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Improving Construction Takt Production Efficiency by Using Digitalization

Master's thesis submitted for examination for the degree of Master of Science in Technology.

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Abstract of master's thesis

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Abstract

The construction industry is one of the largest economies globally however, during the past decades construction production has only increased by 1% annually. With the actively growing urbanization, construction industry is looking for the methods to build faster and achieve a better production flow. Construction sites do generate a lot of data that could be used to boost the production but, this data is still being collected manually using spreadsheets and hand-written notes. In order to enhance productivity improvement and cost efficiency, manual data collection must be eliminated and digital technology and advanced automation should be infused into construction daily activities.

The objective of this thesis was to develop standards for efficient digital data collection and to propose improvement ideas for applying the generated digital data in construction site management in construction company Fira Oy. The research was tackled with two methods: a literature review and a case study that included observations, examination of used digital tools and currently available data, and semi-structured interviews. The literature review provided a definition for good construction productivity, theoretical background of takt production and introduced the concept of digitalization in construction. The aim of the empirical research was to test applicability of takt production in residential project, identify data users, find available and missing data. Combining recent theory on takt production and digitalization in construction with outcomes of the case study, four essential behavioral changes were identified that can help to increase digitalization integration level at the construction site: creating clear common rules and instruction for all potential users of digital systems; providing intensive training for site management on digital tools, sufficient training of subcontractors; obliging subcontractors to takt plan following and digital tools usage through contracts; and establishing clear communication by organizing regular daily and weekly meetings. In addition, several technical development ideas were proposed.

The outcomes of research were based on a single case study and therefore, further research is required to specify the results and test them. The research proved workability of takt production in residential projects and showed that digital tools can provide more accurate work tracking, possibility for efficient learning and continuous improvement through proper processing and analysis of collected data. Utilizing digital tools has become a prerequisite for the competitiveness in construction industry but only well planned implementation of digitalization can bring the success.

Keywords digitalization, data in construction, digital tools, takt production

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1 Introduction

1.1 Background of the research

The construction industry is one of the largest economies in the world where yearly spending accounts for 13% of the world´s GDP. However, during the past decades construction productivity has only increased by 1% annually. (McKinsey & Company 2017). Since the 1960s all non-farming labor based productions have doubled or more except for the construction industry. Currently, nearly 70% of building projects are delivered late and exceed the budgets. (Seed et al. 2018) The construction industry is deficient in innovation and technology culture, the businesses suffer from slow and inefficient process execution and absence of cross-project knowledge transfer (World Economic Forum 2015). The struggle is being explained by extensive regulations and highly cyclical markets where supply adjusts rather slowly to the demand. (McKinsey & Company 2017). With the actively growing urbanization, construction industry is looking for the methods to build faster and achieve a better production flow. Increasing construction productivity has become priority task for all construction firms.

Meanwhile the modern business world seems to be all about data: collection, generation, protection, analysis, and the significance of data keeps growing. Data is a simple tool that can be used to strengthen business activities and provide more profit by monetizing it (Thomas and Leiponen 2016). Construction sites generate a lot of data however, the industry has traditionally been slow at technological development and construction business has not yet been taking the advantage of the data-driven analysis and decision-making. Much of the collected data during construction is still dependent on manual collection and paper which creates inefficiencies and inaccuracy (TrackVia 2018). Furthermore, workforce in the construction is relatively conservative towards technology and there is a visible deficit of young specialists and feeble employee development (McKinsey & Company 2017).

1.2 Research problem

According to McKinsey & Company (2017) construction productivity could be boosted by 50-60% by shifting the industry towards a manufacturing-style production system. And indeed certain progress in the industry has been achieved by implementing lean principles and takt production in particular. The key idea of takt production is synchronized work-cycles aligned with requirement to avoid underproduction or overproduction. Takt time determines the pace for all production processes and enables the accurate prediction of work amount that can be completed. Optimization of takt time reduces resource wastefulness by minimizing the risk of time delays and decreases the cost of work time and materials. (Haghsheno et el. 2016) Takt production was applied in construction to achieve continuous work flow and reduce variability and time waste which are typical for the industry. In fact, takt principles have been proven to add value and decrease time and inventory buffers when following the methodology systematically.

(Yassine et al. 2014) However, only several studies have recorded the practical implementation of takt driven cases in residential construction (Lehtovaara et al. 2019).

Most of the construction managers believe that correct data at right time is crucial for the success of any construction project. But despite the importance of accurate data, it is still being collected manually using spreadsheets and hand-written notes. Manually collected data is often incomplete and full of errors, and it complicates communication between main contractor and subcontractors, which delays the final handover to the client and increases project costs. (TrackVia 2018) In order to enhance productivity growth and cost efficiency, manual data collection must be eliminated and digital technology and advanced automation should be infused into construction daily activities. Recently digital and mobile technologies have started to spread among construction industry quite rapidly. (McKinsey & Company 2017).

Another problem comes with the current utilization of digitals tools in construction – it is inconsistent and disorganized. Many of construction professionals are rather conservative towards technology (World Economic Forum 2015) and consider digital data processing as additional non-value bringing work. However, if they do realize the advantage and do use the digital tools, they do not do it systematically or do not follow any common instructions and therefore, collected data is incomplete and messy. TrackVia's (2018) research confirms that the construction industry would greatly benefit from unified efficient data collection and analysis methods with solid digital solutions.

1.3 Research objective and questions

This research is made for a construction company Fira Oy, which from now on is referred as construction company. This construction company has started to implement innovative approaches such as takt planning in their projects however, it has been a struggle to achieve accurate digital data collection at sites. Management wants to have a quality digital footprint for efficient analysis, decision making and cross-project learning.

In order to improve the quality of digital footprint at construction projects and thereby work efficiency, this thesis aims to develop standards for efficient digital data collection and to propose improvement ideas for applying the generated digital data in management and construction work execution. To fulfil the research aim a primary research question and three sub-questions are set for this thesis project:

1. How can a construction company change the ways digital data is collected and processed at construction sites in order to increase process productivity?

a) Who needs the data at a construction site and for what purposes?
b) What is the crucial data for executives and for site workers?
c) What data is currently available and what data is missing?
d) How can takt production in residential construction be supported by data?

The scope of the thesis will be limited to residential construction due to existing gap in the current studies. In addition, the thesis will focus on digitalization in takt production during interior construction phases on the grounds of the construction company needs.

1.4 Thesis approach

In order to develop standards for efficient digital data collection, theoretical background of takt production and existing practices in digitalization in construction have to be examined. The theoretical review includes scientific articles, journals and reports from the field of lean construction. In addition, latest studies on digitalization in construction management will provide a sufficient overview on current practices, innovations and challenges in the industry.

The study target for this research is digital platforms and data management in construction production context. The developed standards have to be feasible and applied at a construction site and therefore, this research has to be executed as a case study. The case target for this project is a 14-floor apartment building in Jätkäsaari district in Helsinki, where takt planning was implemented and several digital tool were used for management.

This case study uses the following qualitative tools for data gathering: case observations, including existing digital tools and data; semi-structured interviews; a real-time location tracking tool that was piloted at the case site and analysis of collected information.

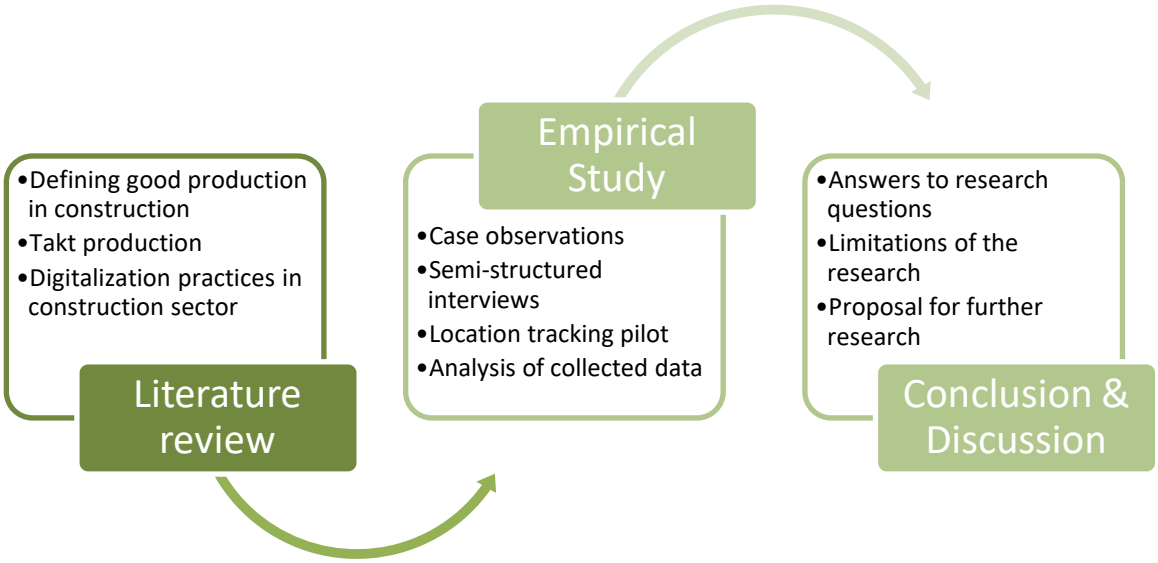


Figure 1. Research process.

Observations, as a case study launching tool, allow the researcher to increase understanding of the case. The observations are targeted at currently used digital platforms at the site, management practices and general problems in takt production and work of furniture installation subcontractor.

Semi-structured interview is the type of interview where several open-ended questions are predetermined but at the same time participants can openly discuss wider topics and interviewer can form new questions during the interview (Creswell 2003). The interviewees for the case study were workers of the construction company who represent site management and executives from the headquarters of the company. The participants for semi-structured interviews were chosen based on their role in the case project to get a full situation picture of the case site and collect complete data sample.

In addition, to get quantitative data, a real-time location tracking tool was piloted at the case site and it served as one of the additional research tools for the thesis. Jianyu et al. (2017) develops a prototype of an intelligent system that is intended to improve construction efficiency and detect and reduce production waste. The data collected through the tool during the pilot can potentially give valuable numerical information on efficiency of several subcontractors. The research design process and the methods of analysis are described in the Chapter 3.

1.5 Thesis structure

This thesis is divided into six chapters. Chapter 2 reviews the literature on the production flow, takt production and digitalization in construction sector. Chapter 3 explains the research design of this thesis project by introducing chosen research and analysis methods. Chapter 4 introduces the case study, takt production planning process, digital tools and data available at the site. Chapter 5 reports the outcomes of empirical study and provides final answers to research question and presents proposed improvement actions for efficient digital data collection and its employment in construction business. Finally, Chapter 6 concludes the thesis by discussing the accuracy of outcomes, limitations of the study and recommendations for further research.

Figure 2. Thesis structure.

2 Literature review

This chapter reviews the theory behind takt production and introduces current digitalization practices in the construction sector. Section 2.1 defines efficiency and good production flow in construction. Section 2.2 describes the process of takt planning and production, after which digitalization in construction is introduced in Section 2.3. Section 2.4 presents theoretical framework for the thesis and summarizes the findings of the literature review.

2.1 Good production flow in construction

Since the 1960s all non-farming labor based productions have doubled or more except for the construction sector. Currently, nearly 70% of building projects are delivered late and exceed the budgets. (Seed et al. 2018) With the actively growing urbanization, construction business is trying to find the ways to build faster and achieve a better production flow. But what is the good production flow in construction context?

Up until now civil engineers have focused on the end product using so called “earned-value method” which measures the amount of completed work and doesn´t give any information on the quality of the production flow. To compare, a good flow in manufacturing production means a value stream that has eliminated or minimized all the non-value adding activities, such as pauses between the operations. Early economists have developed production subdivision practice and this idea has become fundamental in the efficient manufacturing production and later also in construction. The production subdivision implies that the raw product moves along the sequence of tasks, and each task is performed by a specific skilled person or a machine, providing continuous occupation for all the resources. In traditional construction practice we also see that building process is subdivided but subprocesses are not linked closely enough and the waiting times between the operations can be really long. In order for process to be continuous and progressive, a time cycle, or a “takt”, must be identified and maintained at all times. (Sacks 2016)

Kenly and Seppänen (2009) suggested that a product flow in manufacturing is an analogue of location flow in construction. Even though locations do not move along the manufacturing line, they do “move” in the eyes of a construction worker, who starts working on the next space after the previous one has been completed. In this way Kenly and Seppänen define construction flow through location-based scheduling, instead of activity-based. (Kenly and Seppänen 2009) Work package, meaning location size in construction, is rather flexible and can be defined upon production planning. The concept of takt in construction slightly differs from manufacturing as the size and number of locations define the takt time. To be noted that in location-based production the sequence of products between operations is fixed and it is possible for more than one trade to work in the same location, even though it was proven to reduce productivity. (Sacks 2016)

Construction work flow can be viewed as a function on three axes: portfolio, process and operation (PPO) (See Figure 3). Process axis follows the work time or takt, operation axis follows the flow of trade crews between locations, and the portfolio axis follows the flow of trade crews between different projects or houses. This concept makes it clear that trade crews move not only within single project, but also between projects because, the trade crew supervisor tries to provide continuous employment for his workers. Meanwhile general contractor is concerned only for the own project delivery by operating with subcontractors through contracts. The site superintendent advances and controls subcontractors' work, at the same time ensuring continuous work in the locations. (Sacks 2016)

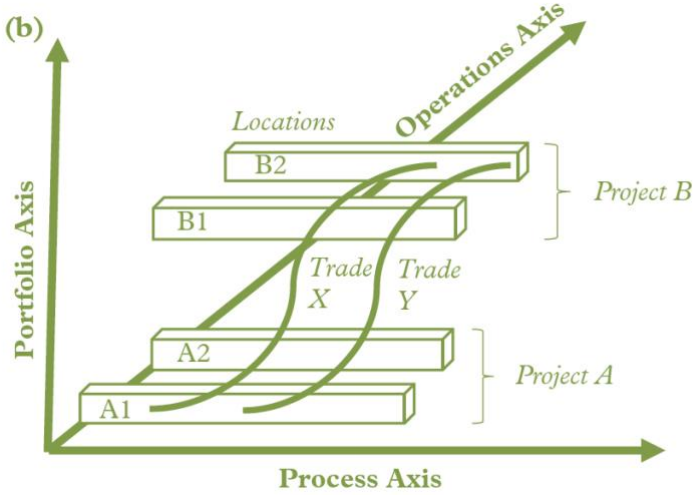


Figure 3. Three-dimensional portfolio, process and operations model of construction flows (Sacks 2016)

Unlike manufacturing factories, construction projects are codependent on the pool of regional subcontractors. Subcontractors' shifting across different projects restricts general contractors' ability to plan ahead and set precise milestones. Thus, continuity of trade flow for subcontractors is created at the expense of location flow at a given construction project. Above mentioned concludes that there is an interdependence between operations and portfolio of projects so, the PPO concept is a cyclical relationship (Figure 4), meaning that without good flow in one of the areas there can't be good flow in the other. (Sacks 2016)

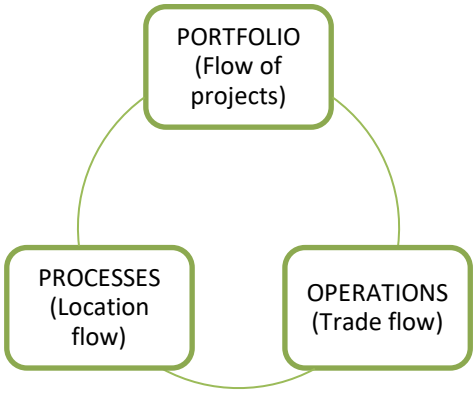


Figure 4. Cyclical view of the relationship between project portfolios, processes and operations. (Sacks 2016)

As we have seen, performance of general contractor depends on the work and productivity of subcontractors. Subcontracting has taken a strong position in the construction business despite the shifting, as it had proved to be an economically feasible and low-risk way of working: general contractor doesn't need to invest in personnel and equipment and trade specializations allow to transfer liability and risk from contractor to subcontractor. However, every construction project has a set of different subcontractors and it makes implementation of any flow standardizing process very difficult. Moreover, subcontractors are usually chosen on a lowest-offered-price basis, meaning subcontractor's key objective is to maximize income per unit time and not to maximize productivity. (Sacks 2016) According to Eriksson (2010) partnering between contractor and subcontractor or contractor and producer provides possibilities for continuous improvement of construction production process. However, in order to achieve production efficiency the partners should be involved in the project planning at early stages. (Eriksson 2010)

So, it comes to a question: how to provide continuous good work flow at a construction site? Based on the portfolio, process and operation model, it can be said that in order to achieve good production flow in construction, there should be good project flow, location flow and trade flow simultaneously. In addition, collaboration or partnerships between general contractor and subcontractors is crucial. Synchronous location flow and trade flow is a challenge because of conflicting interests of the participants, variability of work tasks and instability of supply chains. However, as the flows are interdependent, improving of location flow for instance can improve project flow and trade flow. (Sacks 2016)

There is a need for a systematic way of improving production flow in construction if the industry wants to develop in long term. When all construction activities move at different paces, every projects becomes somewhat chaotic. Takt production is one of the practices to produce quality location work flow in construction with the assistance of application, physical and digital tools. Takt-time planning as a work structuring tool, is an attempt in project-based production improvement. In the following chapters we will see why takt-planning is beneficial in construction project and especially in interior works management.

2.2 Takt production in construction sector

2.2.1 Definition and planning

Lean principles were brought to construction industry in early 1990's (Heyl & Teizer 2017) in order to increase production by maximizing value for customers while minimizing waste and utilizing fewer resources (Lean Enterprise Institute 2019). Koskela (1992) was first to describe construction with the "transformation of resources and the creation of Value and Flow of materials and people" and adapt lean management in the industry.

