Aalto-yliopisto
Insinööritieteiden
korkeakoulu

Hans-Johan Pasila

Impact of Lean-Intervention on Productivity

Diplomityö, joka on jätetty opinnäytteenä tarkastettavaksi diplomi-insinöörin tutkintoa varten.

Espoossa 27.05.2019
Valvoja: Professori Olli Seppänen
Ohjaaja: Risto Kärkkäinen

Aalto-yliopisto
Insinööritieteiden korkeakoulu

Aalto-yliopisto, PL 11000, 00076 AALTO
www.aalto.fi

Diplomityön tiivistelmä

Tekijä Hans-Johan Pasila		
Työn nimi Impact of Lean-Intervention on Productivity		
Maisteriohjelma Master's Programme in Building Technology		**Koodi** ENG27
Työn valvoja Prof. Olli Seppänen		
Työn ohjaaja(t) Risto Kärkkäinen		
Päivämäärä 27.05.2019	**Sivumäärä** 73	**Kieli** Englanti

Tiivistelmä

Työssäni tutkin lean filosofian käyttöönottoa rakennusprosessin aikataulun, resurssien ja materiaalien käytön tehostamisen tavoittelussa. Tutkimuksessa tutkitaan erilaisten arvoa lisäävien ja lisäämättömien toimintojen osuuksia Suomalaisen rakennustyömaan toiminnassa.

Rakennusyrityksen nykykäytäntöjä tutkimalla ja niiden sisältämien kehitysmahdollisuuksien avulla luodaan interventio, jonka avulla pyritään luomaan muutos yksittäisen työvaiheen toiminnassa tehokkaampaan suuntaan. Muutos perustuu tutkittuun dataan ja siitä löytyneisiin arvoa lisääviin ja lisäämättömiin toimintoihin. Interventiolla pyritään vähentämään suurimpia arvoa lisäämättömien eli hukkaa aiheuttavien toimintojen osuuksia ja kasvatetaan arvoa lisäävien toimintojen osuutta.

Interventio sisältää suunnitelmallisia seikkoja, mutta siinä korostetaan myös työmaan henkilöstön sitoutumista tehtyyn suunnitelmaan. Se toimii vaihtoehtoisena lähestymistapana totuttuihin työskentelytapoihin ja tarjoaa laajemman kontrollityökaluston työnjohdolle. Interventiossa tutkimus kohdistuu erilaisten avustavien sovellusten käyttöön, resurssien tehokkaampaan hallintaan sekä materiaalien toimivampaan toimitukseen, varastointiin ja käyttöön. Siinä pyritään pääasiassa luomaan työntekijöille mahdollisimman hyvät lähtökohdat työn tekoon sekä työnjohdolle parannetut seurantamahdollisuudet.

Lopullinen työ tarjoaa työkaluja parantamaan yrityksen nykyistä toimintaa. Tutkimuksen lopussa tehdyt laskelmat toimivat perusteluina intervention onnistumiselle niin aikataulullisesti kuin myös taloudellisesti. Verrokkina parannettuun suoritukseen on käytetty yrityksen muita työmaita vastaavine rakennusvaiheineen.

Avainsanat Lean, Waste, Construction, Intervention, Measurement

Author Hans-Johan Pasila

Title of thesis Impact of Lean-Intervention on Productivity

Master programme Master's Programme in Building Technology **Code** ENG27

Thesis supervisor Prof. Olli Seppänen

Thesis advisor(s) Risto Kärkkäinen

Date 27.05.2019 **Number of pages** 73 **Language** English

Abstract

In this Thesis I study what kind of improvements the implementation of lean philosophy has on schedule, resource usage and material consumption on a construction site. The research focuses on the division of value-adding and non-value-adding activities on a Finnish construction site.

By studying the present policies on a case study an intervention is created by utilizing the development possibilities. This intervention is carried out in order to improve the production rate of a single construction phase. The intervention is based on data collected from the work phase by helmet camera video recordings. The goal is to decrease the amount of non-value-adding activities compared to the original situation and to improve the value-adding activities respectfully.

