, meetings in takt production, the interviews indicated that the number of the meetings is considered too high. At the same time, meetings were noticed to be ineffective and long, with no clear agenda or chairperson, which may explain some of the complaints rather than the number of meetings.

Contributions digital systems have in the management process are enhanced information flow, transparency and better situational awareness. Digital tools make sharing the information easy, and all the users have access to it. Better knowledge of the stage of the project could improve meetings; sharing the stage of different works has a major part in the meetings, which were estimated to last too long. On the other hand, the amount of data is so high, that it sets further demands for organizing and refining data into information and knowledge. It must be noticed, that overlapping systems cause additional work, and if there are no experienced benefits, it reduces motivation to stick to the systems. Hence, the set of tools and their coverage should be carefully planned, and maybe consider fully replacing some old habits.

4.2 Limitations of the study

There were some limitations in this research. Research methods were clearly qualitative in nature, because the case study concerned only one construction site and the number of interviews is small. Interviewees were chosen by quota sampling, which is non-random sample. Different sampling or better coverage could have provided valuable information about the potential users, who are not willing to test new tools. Results could have different in some other construction site, because of different project, organization and procedures. Interviews were semi-structured, which means that the results are not exact, and they may be hard to compare. The questions were not very accurate, because of the diverse population of interviewees, and the management process was not included in the interviews.

Takt schedule concerned all the interviewees, but the tested combination of the digital tools varied greatly among interviewees. Because the tools were not systematically implemented, it was not clear if the interviewees refused using them, or were they not even offered. Variable number of users make the sample even smaller, at least in case of Insite, location tracking and condition monitoring systems. During this study, digital tools did not replace for example company's own quality system, subcontractor's work stage reports and traditional condition measurements, so overlapping systems may have caused frustration and hence affected to the interview results. Some systems were at stage of development or early testing, so the recommendations may depend on improvements. Many of the system developers are in close co-operation with the case company, and there were improvements made even during this study. Additional features and technical improvements make the situation constantly changing. The suggested management process, which better matches the takt, has not yet been tested, so further research is necessary. Suggested processes are tightly related to the case company policies, so they may not necessarily fit to other construction companies as such.

5. CONCLUSIONS

As a conclusion it can be said, that a takt schedule shortens the lead time and provides clear framework for the project. Takt schedule needs to be integrated in earlier stages of the project. Planning, procurements and contracts are an important part of successful project, because they ensure predictable execution and good constructability, unify objectives and provide support for conflict situations. After the execution has started, it is more difficult to influence these factors, because contracts are the most important interface to other stakeholders. Faults and shortages in structural design may cause need for changing the whole schedule, and their correction takes lots of time. Subcontractors' revenue logic and workers' pay for performance were noticed to conflict with takt schedule objectives, and some deliveries were hard to adapt to match the unconventional needs. Literature review introduces the idea of partnering and co-operation with subcontractors, which could provide valuable information not only for execution phase but planning and scheduling too. It could also enhance achieving common objectives and improve commitment to them, and the learning curve would continue between projects.

Along with structural planning, the execution stage should be carefully planned. It was noticed, that especially drying, and logistics need more attention than in conventional projects, because the duration is significantly shorter. Instead of only preventing the building from getting wet, the mindset should be changed to actively ensuring the drying. Digital condition monitoring systems, like Bliot, enhance awareness of the stage of drying conditions, and alarms and forecasts can be developed to support it. Better risks analysis could prevent unexpected occasions or minimize their consequences. Additionally, fallback plans for sick leaves, lack of task requirements, organizational changes or other probable challenges should be considered in advance for each subcontractor, to prevent them leaving the site.

All in all, digital systems seem to improve information flow, transparency and situational awareness in a construction project, so their implementation is worth continuing further. Some of the piloted digital systems need further development and unified instructions. SiteDrive needs to develop a practical view for a takt schedule, to dispose the need of two different software and parallel schedules. Utilizing the three-level model could improve the view even further. Replacing the work stage reports with SiteDrive and sharing the actualized durations to the subcontractors could be some motivators for more disciplined use. SiteDrive could provide valuable information for upcoming projects and their planning if the recordings are precise. Congrid needs common instructions, because there are too many variations for creating the notices and the further use of the data is difficult. Electrical signature could be beneficial feature. Implementation of the location tracking systems should be reconsidered, because in the case study they seemed not providing enough benefits to motivate the use. WhatsApp appeared to be the most popular digital tool, even though it has not been intended to belong in site tool set. To compete with it, notifications, good usability and big percentage of users could be some desirable trends in further development and implementation.

Implementations should be better defined beforehand. Implementation of the digital systems should not be partial, if the benefits, and hence the momentum, cannot be fully gained by partial use. Especially software that provides situational picture, like SiteDrive of Insite, suffer from lack of users, irregular use and neglecting the updates. Overlapping systems or procedures should be avoided, by choosing the preferred ways and replacing the old ones with them. Overlapping systems cause additional work and confusion, when the changes require updating in different systems. Better education is needed in all different groups, and it should contain clarifying the objectives along with technical instructions. It should be ensured that all the stakeholders are using the same systems, so the communication and transparency are not deteriorating. Digital systems have some contributions to the management processes. They could improve the procedures if the situational picture is not necessary to be investigated during them. Including the desired digital tools in contracts ensures that all the subcontractors use them. Relations of different systems and site management processes are shown in the figure 18.