Takt Planning and Takt Control (further TPTC) is one of the lean work structuring methods which is used to organize production and supply schedule (Frandson et al. 2013). TPTC aims to establish continuous workflow for subcontractors and manage possible time and space buffers. The workflow is divided into packages of tasks – chunks, and the working area is divided into zones. Takt-time is a pace planned for every construction activity within which it should be completed in a given zone. (Frandson et al. 2014) Ideally takt production balances work tasks in a way that all of them proceed around the same unit of time. Suchlike structured production allows to achieve efficient daily control, stability and continuous flow. (Lehtovaara et al. 2019) Takt-time provides a construction project with a feasible pace. That clear pace, allows to have work chunks of appropriate size and a clear view of upcoming activities. In addition, takt gives general contractor clear target and peace of mind: as long as every smaller work chunk is completed on time, the whole project is also on track (Frandson et al. 2014).

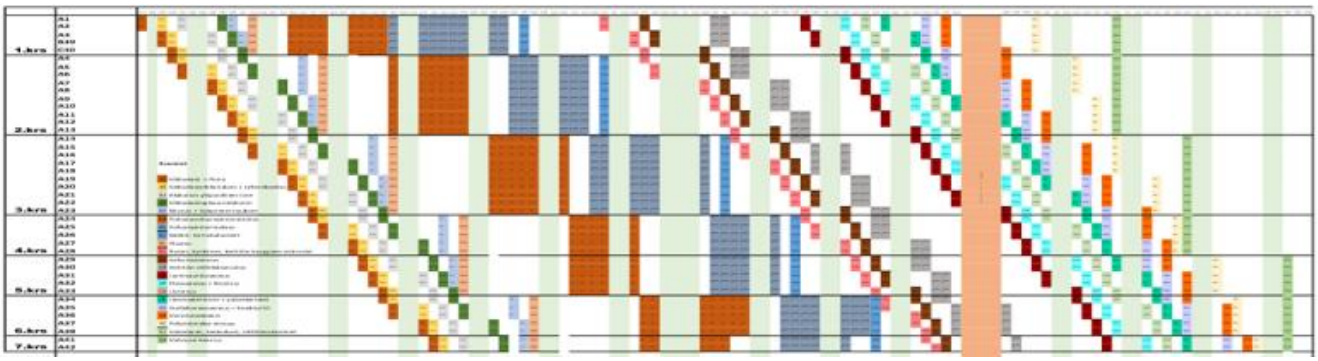


Figure 5. Example of takt production schedule (Fira Oy 2019)

Figure 5 demonstrates the entire takt plan with floors and apartments on the y-axis and days/takt time on the x-axis. Each wagon is associated with one color identifying the work for each subcontractor, which makes takt schedule easy to read and understand.

Takt production planning is always initiated with process analysis and followed by takt planning and takt control (Frandson et al. 2013). Each stage of Takt production consists of three essential steps that are represented in the Figure 6 below.

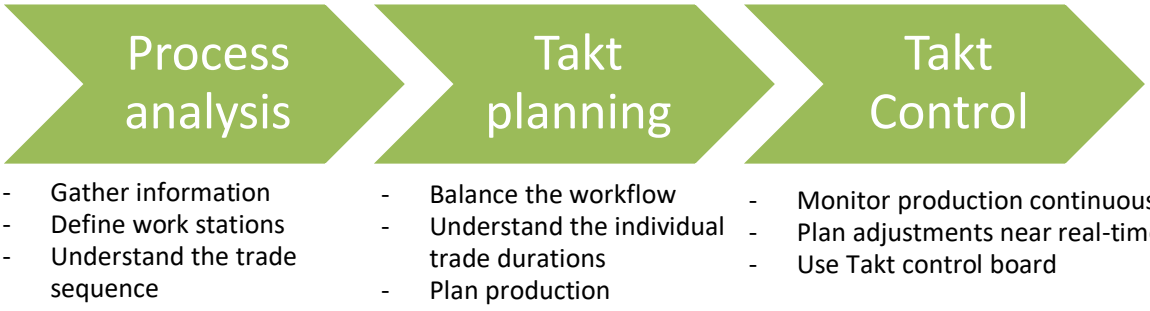


Figure 6. Process of Takt Planning and Takt Control (Heyl & Teizer 2017)

Process analysis and takt planning phases are aimed to identify sizes of work chunks given to subcontractors, their sequence, work release procedure when trade crew moves from one zone to another, ways to eliminate possible buffers and pace for every trade activity (Tsao et al. 2000). Takt production planning process intends to set a feasible working schedule and space flow that could be followed throughout the project (Heyl & Teizer 2017). The ultimate goal of Takt production is to achieve the shortest possible turn-around time of the project, meaning minimized start-to-finish time, as workers produce more in less time, and reduced project costs (Vatne & Drevland 2016).

When planning the takt production, it should be noted that all activities inside working packages are different in their nature: they have different technological constraints and may take different time to complete. Some processes do not have any technical dependence on each other, such as electrical and plumbing, but some other processes, that mainly conduct the interior phase, have to come in a certain sequence. (Sacks 2016) In addition, as working packages, availability of trades and supply chain are highly interdependent and together they influence the project schedule, constant control and frequent update of production plan are essential for the risk and change management (Haghsheno et al. 2016). Current solution for such control is regular meetings at construction sites that allow to ensure work stability, monitor current developments and do necessary adjustments immediately if required (Kenley and Seppänen 2010).

In order to make those adjustments and manage occurring buffers, takt-planning separates process fluctuations into “schedule noise” and “schedule variance” (see Figure 7). Schedule noise is passing movement of an activity within takt sequence and does not influence general work schedule. Schedule variance is the temporal movement big enough to shift into the following activity sequence creating a trade conflict. There are two ways to solve this conflict: either work it out as soon as possible on the site so, incoming subcontractor will not be affected, or rearrange the whole sequence because otherwise the incoming subcontractor will be late with its work. Distinguishing these two terms allow to reduce stress on production workers and minimize resource waste on micromanagement of minor schedule changes that do not actually affect the bigger picture. (Frandson et al. 2014)

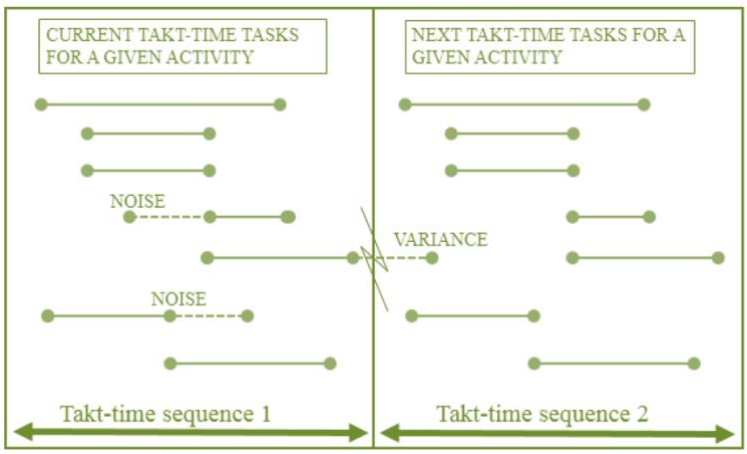


Figure 7. Difference between Schedule noise and Schedule variance (Frandson et al. 2014)

2.2.2 Takt practices in residential construction

Appliance of TPTC method in construction sector has been developed in Germany since mid 2000's and it was implemented in many construction projects (Haghsheno et al. 2016), however, only few studies have documented the implementation, ways of improvement and analysis of takt controlled cases in residential construction (Lehtovaara et al. 2019).

Authors, year	Research and/or case
Vatne & Drevland 2016	Practical Benefits of Using Takt Time Planning: a Case Study
Lehtovaara et al. 2018	Implementing Takt Planning and Takt Control into Residential Construction
Mustonen 2019	Implementation of Lean Construction Tools and their Contribution to Site Management Process
Nieminen 2019	Johtamiskäytännöt: Case Keinulaudankuja

Table 1. Documented Takt cases in residential construction.

Vatne & Drevland (2016) studied a construction project of student dormitories in Norway where Takt planning was applied. Takt production was considered necessary to deliver project in time and it progressed rather quickly due to usage of massive elements and prefabricated modular bathrooms. The site manager initiated the takt implementation at the site and arranged three meetings for foremen and trade supervisors to identify work packages, their sequence, takt areas and takt time. The takt area was set to one floor and takt time to one week. In addition, these meetings helped the trades to understand each other's work and highlight potential problems even before the actual work started. By the end of the project several problems had been identified. First of all, some work packages were not completed on time due to delays in materials' delivery and caused waiting buffer for the following subcontractors. Secondly, project's costs per production unit of one square meter appeared to be 14% greater than in non-TPTC projects. Thirdly, the site management couldn't work out the elimination of buffers: site manager used ground-floor as off-takt buffer to utilize extra trade craftsmen however, this idea failed because usually there was nothing to do in the ground floor for those workers. Lastly, the site management found Microsoft Excel inefficient for takt plan visualizing and would prefer to use specialized software in the next takt based project. Otherwise, the construction project was delivered on time and a noticeable reduction in waiting time waste and in site administrative costs. (Vatne & Drevland 2016)

Another example of takt production implementation can be seen in Lehtovaara et al. (2019) and Mustonen's (2019) researches. The case project was an seven-story apartment building located in Helsinki, Finland managed by Fira Oy. It was the first project for the company where the takt production was piloted. Takt was implemented only during the interior work phases so, it was not in the original production plans of main contractor and subcontractors were employed without takt production agreement. The takt area was set

to one apartment and takt time to one day. The major challenges and learning points included: unpredicted drying times of concrete delayed the following activities; logistics of bigger objects was challenging and took a lot of time for re-allocation; smaller phases that were missing from the schedule caused disruptions and delays in takt schedule. All in all, the takt schedule allowed to shorten the turn-around time of the case project by around 2 months with only slightly increased direct costs. The management of the construction site found takt schedule useful and helpful when planning interior work activities. However, the workers didn't know the essence and the objectives of the takt production, and therefore thought that the contractor just wants make them work faster. The above mentioned proves that clear communication and education of all workers involved is required when implementing takt production. In addition, it is crucial to partner with subcontractors and agree on takt execution before the contracts are signed. (Lehtovaara et al. 2019; Mustonen 2019)

In addition to takt schedule, seven digital tools were piloted at the case site that allowed to control and track general situational picture, schedule, safety and quality indicators, and real-time location of employees and equipment. Incompatibility of the data and overlapping of information in the digital tools were the main challenges: organizing the data took a lot of extra time as the tools did not interact with each other. Additional work with digital tools decreased the motivation of managers and workers to regularly update the systems and therefore, big amount of the generated data was nor timely or trustable. Nevertheless, the contribution of digital tools in the management process at the case site did bring enhanced information flow, transparency and better situational awareness. (Mustonen 2019)

The most recently documented residential case using takt production is Keinulaudankuja case managed also by Fira Oy in Helsinki, Finland. The six-story building consisted of 79 studio apartments. In comparison to previously described cases, takt production in Keinulaudankuja was planned from the very beginning, meaning all stakeholders were aware and agreed to work according to takt schedule and plan. Due to the small size of apartments, one takt area included three apartments and takt time was set to 1 day. The top benefits experienced with takt production at the site were constantly keeping up with the planned schedule and having a real-time snapshot; focusing on construction tasks at a more accurate level; possibility to complete every task earlier than expected; problems come in steadily and are quick to identify and therefore, easy to respond to; simplified tracking of HVAC installations; and finally easier delivery to a client at the end of the project. (Nieminen 2019)

From the very beginning of the project site manager was determined to ensure that every worker is aware at all times of what they need to do and believe that they can complete the given tasks, maintain clear communication and situational picture for everyone, regularly update the schedule and fully commit to it. Implemented takt production together with improved communication allowed to achieve delivery to the client two months earlier than planned with zero mistakes at the final check and increased profit margin by around 30%. The key learnings for the project team were: to partner up with subcontractors and involve them is schedule planning; make realistic schedule that is not

too detailed and has room for some process noise; focus on a few goals at the same time; concrete drying time, weather conditions and logistics must always be considered when planning the schedule; and finally, keeping up with quality controls and achieving the quality goals too. (Nieminen 2019)

After examining these projects, it can be stated that takt production is suitable for the interior phase of the residential construction due to high repetitious level of the processes. Takt production has also proved itself to improve project's transparency and the potential of digital tools assures that there is still room for efficiency improvement even in the takt production context. There are several factors that have to be realized for takt production to be executed and be beneficial. The next section describes requirements for takt production and challenges that have to be tackled.

2.2.3 Requirements and challenges of Takt production

Several researches and practical projects confirmed that the takt planning has to start at early stages of a construction project (Vatne & Drevland 2016). A soft start and a determined planning phase will let all project actors gain a better overview of project goals and also understand the benefits of takt production before the construction process starts (Lehtovaara et al. 2019). Nevertheless, as Binninger et al. (2018) anticipates that despite the advantages of determined planning period, the planning time is always limited and should therefore be optimized.

The ability of subcontractor to commit to takt plan should be taken into account already during the procurement phase (Binninger et al. 2018). In order to avoid rejection of subcontractors towards takt, the contracts have to oblige them to follow the takt schedule and zone order. Nevertheless, the contracts should address the revenue interests of main contractor, subcontractor and its workers and at the same time not create any major barriers for working according to takt production plan (Lehtovaara et al. 2019).

In addition to early takt planning in general, comprehensive plans have to be done together with subcontractors to make construction process as organized as possible. This will allow to identify all work activities that have to be done and find the optimal order of work wagons and takt time to structure the project. Most of the interior construction work cannot be done without the previous trade finishing their tasks so, the cooperative schedule planning will let subcontractors understand work and challenges of their fellow trades, highlight potential problems and in that way smoothen the transition between takt areas. (Vatne & Drevland 2016)

Bolviken (2015) claims TPTC can be simplified by identifying clear takt zones with repetitive work tasks. Repetitiveness of task and zones allows to plan work only for one zone and copy that plan to every other zone in the project (Kenley & Seppänen 2009). In addition, low complexity and logical sequencing provide smooth trade transition between zones and minimize the setbacks (Vatne & Drevland 2016). Lehtovaara et al. (2019)

suggest that more detailed planning of wagons and tighter collaboration between all the project participants should be considered when working by takt in residential project.

Based on the research of Frandson et al. (2013) the biggest challenge of takt production is communication of the production plan and methods to the trades and workers. Training and regular takt meetings are efficient methods in establishing the foundation for takt production (Vatne & Drevland 2016). Keinulaudankuja case reviewed in previous section, achieved especially good results by having daily morning meetings with site workers and weekly management meetings, subcontractor meetings and takt control meetings (Nieminen 2019).

Since the takt work plan is quite detailed, also craftsmen will have clarity as they know what todays work is going to be and have no confusion about what to do next (Vatne & Drevland 2016). In general, being engaged in the takt-production makes workers feel valuable because they understand overall production strategy and the importance of their work so, they are set to achieve daily goals (Frandson et al. 2014).

The execution of takt production will succeed when all of the team members understand the importance of pre-production planning and potential improvements that can be achieved with TPTC (Frandson et al. 2014). For efficient management and smooth trade onboarding, high-quality training on takt production is required for all project actors including site management, subcontractors, their supervisors and workers (Frandson et al. 2013). In addition, thorough system thinking and effective knowledge management of the entire team play a significant role in successful takt production execution and controlling (Frandson et al. 2014).

One rather big challenge of the TPTC method is lack of flexibility when unpredicted events occur (Heyl & Teizer 2017). For instance re-entrance flow is a major hazard to takt execution: a trade is compelled to return to the same workspace to complete different work stage or to correct defects, and this brings additional unplanned work for the trade and main contractor (Sacks 2016) and discontinues takt flow.

As it was confirmed by many construction projects, takt production requires frequent updates for smooth running (Heyl & Teizer 2017). These updates can take a lot of working time to perform and cause massive time costs. However, when updated are made responsibly on a regular basis, ultimate quality, clarity, control and bigger time savings can be achieved (Nieminen 2019). Visualizing the takt schedule is very important so, in order to do it efficiently certain software should be used that will allow to track a work flow progress line. (Vatne & Drevland 2016). Therefore, there is a high demand for correct and timely data and constant reliable information flow for visualizing, controlling and updating takt plan (Heyl & Teizer 2017).

Finally, takt-time planning requires efficient production control system that would allow to maximize plan reliability, easily make updates to the schedule and record improvements and learning points (Ballard 2008). Modern technology and digital tools, when properly implemented, can provide possibilities for more accurate planning and

tracking of work, continuous improvement through data-driven analysis and inter-project learning (Lehtovaara et al. 2019).

2.3 Digitalization in construction sector

Before introducing the topic, it is important to distinguish two close-sounding terms: digitization and digitalization. Digitization is the conversion of analog source information such as image, sound or text, into an electronic format in a way, that this information can be processed, stored and transferred through digital equipment or networks (BusinessDictionary 2019). Digitalization in its turn "is the use of digital technologies to change a business model and provide new revenue and value-producing opportunities" (Gartner Glossary 2019).

The modern business world is digitizing rapidly but unevenly, and while advanced digital users capture great benefits and reshape entire industries, some other companies struggle to adapt. The digitalization is not just about purchasing and using software and equipment but it is about integrating and essentializing digital tools into expanding variety of business processes. (McKinsey Global Institute 2015)

The MGI Industry Digitization Index is the first major indicator that evaluates economic sectors by the degree of their digitization, digital assets and usage. ICT, media, professional and financial services business areas currently set the standards for the highest levels of digitization. Construction as an industry which is highly labor-focused and localized is ranked at the bottom of the MGI Index list (see Figure 8). (McKinsey Global Institute 2015) The construction industry is usually described as stubborn and slow to adopt technological innovations (Congrid & University of Turku 2019).