The intervention consists of plans and actions, but it also emphasizes the commitment of the personnel and work force of the site. It is presented as an alternative to the familiar working methods for the workers and as a wider set of control tools for the management. The utilization of different applications, more effective ways to use resources and more planned use and logistics of materials are studied for the intervention with a target in mind to offer the best possible starting point for the workers to conduct their needed work in separate apartments and to offer better control and monitoring tools for the management.

The finalized Thesis offers the case company tools to improve their present operations. Calculations were made in the post-intervention study to support the successful execution of the intervention schedule-wise as well as economically. The success of the work is compared to the other sites of the case company.

Keywords Lean, Waste, Construction, Intervention, Measurement

Preface

I got interested in green building and finding efficient ways to do things in the early stage of my career in Varte Oy when I got to work on a LEED-project in 2014. I feel that the long-idle construction industry should take steps to improve the efficiency of the processes it contains. It seems that many people working in the industry have somewhat negative attitude towards the changes that are being made and the usual answer is that some things should not be changed since they always have been done the same, well-functioning way. I wanted to challenge that thinking by doing something to prove them that improving the operations is something that should be done all the time; not only in the company, but also in everybody's individual knowledge and development.

The topic for this thesis was introduced to me by the executives of Varte Oy in pursuit of improving the efficiency of the operations in the company. The company was interested in developing their operations in a way that includes less waste in everyday operations. My supervisor Professor Olli Seppänen from Aalto University helped a lot with the specification of the topic and with the contents of this thesis. He also had expertise about the topic and offered additional tools, such as iCONS-system, to my disposal. I thank Prof. Seppänen for the help I got. The findings of this thesis will also be used to hopefully further develop the industry and therefore I will offer the gathered data to Aalto University for further analysis.

I would also like to thank Mr. Kärkkäinen for the help in starting my thesis in the right direction from the very beginning. The insights that I got from him helped me to modify my idea into an actual executable research.

Varte Oy was the main financial contributor to this work and was therefore entitled to any findings that were included to this thesis but also the findings that were found outside of the scope of this thesis. The rest of the financing was done by me.

A large thanks goes to the management and all workers of the construction site Peltolantie 36; especially to the two workers that initially agreed to be filmed during the research: Heikki Syrjä and Jani Siven.

For the iCONS-system, I thank Mr. Jianyu Zhao.

For additional help with logistics I thank my little brother. For the understanding with long nights and motivation through desperate moments with this thesis I thank my significant other!

Espoo 27.5.2019

Hans-Johan Pasila

Hans-Johan Pasila

Sisällysluettelo

Markings

mAh	[mAh]	milliampere hours

Abbrevations

BIM	Building Information Model
CPA	Construction Processa Analysis
CW	“Contributory work”
GDPR	General Data Protection Regulation 2016/679 is a regulation in EU law on data protection and privacy for all individuals within the European Union and the European Economic Area
iCONS	Indoor positioning system created by Aalto University, Business Finland and a consortium of few Finnish construction companies
Kaikaku	Japanese term, roughly translated as radical improvement
Lead time	Overall time of a single process from start to finish
Lean	
LEED	Leadership in Energy and Environment Design
Muda	A Japanese term that translates into English as “Waste”
NVA	“Non-value-adding”
NWR	“Non-work -related”
PPC	Percentage Planned activities Complete
OMS	Operations Management System
VA	“Value-adding”
QMS	Quality Management System

1 Introduction

Construction industry is one of the largest industries in Finland. A study conducted by Rakennusteollisuus in 2013 (Rakennusteollisuus, 2013) informs that the gross revenue of construction industry is about 29 billion euros. Construction industry is also one of the biggest employers in Finland offering work to about quarter of a million people (Rakennuslehti, 2019). If added with the people who are affiliated with construction of maintaining the built environment, the cluster offer work to more than half a million people making it the largest in Finland.