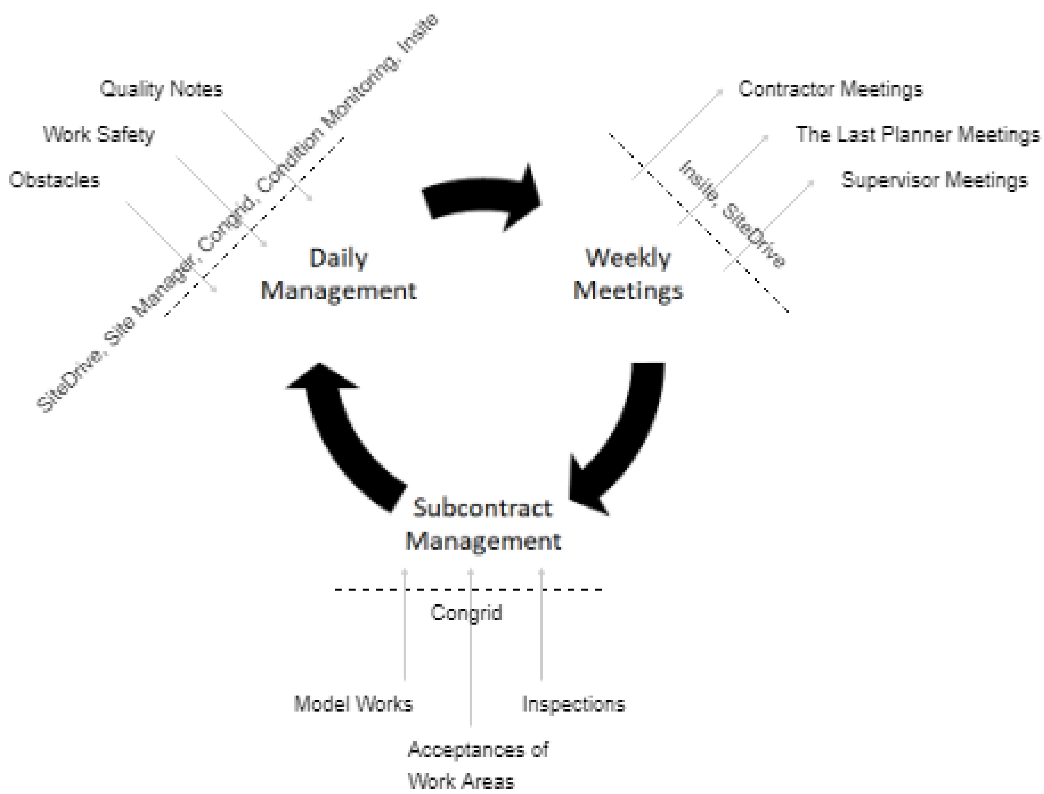

Figure 18: *Relations of different systems and site management processes*

Conventional management processes seem not to fit with takt schedule at some parts. In the case study, the management processes were not adapted to the takt, and some needs for improvements were found. Literature review recommends frequent, often daily meetings, but the interviews indicated that even weekly meetings were experienced too much. Pay for performance decreases workers' incomes during meetings, which along with inefficient and long meetings decreases the motivation to take part. The situation could be improved by enhancing the meetings; they should be shortened with strict agenda and chairperson, so they could be more frequent. If information, plans and schedule are updated, they have positive affect in meetings and enhance their effectivity. Hence, well completed supervisor meeting creates prerequisites for the following Last Planner and contractor meetings.

Subcontract management process should be adapted to takt schedule and change the mindset from traditional division of the areas into takt areas. It should be decided if the model work is done in first actual takt or separately beforehand. Work area acceptances and inspections should be done in each takt area between the tasks, not floor by floor or some other traditional way, which does not match the takt. This leads to more frequent inspections, but the areas are smaller, and the procedures can become a part of daily routine. If model work is done separately, the suggested process is visualized in the figure 19.