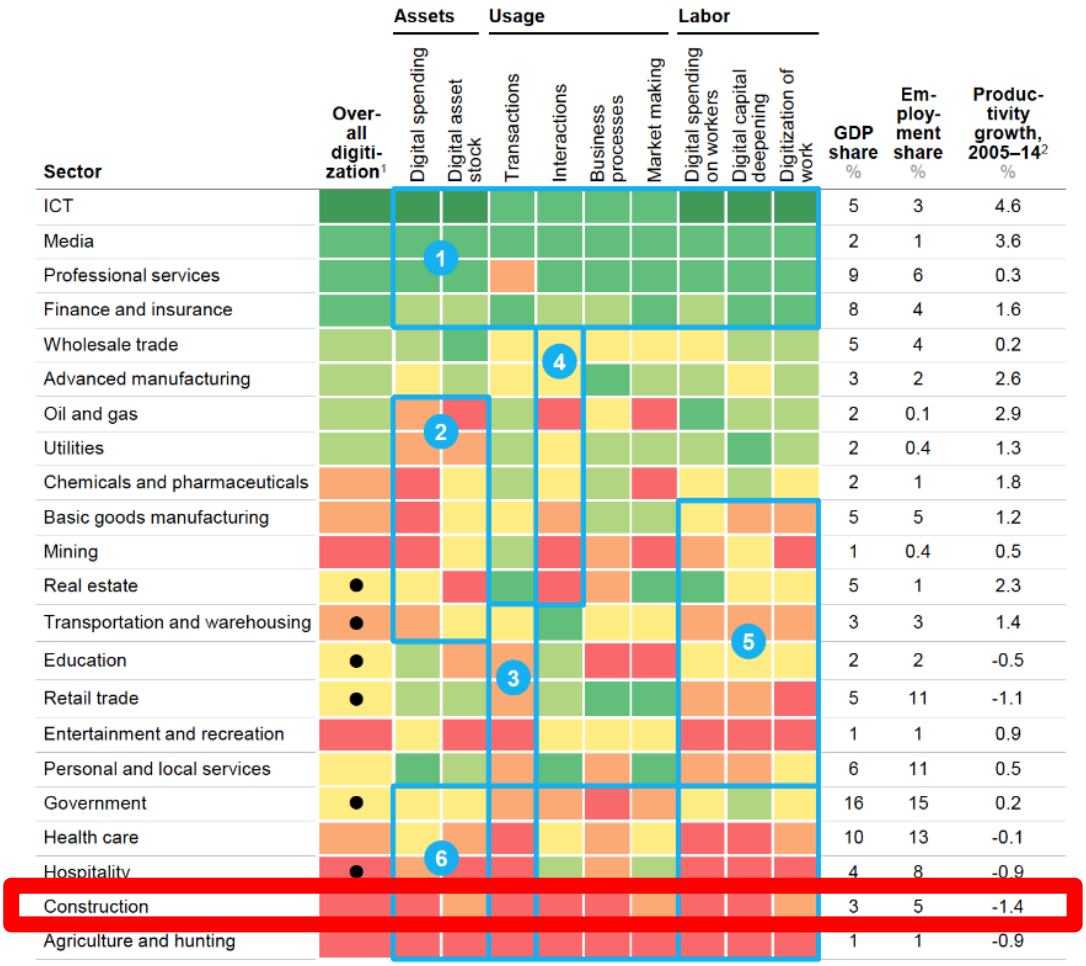


Figure 8. The MGI Industry Digitalization Index (McKinsey Global Institute 2015).

However, the companies should be the ones who lead the technological development of the industry, not the government or other regulatory authorities. Implementation of new digital technologies will improve productivity, reduce project delays, and even enhance the quality of buildings and safety working conditions (World Economic Forum 2016). Effective usage of digitalization can also potentially revolutionize competition among construction companies (Congrid & University of Turku 2019) but at the same time collaboration and knowledge exchange between the sector players will transform the industry much faster (World Economic Forum 2016).

2.3.1 Data in construction

Information management is the key factor for successful production planning and control in construction as it is required to regularly assess work progress, productivity and challenges with the help of trustable and relevant data. There are three data types: planned, actual and forecast data. The data should be collected and constantly adjusted according to feedback sessions (see Figure 9). The frequency of feedback sessions depends on project phase and required assessment methods. (Heyl & Teizer 2017)

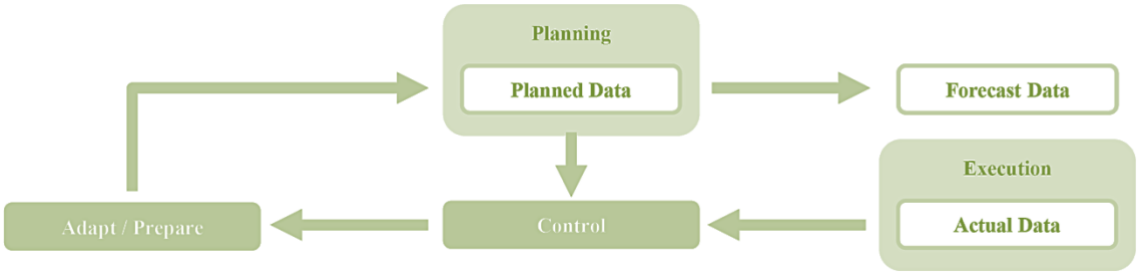


Figure 9. Data control loop (Heyl & Teizer 2017)

The examples of planned data in construction sector are plan and design documents, blueprints, schedule and task assignments. In the beginning of a project planned data focuses on budget, general schedule and milestones, but the closer it gets to execution of a given task, the more accurate and detailed planned data becomes. Actual data is collected during the construction process and it is needed to evaluate ongoing performance, keep track of materials, labor hours, costs and execution times. These data will allow site management to identify possible bottlenecks and challenges and improve the working flow with that knowledge. Finally, the forecast data is the most challenging type as it requires experienced construction managers to execute a complex analysis. (Heyl & Teizer 2017)

Data collected on construction sites is used to track such important factors as quality, safety and productivity and therefore, precise data is crucial. However, currently most of the data on constructions sites is collected manually with the use of spreadsheets or hand-written notes and reports, which is time consuming and likely to have human errors. (Heyl & Teizer 2017) Manual data insertion causes following majors challenges: 1) inadequate level of details attached to work and change orders; 2) incomplete work quality observation data; 3) incomplete information to substantiate claims. (TrackVia 2018) Digital data processing gives possibility to have up-to-date information at all times and eliminate inefficiency related to manual data collection.

Figure 10. Critical data for the success of a construction project (TrackVia 2018)

Based on TrackVia's research, more than two thirds of executives do experience difficulties identifying potential problems before they become challenging. Manual data collection processes obstruct managers from making timely decisions and challenges them to make decisions with outdated or incomplete data. Unwise decisions lead to poor quality control, damaged supplies, materials and equipment and employee downtime. In

addition, manual data collection increases costs related to work quality especially when work has to be redone; employee downtime; damaged supplies, materials and equipment; and finally liquidated damages due to project delays. (TrackVia 2018)

Recent studies have declared that plenty of construction companies do collect data, but only a few have a clear idea how to utilize it (Säynäjoki et al. 2017). The construction industry is indeed in active search for a solution that would allow to collect necessary data efficiently, analyze it and act upon, all through one digital system. At the moment executives and managers who use four or more data systems spend four times more time organizing this data for analysis than managers who use a single system. (TrackVia 2018)

Despite current struggles with data collection and analysis, the majority of managers do realize the importance and potential of on-site data collection. They believe that the most crucial data has an impact on quality of work, cost of production, safety and accurate planning of future projects for the firm. Collected data not only has effect on construction site in question but also on the whole head office and their ability to make critical decisions on current and future projects. (TrackVia 2018)

Most of the executives and managers agree that systems and methods, that they use to collect and analyze data, do not match their need and requirements. Contrariwise, these methods put construction project´s costs, success and safety at risk. Paper notes and reports must be replaced with dynamic mobile apps in order to capture information from any devices at any time or place. The process of data collection should be standardized so, any stakeholder of the project could add or easily access and understand the information. (TrackVia 2018) Good examples of data collection standardization are: barcodes on the materials, geotag locations, attached photos etc.

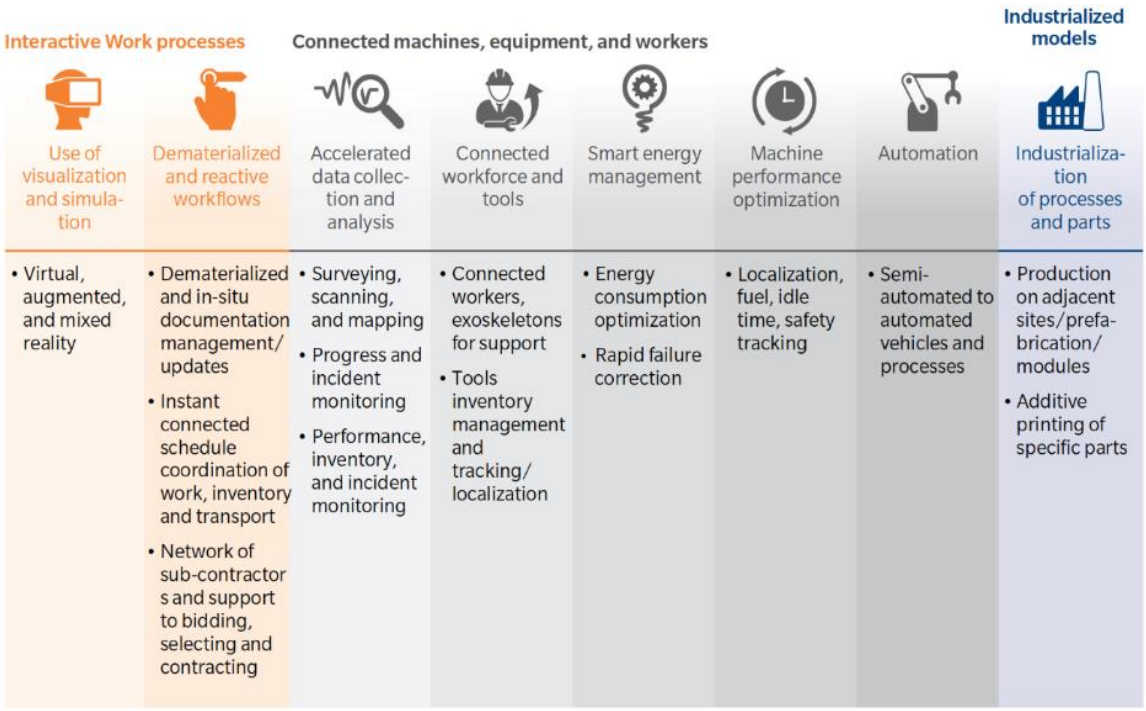
Digitizing and standardizing of data collection process can significantly improve the accuracy and fullness of daily reports, quality checks and safety observations. Half of respondents of TrackVia research (2018) believe that digital data collection can help to prevent many issues coming from manual processes, especially from rework and damaged supplies. Time-to-completion can be accelerated by introducing automatization of tasks and work orders notifications on a construction site. By unifying all available digital tools and methods on site to one digital systems, site managers and executives would be able to make fast and impactful decisions, providing work quality improvement, on-time deliveries and full safety on worksites. (TrackVia 2018)

2.3.2 Digital tools in construction

The use of information and communication technology (ICT) in construction related data analysis has already been proven to improve production flow in lean construction context by identifying non-value adding activities, cycle-times that can be decreased and errors that can be eliminated (Sacks et al. 2010). Rapid access to up-to-date information

supports higher work quality, quantity reporting, on-time project delivery and safe value creation (Heyl & Teizer 2017).

Figure 11. Digital operations efficiency levels (Oliver Wyman 2018)



Many tools have already been invented for data generation and processing in the construction industry, for example Building Information Modelling (BIM) system. BIM is a project management software that facilitates project information, enables collaboration and information sharing among project actors, and frequently serves as a key enabler and facilitator for many other technologies at a site. BIM also contains the physical and functional characteristics of building objects allowing site managers to see all systems in 3D format before the project even has started. (National Institute of Building Sciences 2018; World Economic Forum 2016). Internet of Things (IoT) platform is another valuable invention that in construction industry combines sensors, location tracking, communication devices and cloud storage. All these functions together create an internet-based network for data collection, monitoring and process optimization. (McKinsey & Company, 2013) The research of Heyl & Teizer (2017) confirms that such IoT platform makes the information of directives, prerequisite work and resources conveniently available to the users. In addition, by combining the traceability of workers' location and work hours recording, IoT platform can process and visualize actual performance data. (Heyl & Teizer 2017)

There are numerous opportunities for the digitalization of daily construction operations. Efficiency of construction and management processes has the potential to radically increase through more productive, interactive, transparent and rapid collaboration. In the nearest future digitalization will enhance dematerialization, in-site documentation, realize connected schedules and immediate planning adjustments, provide easy vision of

historical changes, and virtual, augmented and mixed realities (see Figure 11). (Oliver Wyman 2018)

General contractors are most likely to benefit from higher-efficiency engineering and better managed project lead times as well as reduced waste achieved by project management software. Various cloud-based solutions provide the tools to manage all construction project phases from planning to after-completion warranty work, including scheduling, quality and financial tools, and the ability to communicate and collaborate with clients and customers throughout the project (SBS Group 2017).

The key features of construction project management software must include:

1. Real time updates of schedule to easily monitor all the processes going on at the site, quickly access the plans, and track the progress of the project any time;
2. Visualization tools as part of scheduling and planning provide best communication of project goals in visual form to all players;
3. Integrated reporting tools that facilitate regulatory responsibilities of general contractor and allow communication between different actor groups. Automated reporting can rapidly increase productivity within the project and simplify responsibilities of the management;
4. Measuring the safety levels of construction project digitally and recording faults with more precision using extensive specifications;
5. Mobile accessibility of data and reports can save work managers significant amount of time when they have to control the processes on site, check plans and report observations;
6. Secure cloud hosting allows to store all project information in a secure and trustworthy way;
7. File-sharing for smooth collaboration between stakeholders with notification capabilities in case of file modification;
8. Simplified issue tracking with possibility to follow up. (Santos 2019; SiteDrive 2019; Congrid 2019)

Lehtovaaara et al. (2019) believe that there are good opportunities for digital tools to improve the construction productivity. Even though digitalization in the construction is in its infancy at the moment, digital will eventually generate usages and breakthroughs for the whole industry (Oliver Wyman 2018).

2.3.3 Opportunities and challenges of digitalization in construction

The construction industry has not yet embraced new digital technologies but it is ready for disruption (Agarwal et al. 2016). When thinking of construction project management, digital solutions are expected to deliver improvements across the following eight use cases (see Figure 12).

Design management	Scheduling	Materials management	Crew tracking
• Visualize drawings and 3-D models on-site, using mobile platforms • Update blueprints in the field with markups, annotations, and hyperlinks	• Create, assign, and prioritize tasks in real time • Track progress online • Immediately push work plan and schedule to all workers • Issue mobile notifications to all subcontractors	• Identify, track, and locate materials, spools, and equipment across the entire supply chain, stores, and work front	• Provide real-time status updates on total crew deployed across work fronts, number of active working hours, entry into unauthorized areas, and so on
Quality control	**Contract management**	**Performance management**	**Document management**
• Offer remote site inspection using pictures and tags shared through app • Update and track live punch lists across projects to expedite project closure	• Update and track contract-compliance checklists • Maintain standardized communication checklists • Provide updated record of all client and contractor communications	• Monitor progress and performance across teams and work areas • Provide automated dashboards created from field data • Offer staffing updates and past reports generated on handheld devices	• Upload and distribute documents for reviewing, editing, and recording all decisions • Allow universal project search across any phase

Figure 12. Construction project management use cases (Agarwal et al. 2016)

Agarwal (2016) claims that digital transformation can take construction efficiency and productivity to a higher level but there are certain challenges that hamper each of the use cases. In pursuit of getting a competitive advantage by implementing IT tools in construction as fast as possible, companies quite often have no plan on how the digital tools will be improving their operations. Aimed at success process-centered implementation a construction company should identify a process change, the required enablers, e.g. data and technology tools, overall capacity, legal and contractual requirements, and others, and the expected gains. (Koeleman et al. 2019)

The main reasons for the current digitalization failure in construction sector are conservativeness, lack of digital culture, innovation and R&D activities (Congrid & University of Turku 2019). In addition, construction sector has not traditionally been attractive to new talents and current workforce is aging rapidly. In that way construction businesses face a shortage of young talents who are progressive and forward-thinking (World Economic Forum 2016).

Based on TrackVia´s research 58% of managers find it difficult and time-consuming to collect, process, keep track and make data usable for team members. (TrackVia 2018) Indeed companies are able to start using digital tools rather quickly, but it actually takes long time to change behavior and project operation models. The digital tools do save time for worksites and are extremely beneficial when it comes to management efficiency and analytics when everything is documented in real time and as all documentation and information is easily accessible. (Congrid & University of Turku 2019). But in order for digital tools to be beneficial, users have to change their old habits and be systematic in their work with the data (Mustonen 2019). Such conversion of settled workers' mindset will require using their experience to validate model results and companies to look for opportunities for standardization and providing unite instructions (Koeleman et al. 2019).

In addition, in practice there are overlapping systems used at the sites causing additional work, and if there are no visible benefits, frustration and reduced motivation to stick to the systems. (Mustonen 2019) As with takt production so with digitalization, it can be concluded that extensive training is essential for successful implementation in the construction process at all levels. A general contractor and software providers must carry out the necessary training for different user groups including executives, site management, subcontractor supervisors and craftsmen. Different actors are going to use a software or tools in different ways and therefore, it is crucial to educate them separately on how to use the software and most importantly why. (Congrid & University of Turku 2019)

Another big challenge is the flow of information in construction that usually stops at the site's office with site managers and doesn't reach craftsmen that actually perform the planned tasks. Digital has a great opportunity for resource management for field work. By providing a worker with a smart device, he or she can see the real-time overview of what's going on at a construction site and more importantly see, plan and check out own tasks for the day. In that way employees have all the means to work efficiently, increasing site's productivity and decreasing both direct and indirect costs. (Heiskanen 2018)

Clear communication is the key to success of any teamwork including construction projects. The most common communication channels at construction sites are email, phone and radio-phones which are not exactly efficient tools because not everybody involved in the process gets the message and new information. Digital tools and platforms have potential to enable clear communication channels where all relevant stakeholders from planners to subcontractors are in the same information chain (Congrid & University of Turku 2019).