According to Rakennusteollisuus (2013) and Statistics Finland (2019) the development of costs in construction industry has been steadily incremental since the early 2000's as can be seen in figure 1. This increase can also be seen as the rising prices of new apartments (Statistics Finland 2017) presented in figure 2.

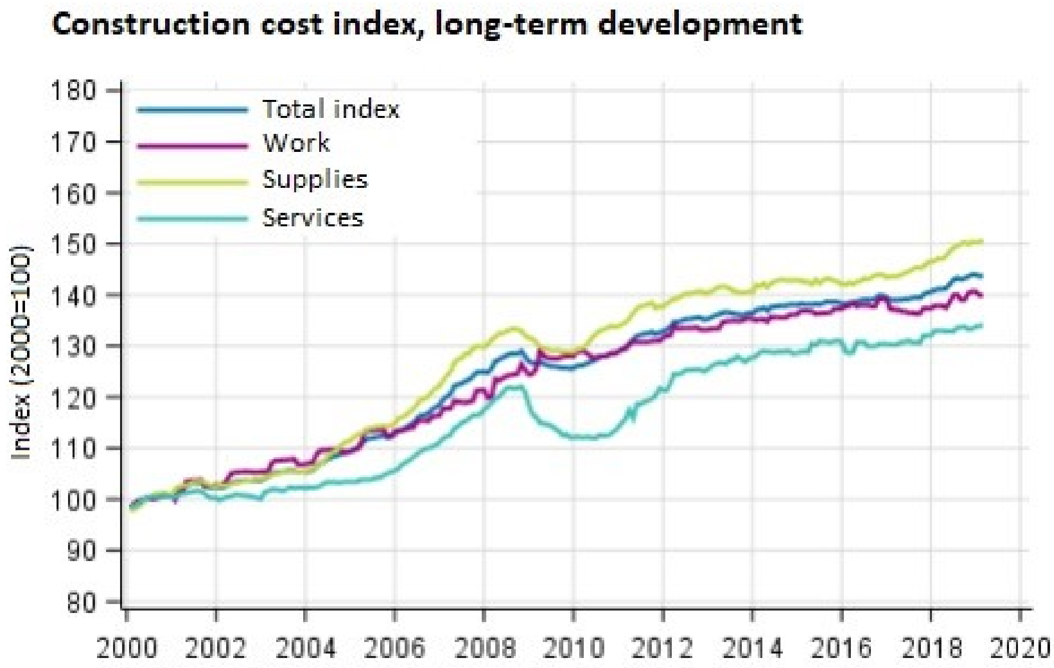

Figure 1: Construction cost index by Statistic Finland in Feb 2019

Figure 2: Price index of new and old apartments analyzed by Statistics Finland in Dec 2017

With rising costs comes the need to be efficient with the given time and money. In every construction project the effectiveness of the work plays a big role. The lead time of a construction project is usually the defining factor with any developer so therefore it is a crucial factor to any main contractor to uphold. In an article Junnonen and Kankainen (2007) pointed out that the developers pursue shorter lead times in their projects which raises the need for improved production efficiency and therefore, removal of non-value adding (NVA) processes of any kind from processes. Although the removal of anything that is not producing value to the customer should be a default function in every project, the changes do not seem to come easily. Why is it so?

An article was written in Finnish newspaper *Helsingin Sanomat* (2, 2017) in which discoveries of the present situation in construction and possible reasons for the long-term static situation in construction were examined. Professor of industrial engineering and management Harri Haapasalo from Oulu University states in the article that in the big picture the development of the industry is not deemed important since the customer always pays the price that is set by the developer or the contractor. The totality of the situation is therefore not viewed from the perspective of improvement since with this viewpoint, it is not needed by the members of the industry. There always seems to be someone who pays, whatever the price.

In that same article, a point is made about the challenges of changes in construction industry. Similar viewpoints are presented by Koskenvesa & Koskela (2012) who found in their study of the state of Finnish construction industry that even if the positive effects of new tools were introduced, people still had difficulties to adapt new methods into their working. "People seem to be happy staying in a comfort zone where people generally don't need to learn new things and therefore don't change." (Koskenvesa and Koskela 2012). Similar observation was made by Junnonen and Kankainen (2007) in their study of changing field of construction in Finland. They found that even though companies are investing in new policies, still a lot of resistance towards any changes can be found.