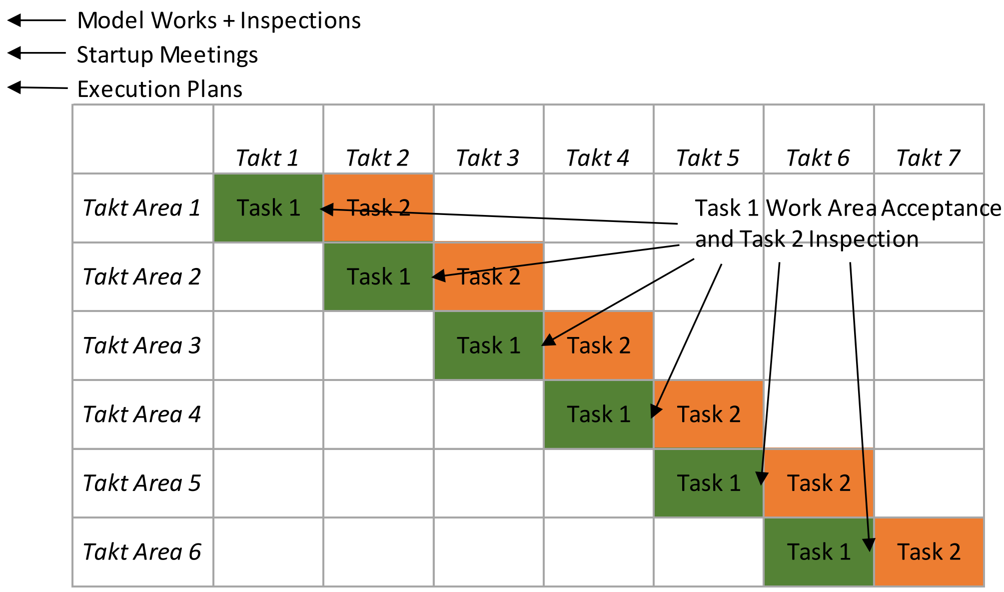

Figure 19: *Subcontract management process adapted to a takt schedule with separate model work*

If model work is performed during the first takt, the suggested process is visualized in the figure 20. This model requires early communication with all the stakeholders because the inspection and possible improvements need to be done before the second takt. If takt is shorter than a workday, separate model work should be considered.

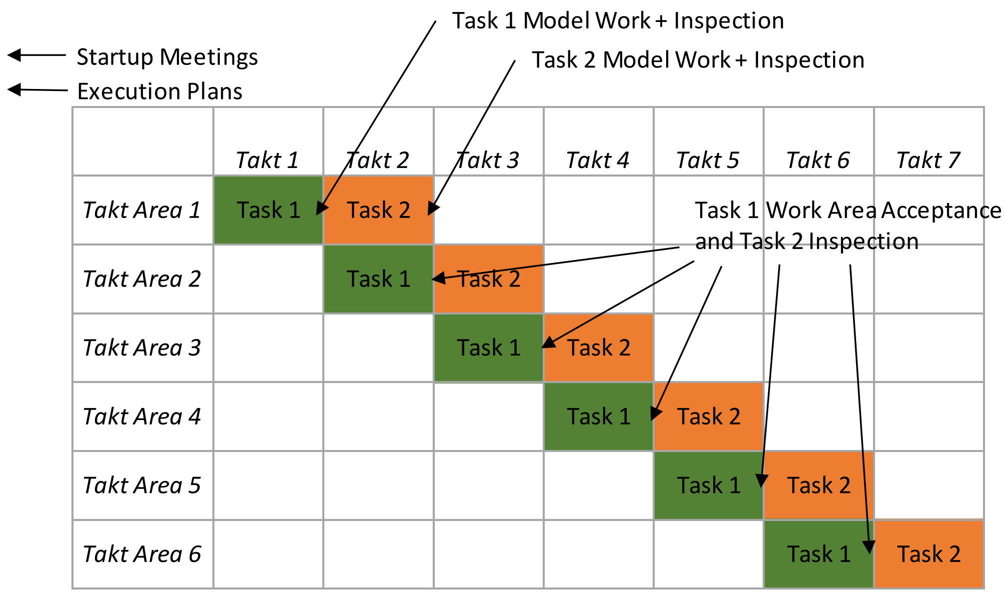

Figure 20: *Subcontract management process adapted to a takt schedule with model work in 1st takt*

Further research is needed in the field of takt planning. Recommended actions, like earlier implementation, integration in contracts, planning and revenue logic, changes in the management procedures, and developing the digital tools should be further studied and their consequences should be investigated. Takt planning should be quantitatively analysed, because the previous research has been mainly qualitative. The information flow seems to be more complex than it has been considered in the field of lean construction, so its role in the concept of flow may need further research. Knowledge management and information technology are still only loosely connected to the flow, but they could provide valuable contribution in lean construction.

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APPENDIX A: SEMI STRUCTURED INTERVIEW QUESTIONS

Common Work Assignment Questions

1. What is your top priority today?
2. What are the expectations you meet in your work?
3. How do you fulfill your expectations?
4. What is important in your work?
5. What are the problems you face regularly in your work?
6. Which matters you need more information about?

Takt Planning

1. What are the objectives of takt planning?
2. How do you keep track of the schedule?
3. Has the schedule been too tight/appropriate/loose?
4. Have the work packages been soundly composed?
5. How the division of the works has been done among the team?
6. How takt schedule has affected in work?
7. Do you consider takt planning as beneficial?
8. Do you consider takt planning as equal to all the workers?
9. What other feedback would you give about takt planning?

Digital tools

1. Which digital tools have you been using and how?
2. How were the tools introduced and has education been adequate?
3. In which cases have you considered digital tools useful/useless?
4. What kind of information would you like to get by using digital tools?

Background Questions

1. Role and work assignments in the case site?
2. Previous work experience in current assignment?
3. Payment type (pay for performance/hourly or monthly payment)