Quality and safety are two crucial process that are usually neglected because of clear priority towards construction activities that bring direct value. Digital tools would allow to efficiently measure safety levels and see potential difficulties during or even before the process and to react in time. Integrated reporting on quality and safety will also save much time for site management and help to fully and correctly fulfill the regulatory responsibilities. (Congrid 2019) In order to eliminate safety problems and physical injuries of craftsmen, even safety training should be provided on a governmental level. The solution to this problem would be a mandatory standardized software for safety recordings, training materials and information on every worker. (Congrid & University of Turku 2019)

The biggest opportunity and challenge that digitalization has to conquer is sufficient knowledge transfer from project to project. Basically construction activities are repeated in their essentials from project to project no mature what is the scale or function of a building. Therefore, lessons learned from one construction project could applied in other projects if a company manages to standardize the level of digitalization across its various business units – construction sites and shares data between projects and head office. Yet in the experience of construction industry all useful generated data and learning points

are often lost, and new building projects are forced to rely on the expertise of individuals and plan projects from a very beginning. (Koeleman et al. 2019)

Most of construction companies have pondered the idea of implementing digital technologies but still construction industry ranks among some of the least digitized businesses. However, companies can overcome the emerged challenges and a digital transformation will yield tangible benefits. The new ways of working will create capacity for site management to focus on more intellectually challenging problems and management itself, when many of activities and processes will be atomized and digitized. (Koeleman et al. 2019)

2.4 Theoretical framework

This section presents the key concepts of the thesis, summarizes the literature research and introduces the theoretical framework for the project.

Coming back to the aim of the thesis, this research aims to develop guidelines for efficient digital data collection and propose improvement ideas for applying the generated digital data in construction management. Therefore, the key concepts of this study are construction productivity and digitalization.

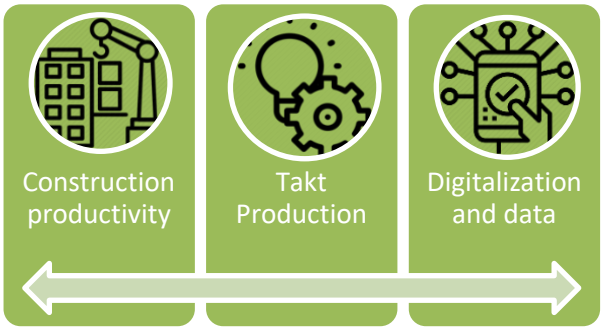
Based on the portfolio, process and operation model by Sacks (2016), in order to achieve good productivity in construction, there should be good project flow, location flow and trade flow at the same time. In addition, collaboration or partnership between general contractor and subcontractors is crucial for proper commitment of both sides and elimination of conflict of interests (Mustonen 2019; Lehtovaara et al. 2019). Takt production is one of the frameworks that aims to provide quality location work flow and utilize the project capacity to its fullest. Takt Planning and Takt Control implies a division of the workflow into packages of tasks – chunks, and the working area into zones. Takt-time is a pace planned for every construction activity within which it should be completed in a given zone. (Frandson et al. 2014) Since mid 2000s when the takt production framework has been developed, it was implemented in many construction projects (Haghsheno et al. 2016), however, only few studies have documented the implementation in residential construction (Lehtovaara et al. 2019). Therefore, this study will capture takt production employment in a residential building project and provide the basis for further development and process improvement in residential construction.

As it was confirmed by several construction projects, takt production requires frequent updates to make the project run as smooth as possible and provide sufficient risk and change management (Heyl & Teizer 2017). Therefore, takt production is in need of efficient control system that would allow to maximize plan reliability, easily make updates to the schedule and record improvements and learning points (Ballard 2008). Visualizing the takt schedule is also very important so, in order to do it efficiently certain software should be used that will allow to track a work flow progress line. (Vatne & Drevland 2016). This is where modern technology and digitalization need to come in to provide

construction and takt production with the needed solution: when properly implemented, digitalization can provide possibilities for more accurate planning and tracking of work, continuous improvement through data-driven analysis and inter-project learning (Lehtovaara et al. 2019).

If we look at the definition of digitalization, it is “a use of digital technologies to change a business model and provide new revenue and value-producing opportunities” (Gartner Glossary 2019). According to World Economic Forum (2016) implementation of new digital technologies in construction can improve productivity, reduce project delays, and enhance the quality of buildings and safety working conditions. Takt production assisted by digitalization has been bringing value to manufacturing for quite some time. However, digitalization in takt production in construction is still in its infancy (Oliver Wyman 2018).

There has been a high demand for correct and up-to-date information coming from construction processes in order to constantly adjust the production plan. Information management is the key factor for successful takt production planning and control and that is why data collection and processing should be digitalized to eliminate possible inconsistencies and errors. (Heyl & Teizer 2017). Collected data has an effect on quality of work, cost of production, safety and also on the whole executive office and their ability to make critical decisions on current and future projects. Digitizing and standardizing of data collection process can significantly improve the accuracy and fullness of daily reports, quality checks and safety observations. Time-to-completion can be accelerated by introducing automatization of tasks and work orders notifications on a construction site. By unifying all available digital tools and methods on site to one digital systems, site managers and executives would be able to make fast and impactful decisions, providing work quality improvement, on-time deliveries and full safety on worksites. (TrackVia



2018)

Figure 13. Theoretical framework of the research.

The above stated proves that there is a research gap as digitalization is not commonly applied in construction projects even for testing, and if applied, there is no record of it providing any significant improvements even the theory states possibilities for opposite. This particular study will test a theory of improving the efficiency of construction process through digitalization and data analysis. The research will be built around the framework of takt production because it connects the concepts of construction productivity and digitalization. As we have seen from the theory, takt production is a lean concept and lean principles have proven to provide 5-8% performance growth along the lean lifecycle

(Schreiber et al. 2018). Thus, lean characteristics of takt production are responsible for improving construction productivity. The use of ICT has been proven to be beneficial to takt production in particular, when it improves the flow of construction processes by identifying nonvalue adding activities that can be eliminated (Heyl & Teizer 2017). Digital technologies have the potential to make a further step in performance (see Figure 14). In a takt production project digitalization and modern tools can make takt planning and schedule tracking more accurate and provide continuous improvement through data-driven analysis and interproject learning.

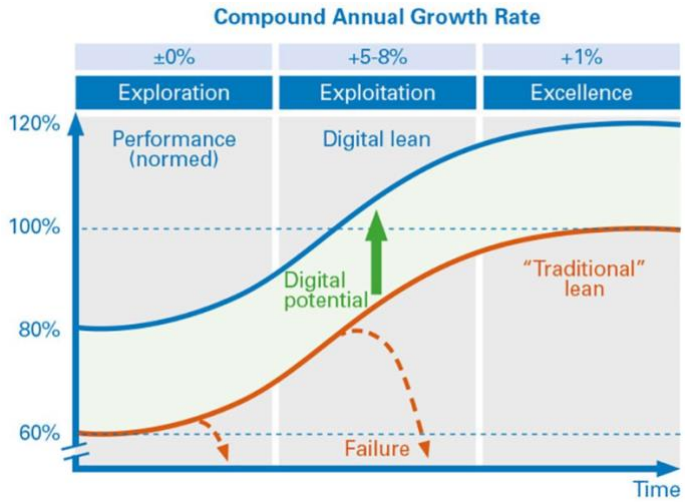


Figure 14. Performance growth rates along the lean lifecycle. (Schreiber et al. 2018)

So far the tendency has been that executives in construction companies managed digital development upon their vision and needs, and that is why rather often digital tools do not meet the needs of site management and do not bring desired value to and from the sites. The empirical research of this study is going to be executed as a case study because the developed improvement ideas have to be feasible and bring direct benefit to construction sites. Information-based site management is in need of proper support of modern systems and applications. Therefore semi-structured interviews were chosen as main research method to reveal who actually needs the digitally generated data, what data and for what purposes. Observations inside of the case study will assist in analysis of takt production implementation in residential construction and its requirements of support by data for best possible execution.

The next chapter represents in detail research design and empirical methods for this study.

3 Research design

Research design is a logical plan for getting from initial set of research questions to a set of conclusions or answers (Yin 2003). The research aim for this project is to develop digital data collection standards and to propose improvement ideas for applying the generated digital data in construction management. The following research design will guide the researcher through the process of collecting, analyzing and interpreting data and observations for the case project. Study questions and propositions were presented in the introduction chapter with the concepts of research objective, questions and scope. This chapter introduces research design plan and methods that are going to be used in the empirical study of this thesis. Section 3.1 introduces main research method which is a case study. Subsections 3.2-3.4 provide a description of data collection tools used for case study and analysis process.

3.1 Case study

The study target for this research is digital platforms and data management in construction production context. The developed standards have to be feasible and applied at a construction site and therefore, this research has to be executed as a case study. Case study is a method of qualitative research, in which the researcher examines a case and collects detailed information using different data collection tools over a continuous period of time. A case study could be a process, a program, an event, an activity, or individuals and it is restricted by time and activity. (Creswell & Creswell 2018)

The case study method allows to involve multiple variables into the research, for instance interests of different stakeholders or various sources of evidence. A case study is typically guided by prior theory and literature review which supports data acquisition and analysis. (Yin 2009) Neale et al. (2006) indicate six stages for the case study research:

1) Planning stage: define research objective and questions, identify stakeholders, required information and theory to be reviewed;
2) Designing stage: select the case for the study, plan the research design, and develop data collection protocol;
3) Preparation stage: develop study protocol, choose and adapt data collection tools and methods;
4) Data collection stage: follow the study protocol, gather all relevant documents and data, conduct interviews and observations, create database;
5) Analyzing stage: review all relevant observed data, documents and interview data. Analyze the examined data in theoretical context and test it in order to conclude empirical research;
6) Conclusion: disseminate findings and results, write and develop a report based on the feedback of core audience.

Case study of this thesis makes it a practical qualitative case study aiming to explore a process. Based on Yin (2003), a case study can be either a single study or include

multiple studies. This case study is considered to be a multiple case study, because it is required by the research aim to study and analyze multiple situations in one case and understand their similarities and differences in order to provide thorough answers to the research questions. (Jack 2008; Stake 1995)

Typically qualitative methods are emerging, such as open-ended questions interview data, observation data, document and audiovisual data, text and image analysis (Creswell 2003). This case study uses observations, interviews and digital data review as qualitative tools for data gathering. Each of the utilized research tools is introduced below (see Table 2).

Data Collection type	Types	Advantages
Observations	Researcher acts as: - Complete participant - Observer as participant - Participant as observer - Complete observer	Firsthand experience with participants Information is recorded upon its occurrence Unusual aspects can be noticed Useful in exploring topics uncomfortable for participants
Semi-structured Interviews	- Face-to face - Telephone - Focus group - E-mail interview	Important when participants cannot be directly observed Participants can provide a lot of different information Participants can directly share their reality Control over the line of questioning
Digital materials	- Public data - Photographs - Public documents - Computer messages - Software	Unobtrusive data collection Can be accessed at any convenient for researcher time Represents data to which participants have given attention Saved time and expense of transcribing Precise quantitative data

Table 2. Qualitative data collection types used in the research. (Adopted from Creswell & Creswell 2018)

3.2 Description of contexts and observations

In order to give the reader full picture of the case study, current situation at the case site should be described. Certain contexts may be important, however attention needs to be paid to the context of case study within the defined scope of the research. The allocation of attention to different contexts in this case study starts from general information about the construction company and narrows down to the performance of a single stakeholder and each digital tool used at the given site.

Observations, as a case study launching tool, allows the researcher and the reader to increase understanding of the case (Stake 1995). Qualitative observation obliges researcher to collect field notes on current situation, behavior of individuals and activities

at the research site. These notes are collected in unstructured or semi-structured way and they contain data on the issues within the research scope. Observations are open-ended and include general discussions with participants to get the informal overview of the research site. (Creswell & Creswell 2018) During the observation, the researcher may not interfere with the processes nor interpret relationships. All findings and events have to be thoroughly recorded during the observation to provide consistent base for further analysis and reporting. On the one hand, the researcher has to be unassuming and abstain from looking for opportunities and improvement ideas. On the other hand, researcher has to be able to test every observation and raise possibilities for alternative outcomes. The qualitative approach for case study usually implies finding good moments for observation to reveal distinctive qualities of the case. (Stake 1995)

The observations for this case study first of all include basic outlook of the construction and management processes at the site including management behavior and their ways to organize the work flow, daily activities and meetings, execution of takt production, trade activities and day by day progress. Secondly, it is crucial for the case study to overview all currently used digital tools and platforms, examine data that is being collected and its utility. Finally, the researcher is going to take a closer look at the working process of furniture installation subcontractor in order to get certain examples of takt production following and to see the most problematic points.

3.3 Semi-structured interviews

Stake (1995) claims that "much of what we cannot observe for ourselves has been or is being observed by others". Obviously, the case is always seen differently by different stakeholders and therefore, interviews is the key tool to multiple perspectives. It is rather easy to get acquiescence to interviews in specific case study research. However, getting good and comprehensive interview requires some work. The interviewer needs to have established plan before executing any of the interviews. (Stake 1995)

Interview is often considered to be a face-to-face conversation between researcher and the participants of case research - interviewees (Hammond & Wellington 2013). Semi-structured interview contains structured and unstructured parts with fixed and open-type questions. Semi-structured interviews allow to cover personal details and attitudes uniformly and reveal qualitative issues in a flexible way. (Walliman 2018) This type of interviews is a very flexible and interactive research approach which still does require established agenda, the outline of planned topics, and questions to be asked arranged in a tentative order. Depending on an interviewee's role in the case site the approach and part of questions will have to be adjusted accordingly. (Newcomer et al. 2015)

The purpose of the semi-structured interviews in this research study was to get insights on planning, communication and the process flow at the site and their interlacement with digitalization. The interview participants were chosen based on their project involvement, expertise on the subject and potential to impact the subject and generate ideas. Interviewee group was comprised of site managers, projects personnel including engineer and production manager, and residential construction executive. The themes included

technical details of planning, control, management, training and visualization as well as social aspects, such as communication flow, trade's involvement in the planning process, training and overall satisfaction with work flow. Additional aim of qualitative research is to increase awareness among participants on the researched topic during the semi-structured interviews, which may require several meetings with the interviewees.

The semi-structured interviews explored the experience and attitude of different project actors towards their daily activities, takt production and applying of digital data and tools. The interviewees were site manager, site engineer, interior work manager, production manager and executive residential construction manager. These people are key informants at the case and because of their positions, activities and responsibilities they have a good understanding of the problems being explored. Even though semi-structured interviews imply flexibility, a set of questions have to be prepared. The objectives of interviews were defined according to theoretical framework of the study: answers to the interview questions had to reveal goals of the case project and current outcomes in sense of productivity; fully open up the process of planning and implementing takt production at the site; and collect experiences and attitude towards digitals tools currently used at the site. In addition, the questions for semi-structured interviews are intended to find out what data the interviewees need for productive work, what data is lacking in their opinion and other demands regarding takt and digitalization implementation.

The executed semi-structured interviews were audio recorded and the results documented in writing. The tentative set of questions used for the semi-structured interviews can be found in Appendix 1 of this document.

3.4 Digital materials review and data analysis

As was mentioned above digitalization is the key research target during this thesis research and therefore, in order to answer the research question a lot of important data will be collected from digital monitoring tools used at the case site (digital tools are introduced in the case description chapter). Precise digital qualitative collection is essential for proper further analysis of production and work flow (O'Connor & Gibson 2003).

To test productivity at the site, location tracking pilot was arranged at the case site. Jianyu et al. (2017) develop a prototype of an intelligent system that has been implemented in the case building for piloting the real time location tracking. The system aims to enhance productivity and waste reduction, provide location based information, control material logistics and strengthen safety management. Location-tracking pilot will provide valuable data for the research and help to get deeper insight of subcontractors' productivity.

Once all the necessary data is collected, including digital data and data from the interviews, it has to be organized and analyzed. Organizing includes transcribing interviews, typing up observation notes, sorting digital data into different types (Creswell & Creswell 2018). The data should be organized in a way that is easy to access and look at, and the researcher will be able to go through each topic to distinguish concepts and build themes. (O'Connor & Gibson 2003)

Figure 15. Data analysis process in Qualitative Research.

As themes and patterns emerge from the data, it is important to validate the accuracy of outcomes and that they yield data reflecting the reality. Ensuring reliability, in other words consistency of the research findings, requires diligent consistency throughout the research process and analyzing phase. (O'Connor & Gibson 2003) One of the most optimal approaches to represent the findings of qualitative research and analysis is a narrative passage. Chapter 5 of this document presents research outcomes and proposed improvement suggestions as a detailed discussion of several themes with complementary visuals for easier understanding and assimilation by the reader. (Creswell & Creswell 2018)

4 Case study

This chapter introduces the case site, takt planning and implementation process and the digital tools used in the case project. Takt planning and the control process is described based on the semi-structured interviews and observations. In order to identify the challenges of takt production, the furnishing installation process is examined in detail as it tends to cause major delays in handovers. Thorough analysis of this process will help to determine the problems causing disruptions and more importantly the reasons behind these.

In order to establish an efficiency development plan based on a construction digital footprint, all digital tools and software currently used at the case site were determined and are described in Section 4.3. Section 4.4 examines site management in terms of daily communication, problem solving practices, usage of digital tools in planning, controlling, managing and reacting to problems. This chapter represents and summarizes the empirical research of this study. Empirical research methods included 5 semi-structured interviews with different project actors, observation of the case site activities, and real-time location tracking of certain subcontractors.

4.1 Introduction of the case

Fira Oy is a construction company founded in 2002 in Helsinki, Finland. Since then Fira has grown into a big business group with over 400 employees and an annual turnover exceeding €200M. Fira's mission is "to increase construction productivity by digitalizing the modular construction process and providing full access to required information to every project member." (Fira 2019) Nevertheless, Fira as any healthy business aims to progressively increase its revenue. In order to do that in construction business, projects have to be executed on time and with minimum errors. In every construction project Fira acts as a general contractors and subcontracts trades for each required activity. In recent years Fira has applied lean thinking principles and it allowed to identify typical waste points, reduce waste and shift from result-oriented management to process management (Korb et al. 2017).

The studied case is a fourteen-story residential building project (further V14 or case building) located in Jätkäsaari district in Helsinki, Finland. This building is part of a three-house residential project (see Figure 16) that was ordered by Sato Oyj and then designed by architects and construction engineers.

The building process is managed by the general contractor Fira Oy, which is responsible for construction production in a case building V14. The building consists of 93 apartments, sauna, laundry and other common and maintenance areas. The size of apartments vary from 25 m^2 studios to 95 m^2 3-bedroom-apartments. All the residential floors have somewhat same layout which makes it suitable for repetitive planning and therefore, takt planning. The production phase was originally scheduled for around 2 years.

Figure 16. Visual representation of V14 and other buildings in the project (Huttunen-Lipasti Architects 2018)

Site management organization remained the same for the whole project and consisted of one site manager, two site engineers, one frame construction supervisor, two interior construction supervisors and two outdoor work supervisors. In addition, logistics and induction of new workers was managed by a outsourced specialist.

4.2 Takt production at the case

Takt production is not yet a standard practice for the construction company's sites, however due to Fira's aspiration towards lean construction, takt production may become integral for every new project in the nearest future. In fact, several flagship projects at the construction company showed positive results even by partial implementation of takt production. Regarding the case building, the takt production wasn't originally in the plans. According to Hatakka (2019), as a site manager he decided to try out takt production in the interior phases in V14 even the project with two other buildings was already ongoing. The reason for takt implementation in V14 building was its height, big floor size and hence, more complicated management of the work flow than usually. By implementing takt principles in the V14 building the site manager hoped to achieve clarity, better flow and smooth turn-around-time in a rather big building.

Fira provided the case site with support to plan and organize takt production in V14 by assigning a production engineer to help to draw up a new schedule and strategy. Takt area was defined by combination area size and workload so, all areas fit the same takt time. Therefore, there were 4 takt areas in V14 (see Figure 17): takt area 1 included one flat size 95 m2; takt area 2 included 2 flats size 26 m2 and 68,5 m2 comprising 94,5 m2; takt area 3 included 2 flats size 25 m2 and 64,5 m2 comprising 89,5 m2; and finally takt area 4 included 2 flats size 25 m2 and 38,5 m2 comprising 63,5 m2. The takt time was set

as 2 days which was justified to be reasonable for the repetitive tasks and suitable for the schedule goals.

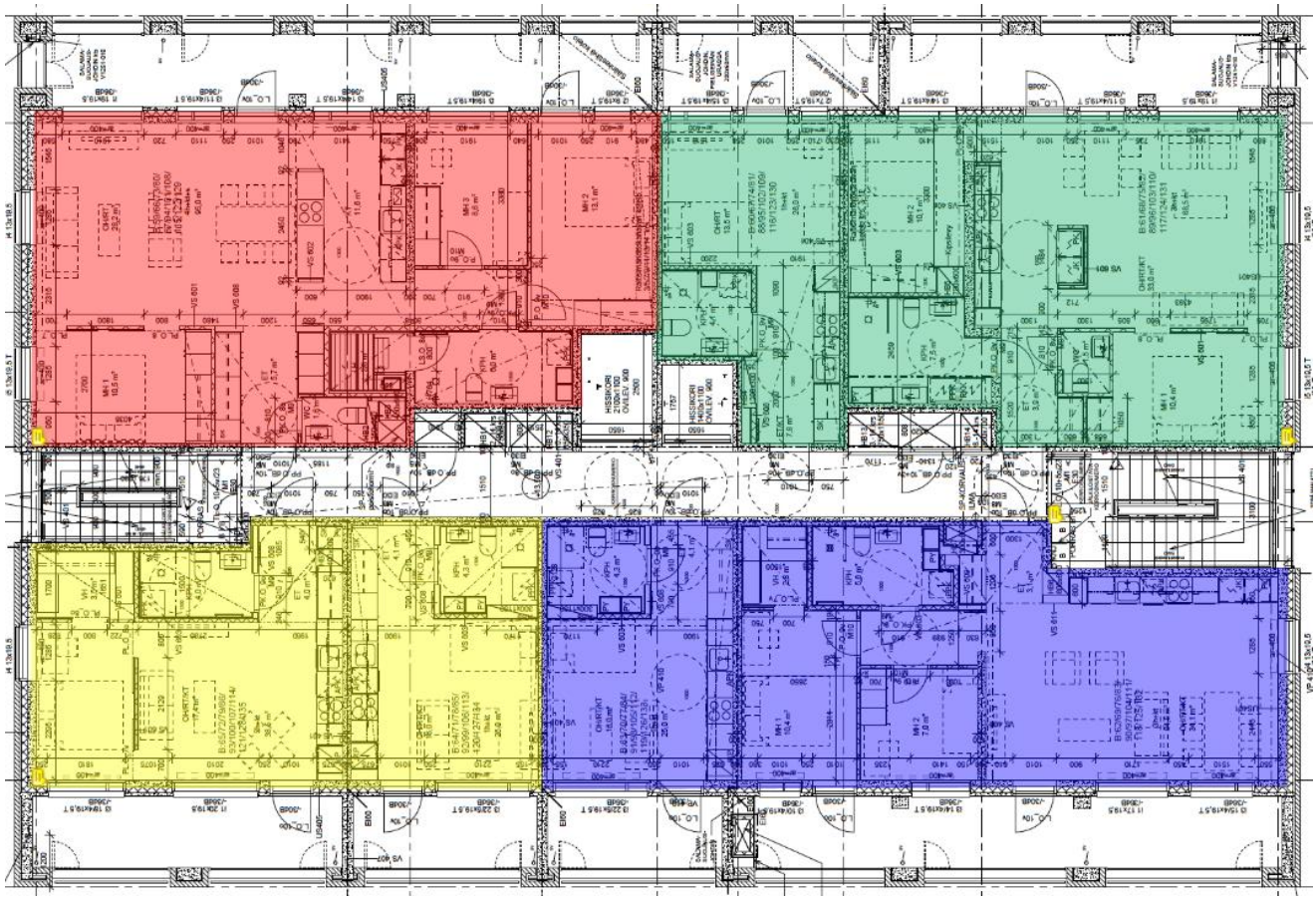


Figure 17. Floor plan of the case building and takt area allocation.

From the very beginning it was a great challenge to make takt production work. Tasks were not started nor completed on the schedule and the subcontractors didn't follow the takt area order. Generally speaking, takt production was realized to a smaller extent than expected. Several causes for not fully realizing takt production in V14 became obvious already after the observations:

1. *Late implementation.* Based on the reviewed theory, takt planning has to start at early stages of a project even before the construction itself starts at the plot (Vatne & Drevland 2016). Members of the case project out of sudden had to follow new ways of working without clear understanding what takt production is about. Therefore, certain level of rejection appeared towards takt among the team members and work managers were not motivated to execute their work by new rules. Subcontractors and their craftsmen had no idea of takt production meaning and were not willing to change their working habits either.
2. *Lack of training and understanding.* None of the team members had previous experiences in takt production and had rather skeptical attitude towards it. Site manager and V14 interior work manager were invited to the training organized by company management already during actual implementation of takt which was

definitely too late. However, even after the training the managers did not know how to plan takt schedule, how to act in practice and react to unpredicted situations even they would understand all the theory and potential benefits of takt production. Therefore the commitment of managers was extremely poor as they have realized that the fact of having takt schedule doesn't solve the problems by itself. Furthermore, as was mentioned earlier, takt schedule requires frequent updating but management would never spend their work time doing it because they were not seeing any benefits from it.

3. *Scheduling tools*. The case site used two schedules: general schedule drawn up in Tocoman and a weekly schedule in SiteDrive, which was updated weekly. Lack of appropriate view in SiteDrive scheduling software and again lack of training on how to use it caused irregular use and therefore, inadequate data for takt production management. More information on scheduling tools experience is presented in the Section 4.3.
4. *Logistics*. Bigger items such as doors, windows and gypsum boards had to be stored inside of the building for some time causing either interruption of takt area order or delay in work due to moving the items around. Just-in-time deliveries were implemented quite well however, there were still phases when for instance doors had to be removed and stored in the apartments blocking other processes.
5. *Contracts and resources.* Obligation to follow Takt schedule was not included in subcontractors' contracts and the decision to implement takt production in V14 was made after all the trades were employed for the project. Also the trades had already completed two other buildings in the project without takt, so they were not interested in changing their ways of working. In addition, in order to balance all work wagons to one takt time, certain flexibility in human resources is required from subcontractors by adding or reducing the amount of workers according to situation. Currently it is not possible because every trade firm need to take care of stable employment for their workers.

Another factor that complicated the construction process is that trade teams did not have their supervisors present at the site, even though the contract states, that every subcontractor should have supervision at the site and communication happens between general contractor and supervisor. However in practice, the absence of supervisors forced contractor managers to guide workers of subcontractors spending significant amount of resources for that.

These circumstances do not prevent the thesis to follow research design and examine digital applications at a case study because some of the above stated reasons have nothing to do with the digitalization and the rest that do, directly lead to additional improvement ideas. So in a sense, the research can gain more impact but analyzing not just digitalization in successful takt production but also how digitalization can enhance takt implementation.

Nevertheless, even the takt production was not realized to its fullest and didn't seem to reduce construction time, the case building is on track to be delivered one month earlier than planned. However, site managers believe that it could be possible to deliver even

two months earlier. Despite the unrealized takt production at the case site, interviewees believe that takt planning can be beneficial and potential for residential construction to clarify and simplify the processes. Currently it is challenging to adjust for instance kitchen and molding installations to the same takt time due to subcontractors' inability to add additional workers when required. This is caused by the current state of Finnish construction labor market when firms are involved in various projects at the same time and have to provide their workers with continuous work and salary.

4.2.1 Furnishing installation case

As was mentioned before, typically for the construction industry (Korb et al. 2017), subcontractors carrying out the work for the case project, were also working on other projects for other firms. These circumstances brought discontinuity of many processes and miscommunication to the case project too. One of the brightest example for this experience would be furnishing installation, which included installation of kitchens and closets. This subcontractor previously has executed several projects with the construction firm however, they caused major delays in every each of them. In addition to frequent discontinuity this process comes with plenty of mistakes and typically causes delays of the final delivery to the client by up to 6 weeks based on previous projects executed for Fira Oy. The initial reason for such delays is numerous damages, like chips and scratches on the furniture parts that have to be replaced.

It has to be noticed that production is handled by the employed subcontractor but delivery and installation are performed by two other companies employed by subcontractor which significantly increases the chances of miscommunication and therefore mistakes. After visiting the factory of furnishing producer in Lahti, Finland it can be stated that the quality control and packaging of the parts are on a high-level however, the practice shows that that order accuracy is not always on point: constantly missing parts and several piece of furnishing produced by the wrong measurements.

The next failure point is the delivery of the furniture (see Figure 18). Inaccurate transportation and careless handling caused most of the damages and therefore, already at this point many of the parts had to be reproduced and reinstalled. Installers work with the materials that they get and they install all parts that arrive even they are already damaged. The observation check after initial installation round has revealed 1,5 flaws in average in each apartment with maximum reaching 32 flaws in one apartment.

Figure 18. Mishandling of furnishing parts by the transportation company.

The struggle with the installing company was the workers who didn't come to work when it was agreed and didn't notify manager about any changes. When the manager tried to reach out to supervisor, nobody answered her calls or email and she received no explanation later on. Obviously, such behavior of installation firm caused delays in the schedule making electrical, HVAC and wooden floor installers wait for the work space. Even though their work flow has stabilized with the time, the employed furnishing producer could not get a single apartment fully flawlessly ready on the first try and that contradicts the principles of takt production fundamentally.

In addition, another big disruptor of takt production observed from the work of installers is the re-entrance flow. Re-entrance flow occurs when workers have to return to a workstation, in our case apartments, in which they have already been earlier. After a few floor of apartments have been completed, the supervisor record the flaws and sends the information on missing and damaged parts to the producer. After the new parts are produced and delivered the installers are forced to return to either install the missing parts or replace the damaged ones because of production and transportation mistakes.

The next bottleneck appears in reproduction of the damaged parts: it takes really long time for producer to react, produce and deliver new parts which makes the furnishing installation even more lately from the plan and block next trades from entering the space. Despite of all the attempts by general contractor to speed up the process by arranging urgent negotiation meetings and explaining the actual damage that the producer causes, no improvements in delivery have been noticed.

Regarding the furnishing installation case, the site management would like to have precise data on what was ordered, what and when was delivered, publicly recorder problems, damages were in delivered materials and what part were returned reproduction and when. It can be achieved by location tracking of the furnishing parts or batches (more on the topic of location tracking in the section 4.3.4). With this kind if data it will be possible to identify crew responsible for the damages and delays. In addition, the actual time between recording the damaged part to its replacement arrival to the site will be available to present to the furnishing producer when the final financial reallocation will be made at the end of the subcontract.

In addition to the kitchen and closet installation, several other subcontractors have caused major problems in the interior phase of the case building: laminate installation crew, moldings and doors crew, sauna and wooden ceiling installation crew. All of them had trouble providing sufficient amount of workers that would execute their tasks in time. The supervisors were frequently missing from the site and they didn't show up at weekly subcontractor meetings.

4.3 Digital tools

The case site had taken into use many different digital tools from the very beginning. Some of the tools were obligatory and automatically given by the construction company, and some of them were either new tools or used by the client. Every construction project at the construction firm is based on BIM (Buiding Information Management) system. By the order of a client the site management used online storage solution called Kopioniini that contained all project blueprints and plans. All the latest revisions were uploaded to the project bank by architects and planning engineers. The digital tools used on the regular basis by site manager and interior work manager included Congrid for updating quality control and site diary, SiteDrive for takt and weekly scheduling, B2B for invoicing, Sitemanager for various functions, and Kopioniini for accessing latest plans. Site engineer also uses PowerBI for forecasting, planning and tracking finances of the project.

Digital tools and systems used at the case site

Generate data	Do not generate data
Sitemanager	BIM
SiteDrive	Kopioniini project bank
Congrid	RIB iTwo
Location tracking tool	B2B Basware invoicing
Communication tools	
What's app group chats	Email

Table 3. Digital tools and systems used at the case site.

In this chapter digital system and tools that generate data will be introduced one by one and experience of case site management with them will be described. The information on management experience with digital tools was obtained during semi-structured interviews.

4.3.1 SiteManager and Teehavainto.fi

SiteManager is an online platform developed by Takamäki Group for construction sites and factories to manage subcontractors. The service covers the entire process of chain management between general contractor and direct subcontractors and their own subcontractors. Site Manager allows to manage contracts, liability documents and billing. (Takamäki 2019)

One of the most important tools of SiteManager is built-in time control, that allows to track working hours. Every worker has own Valtticard which contains worker's picture and tax number. With the help of Valtticards workers punch in when they come to work and punch out when they leave, so the general manager can see if the worker has arrived to work and how many hours they spend at the site.

SiteManager also provides an online training environment where employee can go through site specific induction and take a course of e-induction. SiteManager allows to access employee's personal information, qualifications and permissions. After the worker has been inducted and his information has been checked, he can proceed to work. SiteManager always notifies main contractor in case worker's information is not up to date and or not in order.

Safety management is also supported by the SiteManager tool. The platform allows to execute safety measurements and creates a report out of the collected data (TR-mittaus). Monitoring of accidents and near-miss-situations, along with working time control, allows to calculate accident rate, and therefore helps to see and react to the appearing problems and improve vital safety at a construction site.

In addition, all urgent safety-related findings can be easily reported at teehavainto.fi which is an another tool developed by Takamäki Group. It is a feedback channel that encourages everyone at the site to make observations about work environment, safety issues, or anything else worthy reporting. An observation form at teehavainto.fi recognizes user's location and suggests nearby sites to be targeted. It also possible to attach an image to the observation. The feedback is transmitted to the general contractor, where the feedback is processed and the necessary actions are taken.

At the case site SiteManager system is used regularly and to its full potential. Data collected by the SiteManager is definitely beneficial however, is not fully utilized for analysis, further planning and control.

4.3.2 Site Drive

SiteDrive is a scheduling software created specifically for construction sites' needs. It allows to match schedule and workforce by sequencing and leveling of activities through identified zones. Site Drive unites the site manager, supervisors and subcontractors in one scheduling platform and creates transparency in communication. SiteDrive can be used on the desktop or through a mobile application. (Fira SiteDrive 2019)

When planning a schedule for a construction project, Sitedrive provides easy and intuitive tools for creation and editing. The schedule can be created fully from scratch or based on the available template when planning repetitive work. Planning starts from entering tasks and subtasks, assigning beginning times and duration, in hours or days, for each task. It is also possible to add the location for each task, performing subcontractor, responsible person and a deadline date. In order to have even better control there also such options as productivity rate, notes, reference to a wagon of a task, current state and percent complete rate that can be added to the tracking dashboard.

Schedule planning is done fully online, so there is no need to store files or send them by email. Once a schedule is created and published, it is going into a tracking mode. All authorized workers see their task lists in their mobile phone through the app and they can mark tasks as ongoing and finished. General contractor users in their turn start to receive information on work progress and finished tasks. By adding subcontractors to a project in SiteDrive as users, it is possible to give them right and responsibility to check out the completed tasks in the system by themselves. In practice a worker uses the app on their phone to confirm that the takt has been started and later completed, and this information is passed on to other workers immediately so, they can start they work as soon as possible. Site manager can see, whether previous handoffs have been made and firm's management and customer can see immediately the progress and finished tasks.

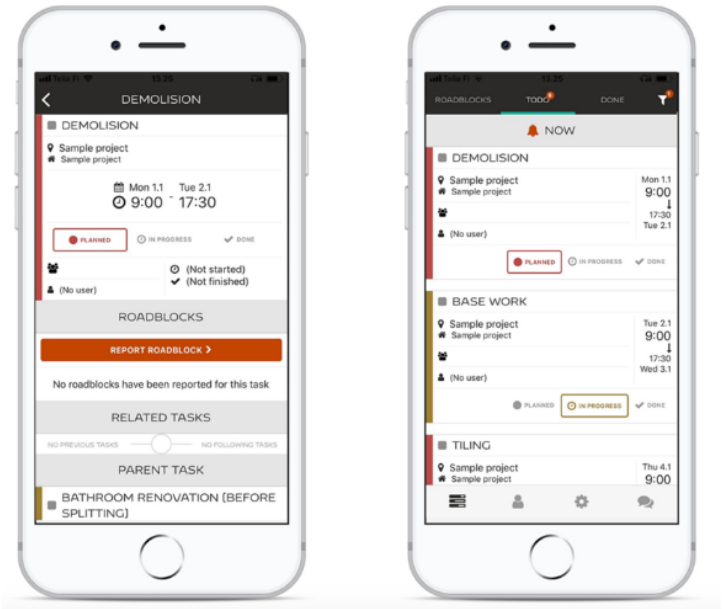


Figure 19. SiteDrive app view for the user (SiteDrive 2019)

In the case project V14 the admin rights were granted to the general contractor's engineers and work managers, and the user rights to supervisors of electrical installation, laminate installation, drywalls installation, Kahva Oy, smoothing and painting, MYT, cleaning, pipes installation and tiling subcontractors. To be noted that user rights were not given to furnishing installation subcontractor. However, as the project proceeded only one subcontractor – drywall installation, used SiteDrive to follow and check out the tasks.

So it comes to a question how to motivate and/or obligate the rest of subcontractors to use the service that can potentially provide the general contractor with valuable data.

Sitedrive offers metrics and statistics to show and predict the success of a project. Sitedrive estimates the quality of the schedule, and tracks the activity level of all users so that site manager can see if colleagues or workers are not working according to schedule in Sitedrive. On-site performance is the metric that shows the value of Sitedrive – are things happening on time or not.

Figure 20. Metrics and statistics dashboard of SiteDrive solution (SiteDrive 2019)

In the case building SiteDrive was used to facilitate takt-time schedule and production. Every interior construction task was divided into subtasks based on the takt areas. So there are 54 takt areas in V14, meaning there are 54 or more subtasks under each tasks. It may appear that schedule is split into too many pieces, and despite of takt schedule clarity, it makes it hard to follow and keep track of all the tasks. Even technically it is easy "to drag" tasks and change their timing, managers do not want to put effort into micro-management of small schedule noises and variances. The second challenge is that SiteDrive schedule is currently seen as additional work at the case site instead of being helpful management instrument. Work managers barely update SiteDrive because it is something mandatory and have no habit of recording every change into the system, but they just keep them in own notebooks or emails. In order to change that, workers' attitude towards digitalization in construction should be changed. It can be done through training, availability of handy simple instructions and constant support.

When the crated in SiteDrive schedule became too big and confusing or some changes were required, it was easier for managers to create a new version from scratch. In this way there were 4 different schedule versions only for V14 building: weekly schedule, wet space schedule, takt schedule, and pre-delivery schedule. Multiple versions of the schedule were noticed to cause confusion and extra work. SiteDrive appeared to be rather hard to read to the site managers and felt like it requires too much time to update the schedules. One of the main points of SiteDrive is the possibility for subcontractors to

follow the schedule and task list and update the status of those tasks. In this way, additional benefits of more efficient trade control was missed.

4.3.3 Congrid

Work managers main responsibility is to be at the construction site supervising the work, however they are also required to handle a lot of documentation and reporting work. The amount of required documentation is increasing due to management's desire to improve, guide and monitor the quality of the construction process and new requirements from the local authorities. Therefore, documentation and inspections are very important for the project's legal and financial success at any construction site. (Congrid 2019)

Congrid is a cloud service software that is used for quality and safety management at construction companies. Congrid provides customized service by scaling the work package for company's needs. (Congrid 2019)

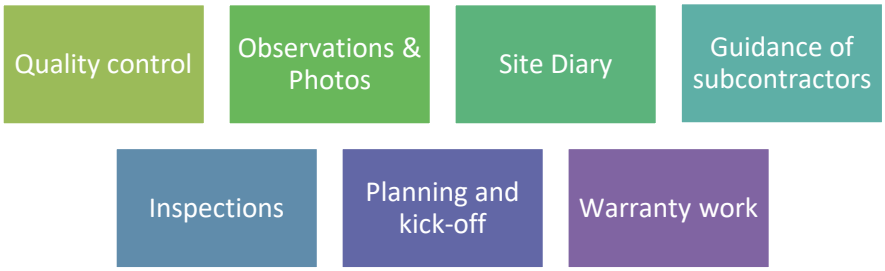


Figure 21. Features of Congrid software (Fira 2019)

Congrid software provides a set of tools that allow construction site to handle documentation, regulatory responsibilities and inspections. The software package includes Live Portal for computer desktop, mobile app and Congrid Lite application for subcontractors use. These tools allow general contractor, developers and subcontractors to access the plans and other files at any given time, complete inspections, insert observations and monitor the construction processes. Importantly, observation and quality control functions allow site managers to check the progress of each work process in a timely manner and identify defects or errors before any major damage occurs.

Using Congrid in the construction firm was higher management´s decision and therefore, the whole company should act accordingly and use the software for quality management and documentation of inspections. Observations during inspections or checkups are always marked with the photo on the floor plans and directed straight to the subcontractor, after that subcontractor corrects the errors, they mark it as completed and documentation moves forward. The ultimate goal is to achieve zero-error submissions to the client.

Congrid Software provides wide possibilities for digital footprint generation: potentially with the collected digital data, the construction firm can provide traceability and transparency to any project, do thorough analysis of the processes and enhance further learning for the following projects. However, there are several challenges: Mustonen's research (2018) has revealed that there are no unified instructions in the construction company on how to use the Congrid software, therefore some workers use system as a checklist with no organized structure and some use just certain features of the platform. There is a definite need in standardizing data collection to Congrid as well as additional training to the employees.

In addition, to digital footprint generation, Congrid can serve as productivity and quality booster. Construction site managers are able to see the current situation with ongoing inspections and undone work at the site. Therefore, the can manage the quality and reduce time buffers between tasks. When the quality documentation is up-to-date, manager can handle risks, reduce repetitive errors at different stages of work, reduce the number of defects and improve quality. With all of the above mentioned it is easier to stay on schedule and achieve cost reduction, and therefore decrease turnaround time and increase customer satisfaction.

Congrid has been appreciated among the users as it provides precise needed data required for quality control and reporting. Quality control via Congrid is in fact crucial, but site managers admit that there is never enough time to handle it thoroughly. The Congrid needs to be more visible elsewhere. The beginning phases of the project and planning are very important for the quality. Every foreman should study quality responsibilities regarding own area of work.

4.3.4 Location control tool pilot

Location tracking was organized and piloted by Jianyu Zhao – doctoral student of Aalto University. The goals for the pilot were to test the system from technological point of view, to measure efficiency of subcontractors for further research of Jianyu and for Fira's knowledge. In case of success the location tracking could become essential data source for construction business development.

This location control system consists of four main components: beacons, gateways, cloud-storage and web-based application. The workers that are being tracked receive beacons that constantly send data to the gateways – data-receiving modems. (Jianyu et al. 2017) Furnishing and hardwood floor installation subcontractors were chosen for this case pilot and workers were told to carry beacons with them at all times. The getaways were installed at the entrance of break room, at the entrance of the V14 building and on the floors from 5 to 14. There were two getaways installed on each floor in order to provide stable signal no matter which flat a worker is located in. The idea was that one getaway covers takt zones 1 and 3, and the second getaway covers takt zones 2 and 4. Gateways receive signals from workers' beacons and forward it to the cloud service via Wi-Fi network transforming signals into relevant location information. After that the cloud

analyzes the data and displays the results on the web-based application (Jianyu et al. 2017).

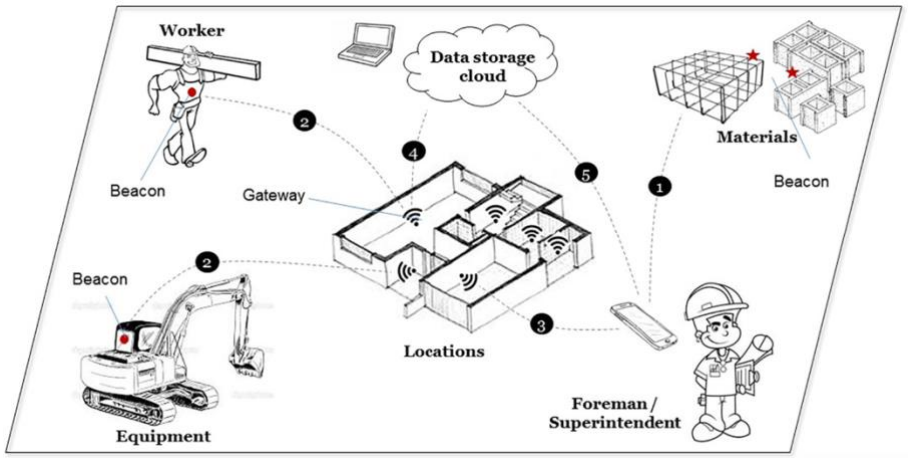


Figure 22. Proposed real-time tracking scheme on a construction site (Olivieri et al. 2017)

During the pilot it has been possible to collect five types of data with the described above intelligent system: time spent by worker in each defined location; total labor time in each location; real-time location of each worker; time spent in the break room; and time stamp of workers, meaning the whole time they spent at the construction site.

The time stamp indicator and time spent on breaks were the most correct and trustable numbers due to signal accuracy. With these data site managers can observe productivity of each worker and actual working hours. Working hours data from location tracking tool is more trustable than SiteManager's data because data in SiteManager is based on worker's inconsistent manual punches with Valtticards.

Potentially location based tracked data can support production control as it allows to identify waste of resources and record productivity. According to Jianyu et al. (2017) the location tracking tool can be utilized in two ways:

1) Time analysis. From the collected data by location tracking it is possible to calculate several useful coefficients. The time that was spent in each area by each individual worker allows to see movements of a worker throughout the day and identify non-value adding activities. Distribution of worker's time per day can reveal value-adding time, and time spent at each area allows to measure work productivity. Vacant time at a given location shows work-in progress that can be compared to the planned schedule. And finally real-time location of workers shows possible clusters or subcontractor overlaps, and site manager can walk straight to the problem area to resolve it.
2) Resource waste analysis. Waste can be seen straight away when the worker is moving outside of the planned area: looking for tools, coworkers or management, returning to fix something in the area that has been completed, or spending significant amount of time in the break area. With this knowledge management can solve the appearing problems faster and reduce waste buffers.

From the takt production point of view, it would be beneficial to have a getaway covering each takt area separately. In that way, site management can adjust takt time after the first floor of the building has been completed and achieve feasible schedule. In addition, location tracking tool has potential to enhance safety management, where gateways could act as alarm and notify workers if they have entered dangerous area (Jianyu et al. 2017).

Two major challenges have become visible during the pilot that can prevent location tracking implementation at construction sites. First of all it is workers' unwillingness to wear beacons with them at all times: they either forget them or are afraid that management will see that they are not at the workplace. The other problem is the technology that can't be trusted just yet: the signal coming from getaways is too weak, data from beacons is not always recorded fully, getaways from time to time go offline. All of that brings inconsistencies to the collected data and analyzed information is incomplete. When the technology will be developed to perfection, it could revolutionize construction production since most of the data would not be collected manually. Due to technological problems and people factors most of the generated data at the case site is not reliable however, it allows to make certain conclusions.

5 Results

This chapter represents the outcomes of case study and empirical research. Sections 5.1-5.2 answer to the set sub-questions building up to section 5.3 which proposes improvement ideas regarding digitalization in takt driven residential project and give suggestions for implementing digital data to further develop the construction business.

The answers to the research sub-questions are based on the twenty-nine-question semi structured interviews that explored actors' experience with takt production, data and existing digital tools and platforms. The interviewees were workers of the construction company however, less formal conversations were implemented with its subcontractors. First set of questions addressed general information on the interviewed. The second set of questions explored their experience and attitude towards takt production. The third set of questions reviewed current communication situation and practices between management and subcontractors. The intention of second and third sections was to collect information from the interviewee without him or her thinking of digitalization. So finally, the fourth set of questions examined which tools and platforms are being used by different actors, their data needs, for what purposes are the platform data used, and possible development ideas.

5.1 Data users and required data

When looking at the construction process at the construction firm, three types of actors can be identified by their work activity: management, supervision and performers. In fact some people may belong to two actor types depending on situation and their activity at a certain moment.

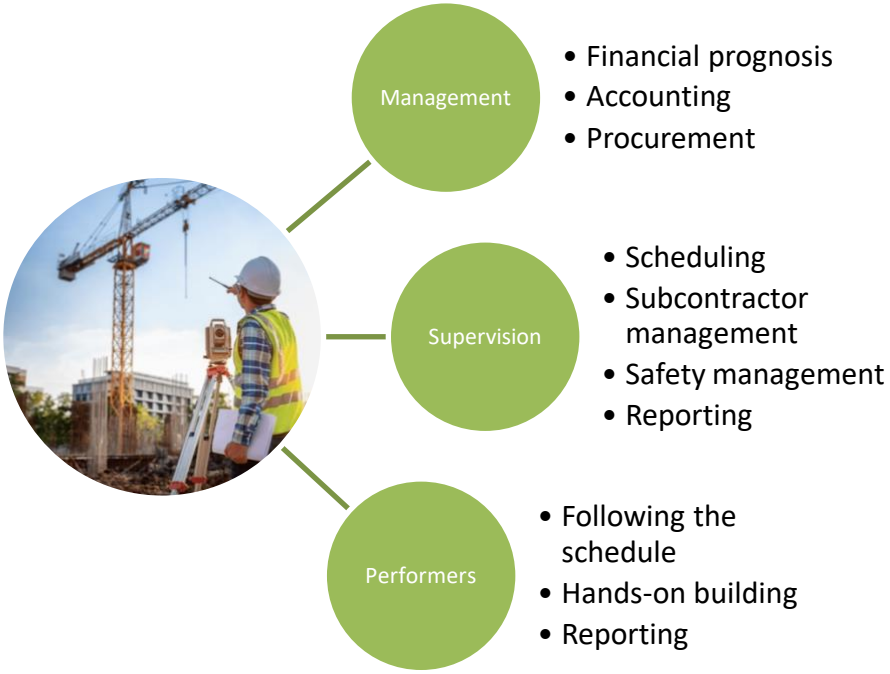


Figure 23. Actor groups at the case construction site and their responsibilities.

Management group is mainly observing the process controlling the bigger milestones of the project. This group includes the executives of the firm, project manager, production manager, acquisition manager, accountant, site manager and site engineer. These actors do require precise financial information for accounting, reporting and controlling cash flow. The data that they need is up-to-date expenditure and revenue numbers, compared against the preliminary financial plan. The management group works mainly with Power B system, which shows situation picture, financial state and costs, change in financial forecast. However the generated data lacks of proactive indicators, prognosis and change in costs (Sireni 2019).

For accounting purposes incoming and outgoing invoices need to be correctly recorded, referenced and contain due figures. Even though the construction company uses e-invoicing there has been a common struggle with invoice referencing. Case site has a certain nomenclature of activities with their own code to be classified to when receiving invoices from subcontractors however, as classification has to be done manually, it consumes extra time from the work of engineer and supervisor and it is at risk of inaccuracy.

Site engineer as a person who handles site's material acquisitions and subcontract procurements usually spends a lot of time for research and organizing competitive tenders. She believes that every new site would benefit from information and experiences gained by other sites: if every site would record experience and costs of different subcontractors, expenses for each construction activity, unit prices etc., it would save a lot of resources for every new project.

Supervision group consists of site manager, work supervisors, site engineer and logistics coordinator. Their main tasks include planning and maintaining schedules, procurement of necessary materials, subcontractor management, safety management, documentation and progress reporting. According to interviewed project members, all of them require some data and information to perform their daily tasks. They believe that digital data is something that would help not just execute their tasks but improve the quality and efficiency of their performance. Obviously different roles require different data and information. In order for site manager to successfully go through a working day he needs:

1) Detailed weekly schedule, what was planned and what is the actual progress state including percentage. In Hatakka's opinion it would be very convenient if system would warn when some phase is not progressing as planned so, he could react immediately. In theory with digital tools such as SiteDrive, schedule planning and control should be easier due to possibilities to check out the completed tasks and tasks in progress. In practice the data generated by SiteDrive is not reliable because the information is not updated as regularly as needed. Hatakka wishes that everyone would take SiteDrive to a regular use for weekly panning in order to have that detailed weekly schedule with progress and plan comparison.
2) List of workers currently located at a site with contact details. Again even though it is possible in theory with the help of SiteManager system, in fact the subcontractors workers keep constantly interchanging accessing the site without

induction. Secondly, SiteManager often contains wrong or no contact information and finally, workers forget to punch in and out with their Valtticards even they are instructed to do so.

3) Emphasized costs for hourly workers for tighter resource control.

The site manager wants the schedule, work progress and safety data to be displayed in the office and in the social spaces for workers. He believes that if this information will be visible and easy to read at one glance, it will be easier for management to react to problems and for workers to be knowledgeable and more motivated in the job. Hatakka (2019) suggests the easiest solution for this would be separate tv-screens placed in management room and social spaces and information would be derived from used software. (Hatakka 2019)

Case building's interior work supervisor found the communication with subcontractors very challenging when she needed information on resource availability and work completion estimations. She believes if there would be a constant information flow between contractor and subcontractors, the management of the project would be easier and more efficient. Regarding schedule, supervisor requires a general scheduled delivered by site manager so, she could proceed with detailed weekly planning. Currently the weekly planning is done on paper and then transferred to Site Drive software. (Teräväinen 2019)

As interior work supervisors come to the site in the middle of the project, Teräväinen feels that integration in sense of information could be implemented: when the new work supervisor arrives he or she receives a standardized info-package which contains contact details of key subcontractors, guidelines for material acquisition, general schedule and project targets. (Teräväinen 2019)

Another important responsibility for the whole supervision group is quality checks that are facilitated with the help of Congrid software. In the construction firm Congrid has preset list of tasks that can be modified and have to be scheduled. In addition to main contractor, also subcontractors' supervisor and external overseers have access to it and obligation by contract to use it. General contractor workers feel that even though it is a great tool that provides tight quality control on schedule there should be certain rules for everyone on how to use this software to get maximum benefit out of it. Currently it takes a lot of time to organize generated data in Congrid due to no standard of data collection for users. Site engineer as of the main users also wishes the quality matrix would be clearer and more accurate. Otherwise Congrid generates useful reports that are used for reporting by all involved parties.

As construction work happens outside, it is often very dependent on weather. All interviewed workers agreed that data on weather dependent processes should be recorded at every site for cross-project learning. Based on this and previous case studies for the construction firm, process concrete drying is the one that is often delaying other phases because management couldn't correctly estimate drying times.

Subcontractor supervisors are the intermedium between general contractor and the craftsmen performing the actual work at the site. They also do require certain data such as information on own workers presence at the site, schedule given by site management, actual progress. They need this data in order to control own performance, have correct information to report to main contractor during the meetings and invoice the correct amounts at right time.

Logistics coordinator is someone who is one the border between supervision and performers groups. He is managing the all the logistics flow at the site including arrival of material, equipment, special machinery etc. Thus he needs to have precise information about every delivery coming to the site and location of material and equipment.

Finally craftsmen are the performers who need to be supervised and managed. The data they need is a clear daily and weekly plan of tasks to follow; information on what has been done before and needs to be done after them; location of material and equipment.

5.2 Currently available and missing data

The Figure 24 below represents the kinds of data that are currently being collected or generated by digital tools used at the case construction site. Based on the above represented results of interviews, all of this data is important for the management of a construction site. This section will review the usability and potential of existing data by digital tools, as well as missing data and how it could be collected.

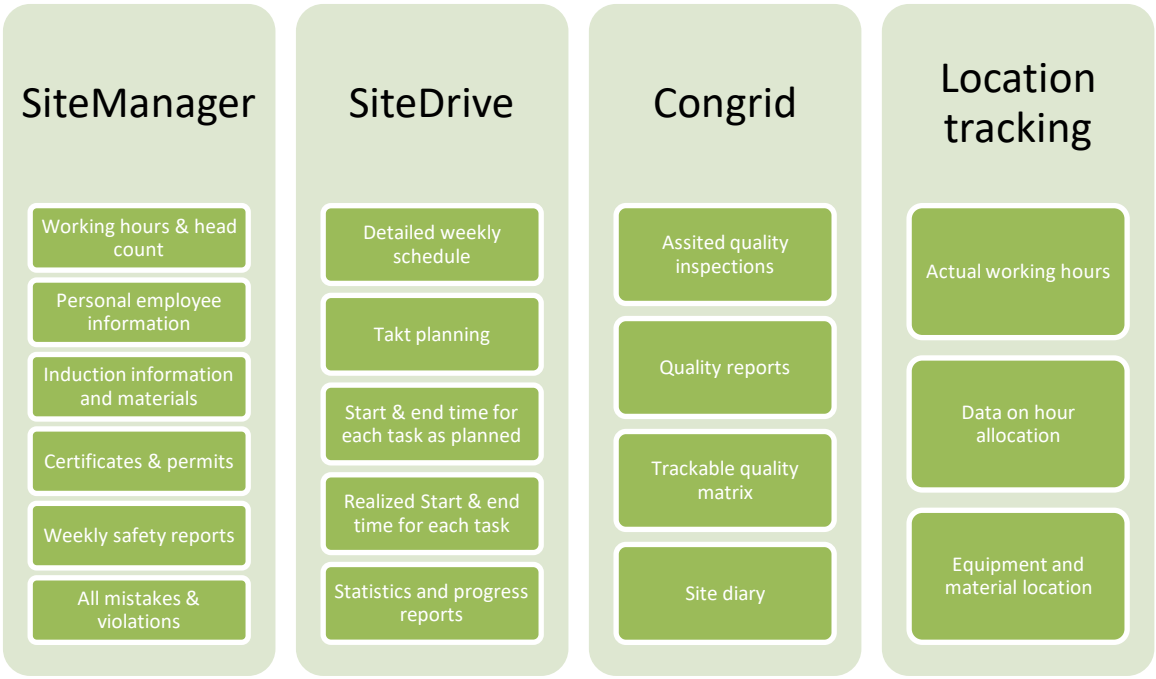


Figure 24. Available data collected with digital tools.

SiteManager is a crucial system for the construction site as it contains lots of important data for management and has strong influence on takt production planning. First of all

SiteManager has information on almost every worker coming to the site, including their contact details, special work certificates and working hours. However, contact details are often missing and work certificates are not updated. In order to fix these, person who carries out the induction of workers has to confirm phone number and update the certificate information implicitly. In this way site manager will be able to reach the right person when needed. Regrading working hours and presence at the site, the data is often missing due to human factor - workers have to manually punch in and punch out and they either forget or violate working hours. To get reliable data on working hours the new technology of real-time location tracking could be implemented ubiquitously. More on the topic below in a paragraph devoted to location tracking.

As mentioned before SiteManager provides solution for easy induction of new workers to the site: workers get registered for certain amount of time to the site, their papers are checked, they listen or read through induction material and digitally sign the induction certificate. Officially only after this procedure workers can proceed to the construction site. The induction process currently is carried out verbally as logistics coordinator introduces new-comers to the specifics of the site in Finnish or English. However, when a person who doesn't speak these languages arrives to the site, it is hard to ensure their knowledgeability. Thus, the construction firm could provide digital induction material in other common languages such as Estonian and Russian to ensure safety at the site.

In addition, with the help of SiteManager logistics coordinator performs safety checks every week. The interface guides on how to collect the observation onto the system and after the round around the site is completed the system generates report with safety statistics and recorded violations. Based on research observations and interviews, this data due to its regularity is very trustful and useful: this data is discussed during weekly subcontractor meetings which allows to clearly communicate problems to supervisors and they can react faster, and moreover when subcontract is finished by a company, these reports allow to gather all their violations to be deducted from their pay according to contract agreement.

Moving on to Site Drive application, it can be said based on the case research that this tool has the most potential but also most problems integrating it to the daily routine of site management. SiteDrive provides all project actors with detailed weekly schedule, planned starting and ending times for each train and wagon of the takt plan. Site manager wishes additional feature for the system when it would notify when some phase is late so, he could address the problem at its roots and not when it is too late. This new kind of feature have to be addressed by development team of SiteDrive.

Once the schedule is planned in the system and tasks get to be checked out, Sitedrive offers lots of autogenerated metrics and statistics however, due to irregularity of SiteDrive usage by site management, the generated statistics was not trustable and couldn't be used for decision making. When regularly used, SiteDrive provides functional reports that speed up management's reaction to obstacles and deviations.

Despite usage irregularity, SiteDrive is still a necessary tool for takt and weekly planning and progress tracking: it makes the planning and adjusting of the schedule easy and after completion all actors see the updates instantly – this feature eliminates inefficiency and non-acquaintance. At the same time there is a possibility to assign tasks to subcontractors which enables workers to see their own tasks for each day always three weeks ahead. And if the worker is responsible and regularly checks out the completed tasks, SiteDrive assists in task monitoring by digital confirmations, meaning that management could receive valuable data on process time, takt production progress and knowledge for the inter-project learning.

Case study has revealed that most of the subcontractors didn't follow takt area or time plans and the reason for that are non-acquaintance and/or ignorance. While ignorance is something that can only be fixed by personal development and tighter management, SiteDrive could become a great tool to acknowledge worker not only on the task list and schedule but also on the area order he or she has to go through. In the case project only supervisors of subcontracting firms had access to their tasks in SiteDrive however, they are not the ones doing work, the craftsmen need clear daily and weekly plans of tasks to follow; takt area order, location of materials and equipment. Since not all craftsmen are comfortable with smartphones, there could be an option in SiteDrive to send task list automatically every morning by text message and when the task is completed, craftsman could just reply "Done" and the system checks out the task by itself. This would ensure everyone's awareness on the plan and schedule and eliminate the excuses for not using smart devices.

In addition, SiteDrive could integrate a special view to schedule material deliveries. Targeted deliveries is important part of successful construction site logistics and as we have found from the interviews the information on deliveries is required not only by management but also logistics coordinator, engineer and subcontractors. Currently the deliveries' content and time were scheduled on a whiteboard in the office at the case site which is really inefficient and may cause miscommunication and oblivion.

Congrid as a quality management system is important part of construction productivity and takt planning in a sense that by insuring proper quality at the initial check, the takt time can be met, redoing avoided and therefore, lower costs achieved. First of all, Congrid provides guidance information for quality inspections of the various work stages which helps to have standardized and concise data. A quality inspection targets are predefined and inspector can specify whether the quality of a work stage is acceptable, unacceptable or not taken into account during the inspection. The Congrid system contains architectural, electrical and HVAC blueprints that can be accessed at any time online to assist quality inspector. Quality inspector reports all detected flaws by recording them in the system and attaching photo and location. A floor plan marking and photo attached to the report provide extra help for contractors and workers in locating information afterwards.
In this way is a great potential for inside and cross-project learning as this kind of information is recorded on a regular basis and processes somewhat repeat in every floor, building and residential project. Secondly, automatic reports from the field with

deviations in quality are instantly shared with project participants which provides faster reaction and correction. Information sharing is made easy for all parties in a project with no need to print out reports or send emails which again eliminates possible miscommunication and loss of time. Congrid desktop system ensures task monitoring and confirmations for tighter control by management in real time.

Site Diary is a summary of each working day at the site with daily notes and an overall situation which is written by site manager or his replacement in Congrid system. The Site Diary is mainly used to document the status of the project's work stages and the subcontractors' resources. Weather information is uploaded automatically twice a day. Thus, every site at the construction firm has a solid data regarding work progress and weather for each day and that can become a great base for cross-project learning and analysis of certain weather dependent phases such as concrete drying times.

Location tracking was piloted at the case site during July-October and involved furnishing and wooden floor installation workers. As mentioned before due to human factor and technological problems numerical data is not reliable however, tracked location data allows to make certain conclusions and discuss the system's potential. When discussing data delivered by SiteManager it was noticed that the working hours data is often missing because workers either forget to punch in and out or violate working hours. The benefit of location tracking is that it requires no manual action from workers – their appearance and leaving from the site was automatically scanned from the beacons they carried with them. If this system could be unified with SiteManager, then site management would have a reliable data on workers present, which also could be transferred to the Site Diary. During this pilot workers were only working in one building, however if the scanning stations would be installed at the entrances of each building in the project, it would make the reporting and cost allocation much easier for the site management.

During the pilot scanning stations were also installed on every floor of the building in the beginning and the end of the corridor. The idea was to check if workers follow the takt area order and is the takt time feasible. The result was that workers hoped from area to area and even floor to floor because of missing material, equipment and other logistical issues. Anyway, when implementing location tracking on a bigger scale later on, personal privacy may become a big problem. But the exact location tracking can be applied towards material and equipment. If the workers can have a real time view of equipment location on their smartphones it could reduce the amount of time buffers significantly.

Now that all available and potentially achievable data was reviewed, it is necessary to look at the missing data. The site manager believes it would be really beneficial to have key information on schedule, safety and quality always displayed separately at the office. Separate computer or TV screens could always display the weekly schedule and progress from SiteDrive, this week's deliveries, safety rate, amount of people working at the site. In addition, site manager wishes that schedule and safety information would be visible in dining room of social spaces for craftsmen. This would enhance workers' understanding of the big picture, what are they responsible for, their own significance and what are the requirements of the project.

Another great idea put forward partly by interior work supervisor and partly by site engineer – digitally generated information packages for every general contractor manager or engineer. Site engineer felt that every new site team would benefit from information and experiences gained in other projects regarding different subcontractors, expenses for each construction activity, unit prices and others. This kind of data can be provided from the Site Diaries of similar sites when the input data will be standardized. The interior work supervisor, as the worker who usually comes to the site when then project is at full speed, would need an info-package which contains contact details of key subcontractors, guidelines for material acquisition, general schedule and project targets. This as well could be generated from Site Diary and SiteManager data. Both types of information packages could save significant amount of time for site workers and direct the freed resources towards value-bringing processes.

5.3 Findings of the research

The literature review on construction productivity and revealed that in order to achieve good production flow in construction, there should be good project flow, location flow and trade flow at the same time. Many researchers had a common opinion on takt production as a suitable tool for construction that aims to produce quality location work flow with the assistance of lean principles: special planning technics and digital tools. Several researches have examined residential projects using takt production, and all documented cases found takt suitable for the interior phase of the residential construction due to high repetitious level. Outcome of the case study was that indeed takt production is a helpful tool, especially in large residential building, that helps to achieve clarity, better flow and smooth turn-around-time. However, the takt production was not realized to its fullest because the management didn't follow basic principle that have been described by various researchers. As several digital tools were implemented at the case site, they showed a great potential in assisting takt production implementation and general efficiency improvement. Based on literature, documented residential takt cases and case study outcomes, several essential factors were identified that have to be realized in order for takt production to be executed successfully:

1) Early implementation and subcontractor involvement in planning. According to Vatne & Drevland (2016) and Nieminen (2019), takt planning has to start at early stages of a project. In addition, involving subcontractors in planning will allow to get best estimation of takt time and area. Most of the problems could have been prevented with better planning in early stage of the project.
2) Sufficient training on takt production for site management. It became clear in the interviews that proper education and training is necessary as nobody from site management team had previous experiences in takt production. Therefore, commitment by general contractor workers was poor as they considered takt maintaining as additional job.
3) Partnerships and subcontractors' commitment. Communication of takt production essence and goals is really important. Currently ordinary workers think that working by takt just means they have to work faster, when in fact according to

Lehtovaara (2019) the point of takt time is to work with less haste with more time for actual work when all the process waste is eliminated. The construction company has to ensure that everyone involved with the project commits to a takt schedule by including this in the contracts and involving the subcontractors in scheduling negotiations. Planning the workloads together with subcontractors allows to make sure that the plans are as detailed as possible.

4) Timely takt schedule updates. It was confirmed by many construction projects, that when regularly and responsibly updating takt schedule, even it takes some additional time to perform, ultimate quality, clarity, control and bigger time savings can be achieved (Nieminen 2019). Supervisors should make sure that the schedule is adjusted to the current situation in order to be able to react quickly to any appearing problem.
5) Support takt production management with modern technology. Site management should integrate use of digital tools to ensure that the construction progress pace matches takt time. Successful data-based management requires up-to-date information and an understanding of the overall situation (SiteDrive 2019).

The empirical research of the case study revealed that not only takt production as a process requires data support but also every each construction process actor needs certain data to follow the takt plan and manage other obligations of construction business. Every construction project involves three types of working groups: management, supervision and performers. Every group has own set of responsibilities (see Figure 23) and different types of data they need to do well in their job. There is a lot of data that being generated at construction site manually and digitally, but most of the time it is not trustable due to collection inefficiencies or just stays unutilized for analysis and improvement purposes.

The Table 4 below summarizes proposed improvement actions for the construction firm to strengthen digitalization and utility of digital footprint for further learning that can be applied immediately.

Digital tool - Purpose	Responsible party	Action	Benefit
SiteManager	Worker in charge of induction	Update phone number and work certificates' validity.	Better communication as management can reach right people.
	Site/company management	Digital induction materials in Finnish, English, Russian and Estonian. Always available to workers.	Better communication, improved safety.
	Site and company management	Tighter rules on punching in and out - included in the contract.	Precise data on working hours and strength at the site.
Site Drive	Site Drive team	Extensive training of management and subcontractors. Constant support of new users.	Regular usage, improved communication, transparency and better quality of generated data.

	Company management	Standard instructions for all site managers and supervisors on how to plan and update schedule in SD.	Reliable data, easy reading, cross-project learning.
	Site and company management	Include in the contract SD using obligations.	Reliable data for efficient takt production control.
Congrid	Site management	Determine common usage rules and practices for all users including subcontractors and quality inspectors.	Orderliness, timely and complete quality inspections, reliable data.

Table 4. Proposed improvement ideas.

Unfortunately at rapidly digitalizing world where most of the people own a smartphone, the construction workers have to be obliged to use digital tools at work. Based on this case study and Mustonen's research on takt production for the same construction company (2019), digital tools are not well implemented at the Fira's sites because of poor usability and lack of education for users. Observations and interviews have indicated that better training and communication is required, because knowledge on takt schedule and digital systems at the site was inadequate. Digital tools despite all their potential were not providing enough visible benefits to maintain the motivation of managers in regular usage. Thus construction firm has to start with proper education to site managers, engineers and supervisors and show them on examples what outcomes can be achieved by using digital tools. Only when full understanding by site management will be achieved, they will consciously use the technology and generated data will not be wasted. In order to enhance proper digital data collection even more, contracts with subcontractors have to be revised and partnerships established. Subcontractors also have to be educated by the general contractor on digital tools usage or even better by the service provider, in this case SiteDrive. It has to be shown to trade supervisors and workers how digital tools can also be beneficial for them. For instance, clearly visually presented task plan for every working day and up-to-minute progress information for reporting during the subcontractors meeting without any additional work. When all partners commit to use the same scheduling software, they start speaking the same language (SiteDrive 2019).

Residential category director at Fira says that digital tools in construction are very important to reflect a real state of situational picture. But all currently used digital tools at the construction firm have to be still developed: scheduling tool, quality control and activity schedules should interact with each other and interface should be more user-friendly and intuitive. At this point it is crucial to find a way to get partners on board with digital tools usage, automate processes that can be automated, identify and get rid of non-value bringing activities. (Sireni 2019) Collected data should be available for everybody, all workers should be able to see and use the data to improve their own performance.

Harmonization of takt and quality schedules, SiteDrive and Congrid, should become a priority aim for the construction firm when thinking of technical improvements to be done. Unification of all site schedules is another target to work on as currently there were noticed 5 schedules at the case site which is highly illogical and inefficient: general

schedule created in Tocoman in a graphical view; SiteDrive which contained in fact around 10 separate detailed schedules for every building and different phases; whiteboard schedule with deliveries; site's outlook calendar with significant official meetings with client, site and subcontractor meetings; and quality inspection schedule in Congrid. In addition, some supervisors have own schedules in excel. Besides the various schedules, interviewees feel that the amount of systems they need to use may be too much and construction firm has to consider combining and eliminating some of them. Based on Trackvia's research (2018) managers that rely on more than three systems to manage data spend four times more time trying to organize it before decision-making, compared to those who use one system. Table 5 represents the development ideas that require technical development over longer amount of time.

Digital tool - Purpose	Responsible party	Action	Benefit
Location tracking	Company management	Sensors automatically scan the arrival and departure of a worker through signal coming from beacon/Valttikortti.	Elimination of human factor to collect precise digital data.
	Site Management	Attach beacons to the most valuable equipment and newly arrived materials.	Real-time location tracking of equipment, decreased time wasted on search of tools.
SiteManager + Location tracking	Company management	Integration of data received from workers' beacons to work hours in SM.	Reliable data on working hours, easy reporting and cost allocation.
SiteDrive	SiteDrive Development	Integrated takt area map, order and takt time to follow.	Improved takt following by subcontractors
	SiteDrive Development	Possibility to schedule deliveries.	Better communication, less confusion, smoother deliveries.
	SiteDrive Development	Possibility to send task lists by text message.	Workers without smartphone or SD access aware of the schedule and goals.
	SiteDrive Development	Possibility to add completion percentage to every task.	Tighter control of the progress, bottlenecks visible.
Congrid	Company management	Obligation to report weather dependent processes' outcomes to Site Diary.	Data for future projects to accurately plan for instance concrete drying times based on experience with similar weather in other projects.
Congrid/New system	Company management	Possibility to record data on experience and costs of different subcontractors, total expenses for each activity, unit prices.	Cross-project learning, lots of saved resources in planning of every new project
Supplies tracking	Company management & subcontractor	Barcode system to be applied for material movement tracking.	Real time data on supplies movement from factory to their destination.

New system	Company management	Pick and develop a platform on which all stakeholders could communicate.	When messaging each other on the same platform, data stays in one place.
All systems	Company management	Minimize amount of systems, maximize useful functions	Less time wasted on organizing the generated data

Table 5. Development ideas requiring technical intervention.

Most of construction managers say that manually collected data is the biggest challenge they face as it brings incomplete and untruthful data (TrackVia 2018). The case site has also demonstrated that poor data management and communication not just leads to wasted time but also increases costs related to work quality, subcontractor downtime, damaged supplies as in furnishing installation case, and overall project delays costs. With data playing critical role, construction firm has to shift towards streamlined and digitized data collection process at the same time replacing paper and excel sheets with dynamic digital tools. Indeed, the construction company has made a step forward and started using digital tools rather quickly but changing people's habits and modes of operation will still take some time. There is no doubt that by developing digitalization in construing steadily little by little, after a while technology culture in construction will start shaping up, people will get warmer to the idea of using apps for work and tools will be developed to be more intuitive and user-friendly.

Good communication is fundamental to the success of any team work such as a construction project. Digital tools indeed enable smooth daily communication channels and all involved stakeholders, from planners to subcontractors can be in the same information chain. Thus, it can be beneficial to have such a platform that offers a messaging feature for all relevant actors. Currently, at the construction firm such platform is not used and around 80% of all project related communication happens over email.

Despite digital platforms functionality in communication, regular organizational meetings and personal connection are still important when building trust and team spirit in a project. Reviewing one flagship takt production project in the same firm showed that several regular meetings bring a lot of value and clarity to all workers involved:

1) Daily meetings with craftsmen before working day starts. The ultimate goal of these meetings is to ensure that every employee is aware of what they are doing today and believes that they can complete it. Also, these meetings help to connect different subcontractor with each other and in that way enhance direct communication.
2) Daily morning management meetings. These meetings imply controlling and maintaining the situational snapshot. Manager and supervisors review the issues raised in the morning meeting with craftsmen and ensure the flow of information throughout the site organization.
3) Weekly subcontractor meeting. The goal here is to formally guide subcontractors to follow a takt-time frame to create value for the project, themselves and other subcontractors. Basic agenda should include safety, quality, schedule from a takt-

time perspective, possible issues and their resolving, subcontractor progress. Nieminen (2019) suggests to systematically and regularly record the statistical occurrences such as number of working hours and violations that can later help to form the final financial settlements with subcontractors.

4) Weekly takt production meeting. Site managers together with subcontractors' supervisor go through the goals for upcoming week, takt pace feasibility, review and learn from the mistakes of the previous week, securing and committing to the week ahead.

Comparing these meeting practices to the case site, it is clear that only around one quarter of proposed meeting load was done. This meeting structure should become a base for every project and after these meetings flow fluently and communication becomes transparent, digital tools and technology can be layered on top.

Regarding the furnishing installation case, the partnership with Novart has to be reviewed and first of all communication on a executive level has to be established properly. The site manager wished to have a visible data on materials movement from factory to the apartments and until installed at the right place. While location tracking via beacons can be still way down the around, the first of option to collect such would be barcodes on every piece of supplies, which would be scanned once every step of delivery and installation is completed.

Summing up, digitizing data collection can dramatically improve the completeness and accuracy of reports, quality inspections and safety observations. Digital tools for takt production and process management can start bringing value only when communication at the site works and everyone is committed to project development and using new technology. Turn-around time has a potential to accelerate if the construction firm will be able to automate site processes, resulting in significant improvements in on-time performance. From the point of Fira's strategy it is crucial that the digitalization successfully integrates to their construction sites so, the company can become internationally acknowledged construction expert and continue to create disruption in the market.

6 Discussion & Conclusion

This chapter summarizes the key findings of the research and provides answer to the research question. After that limitations and reliability of the study are evaluated and recommendations for further research are proposed.

6.1 Key findings of the research

The aim of this research was to develop standards for efficient digital data collection and to propose improvement ideas for takt production execution using modern technology. In order to fulfill this aim, the literature review had to provide a definition for good construction productivity, theoretical background of takt production and introduce the concept of digitalization in construction. Literature review has revealed that in order to achieve good productivity in construction, there should be good project flow, location flow and trade flow at the same time. Takt production is one of the lean frameworks that aims to provide quality location work flow and utilize the project capacity to its fullest. In addition, the literature review has examined previously recorded cases of takt production in residential construction to adopt successful management techniques. The experience from the recorded projects shows that takt production is suitable for the residential construction due to high repetitious level of the exterior and interior phases. To succeed in takt production implementation, partnerships between general contractor and subcontractors are crucial as they can ensure proper commitment of both sides. Besides partnerships takt-time planning requires regular and frequent updates and therefore, efficient production control system that would allow to maximize plan reliability and easily make updates to the schedule is needed. Based on research papers by many large consulting companies, digital tools, when properly implemented, can indeed provide much more accurate takt-planning and tracking of work in construction and in long-run, modern technology can revolutionize the whole industry.

The goal of the empirical research was to test applicability of takt production in residential project, identify data users in construction process, find available and missing data that is or can be digitalized and improve overall performance. To help navigating the empirical research of this study three research sub-questions were set. The empirical research methods included a case study review, description of contexts and observations, semi-structured interviews and review of currently used digitals tools and available data.

First of all it was necessary to find who needs the data at a construction project and for what purposes. After interviewing representatives of different professions involved at the construction site, it became clear that all of the require some data in order to do their job. It was possible to identify three groups of actors in a construction project – management, supervision and performers. Based on their responsibilities it was also possible to identify that management group require mainly financial data for analytics, accounting and procurement purposes; supervision group requires various data on schedule progress, safety, quality and work force presence. Finally, performers group requires task list, detailed schedule and location information of equipment and materials.

All these required data is mainly being collected manually even though inserted into the digital systems.

The empirical research did not find any major data that would be missing completely from the require data pool, however lots of generated data is not being utilized for the intended purpose of analysis and decision-making because of its unreliability. One reason for that is inconsistence and irregularity of data collection by users of digital tools: that mainly relates to the untimely schedule updates and marking accomplishment of tasks not in real time. Second reason for the data unreliability is absence of systematical approach and established rules for data insertion: every actor updates the systems as they see it logical creating a disorder and complicating the data organizing. Third major reason is that site managers did not invest time in organizing the data as all the digital systems were considered as something extra to the actual work and not as something and could support and improve the processes.

Thereby, the objective for the researcher was to generate development ideas on how could a construction company change the ways digital data is collected and processed at construction sites in order to increase construction and management productivity in short and long-term. Combining recent theory on takt production and digitalization in construction with outcomes of recorded takt projects, four crucial actions were identified that should be implemented as soon as possible:

1. Creating clear common rules and instruction for all potential users of digital systems from subcontractors and general contractor to client and quality inspectors. Currently every user is figuring out themselves how to use the systems and that variety in habits creates a disorder in data. When all involved people will have a clear guidelines on how to behave when inserting and exporting data, it will lead to consistent trustable data that can be used for analysis and decision making.
2. Intensive training of site managers on digital systems and tools usage, sufficient training of subcontractors upon the requirements. As different actors use the digital tools for different purposes, it is crucial to educate every user on how they need to use the software and most importantly why.
3. Obliging subcontractors to takt plan following and digital tools usage through contracts and partnerships. Even though for lots of people mobile apps have become a part of daily routine, construction industry is known for its slowness to adopt technological innovations. Therefore, it is necessary to officially obligate subcontractors and general contractor's own employees to use digital tools until the clear benefits will show.
4. Establishing clear communication by organizing regular daily and weekly meetings. The meeting schedule should include daily meetings with craftsmen and site supervisors, and weekly meetings with subcontractors' supervisor and meetings dedicated only to takt schedule and production.

These major behavioral changes will improve the quality of collected and generated data at any construction site, which in its turn will help management to make justified decisions and increase project efficiency. When looking at the takt production

implementation at the case site, the following prerequisites were identified for the successful integration in the future: early planning and implementation; involvement of subcontractors in scheduling; proper training for management and ensuring common understanding of the concept; obligation of subcontractors to follow takt plan through contracts; improved logistics; and support by modern technology and digital scheduling tools.

The examination of case study and data collected from semi-structured interviews allowed to generate several technical development ideas for digitalization at construction. The schedule software SiteDrive could implement possibilities to separately schedule deliveries and insert percentage progress for every task, allow to integrate takt area map that would guide workers to follow the right work order, and finally possibility for supervisors to send task lists to craftsmen by text message or email if they don't have access to SiteDrive. Congrid as a platform containing Site Diary and automatic weather recordings for every working day at a site, could be organized in a way that inserted data is following a standard so, it can be used for learning: weather data should be utilized to accurately plan concrete drying times and work force and experiences with subcontractors can give site engineer better idea and base for decision-making. Finally, location tracking has a lot of potential for collecting trustable digital data and eliminating manual recordings. The pilot demonstrated workers considered their privacy violated and didn't wear the tracking beacons around but Valtticards could have a function of being scanned when a worker arrived to site and enters and exits one of buildings being constructed. That would allow site management to have precise data on workforce and working times to use for costs allocation purposes. Yet attaching beacons to valuable equipment and tracking its location at all times doesn't violate anyone's privacy and would in fact save lot of resources. At the case site many occurrences of lost equipment were observed and workers spent significant amount of time wondering around and searching for it. Regarding delivery of materials such as furnishing or wooden floors, barcode system could be developed which is an inexpensive solution for tracking materials from production to installation.

Unification or at least interaction of systems used in the construction firm should be considered in the nearest future. According to interviewed, different software, systems and various schedules, make them feel overwhelmed especially when they are not fluent with them. They feel it is additional non-value bringing work that they have to do when trying to organize data in those multiple systems. According to Trackvia (2018) with a single system managers can drive fast and impactful decisions around improvements in work quality, on-time deliveries and safety at a site.

6.2 Limitations and validity of the research

The purpose of this research was to develop standards for efficient digital data collection and to propose improvement ideas for applying the generated digital data in construction site management. The research consisted of the literature review and empirical study. The literature review as a research method was essential for this study as it had to introduce and connect topics from different fields. However, due to narrowness of the

topic there was a shortage of scientific papers around takt production in residential projects as well as the theory on digitalization was too general due the novelty of the theme. This created a wider openness to the theoretical framework of the study. The empirical research included case study and data collection methods consisted of observations, examination of used digital tools and currently available data, and semi-structured interviews. To ensure reliability of the research, as Gibbs (2007) suggests observed data was thoroughly recorded with notes and photos and semi-structured interviews audio recorded and later transcribed. It is important to keep in mind that the outcomes of the case study could have been different at another construction site due different nature of the project, team members and common procedures. However, since the study was based on the established theories, the results appeared to be similar to other captured residential construction projects.

Due to partial implementation of takt production at the case site, the research was compelled not only to develop ideas for takt production improvement by digitalization, but also to look at how digitalization can help implement takt production in the first place, widening the research scope. These circumstances somewhat limited and shifted the study focus but did not change the core of the thesis aim.

It is necessary to define the validity of the qualitative research in order to determine whether the findings are accurate (Creswell & Creswell 2018). The literature review utilized numerous established sources and theories to form a chain of evidence as a foundation for the theoretical framework and research design. As for case study, the researcher spent around 1,5 years at the target case site working as assisting site engineer which provided in-depth understanding of the phenomenon – takt production, common ways of working, digital tools usage in construction. The interviewees for interviews were chosen based on their role at the case site. The collected data therefore may reflect their own knowledge on the discussed topics and their perceptions and experiences. To avoid unfounded conclusions based on the interviews, the preliminary results were discussed with interviewees in the end of the sessions. This creates sufficient internal validity for the study.

The proposed improvement ideas regarding takt production and digitalization on construction management has not yet been tested and therefore, further testing and research are required. In addition, the literature and empirical researches were built around construction industry development in technology and digitalization context which is constantly progressing and similar research may result differently in the future.

6.3 Further research

This research focused on changing the ways digital data is collected and processed at construction sites and developing standards for data applying to increase construction and management productivity. The empirical study examined currently available data, missing data and how maximizing digitals tools usage can make improve project efficiency. However, it would also be interesting to explore how can the executives of the company utilize generated digital data from each site for business development in a long-

term. In addition, data processing has not been covered in this research so, it would be beneficial to study the process of data input and using machine learning algorithms in currently used tools to transform data into form of usable information.

The findings of this thesis are based on a single case study and therefore, further research is required to generalize the results. And as it was mentioned above, presented improvement ideas regarding takt production and digitalization in residential construction management has not yet been tested in the industry. The construction firm has a capacity to test these in several projects at the same time and get new valid results after basic improvements are done.

Psychological component and personal motivation to commit to digital tools usage is another hot topic for the industry. According to research of Congrid & University of Turku (2019) digital tools allow one to record own work which in its turn develops commitment to work. But despite all the modern technology and simplicity of devices, many construction professionals refuse to accept the change and continue to work as they are used – collecting data manually and trusting in paper.

6.4 Conclusion

The objective of this research was to develop standards for efficient digital data collection and improvement ideas for applying the generated digital data in construction site management in takt production context. It turned out that takt production implementation challenged the case site team, and the concept was only partially embodied. In such circumstances the research was forced not only to look at how takt production can be improved by digitalization, but also how digitalization can help implement takt production and avoid occurred challenges.

Many valuable lessons were learned regarding early planning, sufficient training of users, subcontractor management and clear communication. There is no doubt that digital tools can provide more accurate work tracking and management, possibility for efficient learning and opportunity for continuous improvement through proper processing and analysis of collected data. Xu (2018) said that data is the “oil” of the digital age and can create significant value for enterprises however, like oil, data cannot create value until it is processed.

Today businesses are entering the age of analytics as technology analyzes massive data streams for comprehension that can drive decisions and generate business insights (McKinsey&Company 2015). Utilizing digital tools has become a prerequisite for the competitiveness in construction industry too and therefore, well planned implementation of digitalization is a crucial factor for success (Congrid & University of Turku 2019). The major reason why construction is so far behind other industries and failing digitalization implementation is that it lacks digital culture and competence. Forward-thinking managers have to acknowledge that a solution is needed to address manual data collection reluctance to use digital technology. The whole industry has to clearly understand why and how they must start the transformation process towards digitalization and make a solid decision to change and get results.

Appendix 1 – Semi-structured interviews

Background Questions

1) What is your role and work assignments in the case site?
2) What are your responsibilities regarding the project? Before, during and after?
3) How do you typically spend your work day?

Takt Planning

1) Why Fira has decided to start implementing takt production at the sites?
2) Why V14 was chosen as a target for takt production?
3) Why takt production wasn't implemented in other building of the case project?
4) What were the expected outcomes from implementing takt in V14?
5) What is required for successful implementation and efficient takt production?
6) What are the current challenges in takt production in V14?
    a. From general contractor side?
    b. From subcontractor side?
7) How do you motivate managers/subcontractors to follow the takt schedule?
8) Are there any visible success points or failures in V14 takt production?
9) What are the bottlenecks in the V14 construction process generally speaking?
10) What are the problems/struggles in daily management?
11) What was the original schedule for V14? What is the outcome?
12) Are digital tools important for the takt production?

Communication with subcontractors

1) How do you communicate with subcontractors on the daily basis?
2) In which form subcontractor receives the schedule and updates?
3) Has the subcontractor officially/in practice committed to the takt schedule?
4) What are consequence for subcontractor not to follow takt/to be late from the schedule?

Data and Digital tools

1) What information do you need to successfully perform your daily tasks?
2) What information you are missing that would be valuable for your work?
3) Who else needs the data at a construction site and for what purposes?
4) What software do you use daily?
5) What software you do and don't enjoy using?
6) Why SiteDrive was chosen for Takt schedule planning
7) What data is there in SiteDrive? Is it used for further analysis and adjusting the schedule?
8) What additional data would be useful for the takt production?
9) What is the crucial data for executives of a construction company and for a site?
10) What are the Fira's intentions towards digitalization? How it will affect the business in the future?

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