New tools of improvement include a method called lean production. Lean production, also known as Just-In-Time (JIT) -production, was developed by one Taiichi Ohno in 1950's aided by among others Shigeo Shingo and Hiroyuki Hirano (Santos et al 2006). Lean was originally developed to the manufacturing industry but has since been translated to construction industry as well. The way for lean to enter construction industry was paved by one Lauri Koskela in 1992 (Alarcón 1997). The focus in lean is in the elimination of all non-value-adding processes, also known as waste or *muda*, by organizing the production system into well-working flow which enables not only efficient production but also effective flow of information, and also in the overall pursue towards perfected processes. Lean as a production method strives to meet the needs of a customer with minimal use of everything (Aziz & Hafez 2013).

Even though, lean production methods have been evolving from the 1950's until today steadily worldwide, for some reason construction industry has been somewhat stagnant for the past 40 or so years in Finland compared to other industries as can be seen in figure 3 which represents the growth of productivity in three different industries; manufacturing, construction and commercial (Tilastokeskus, 2018). In the past decades there has not really been a real improvement in the productivity in global construction industry either even though many efforts have been made to offer the people of that industry tools to improve themselves along the industry (Aziz & Hafez 2013). In the figure 3 one can see the effect of lean entering the construction industry, but the ardor has since then faded and currently the industry is in the same place where it was before lean was introduced.

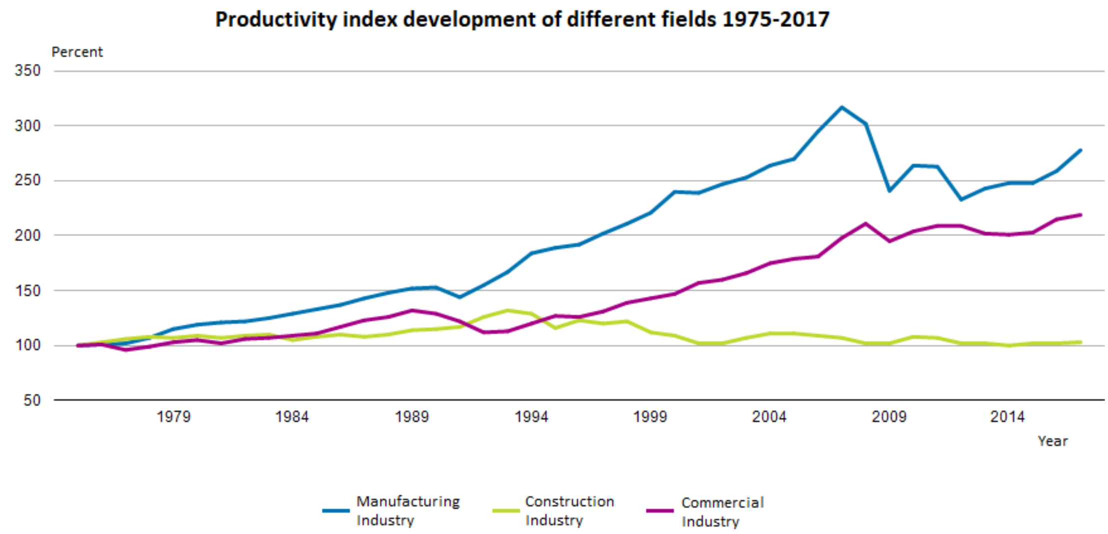

Figure 3: Productivity index of three different industries in Finland in 2015

Probably one of the biggest reasons for such non-progressive way of working was explained by Koskenvesa & Koskela (2012) previously, but a question can be raised from this: is it really that hard to introduce new methods to construction industry? One thing that was pointed out by the research made for this thesis was the fact that everyone has the necessary tools to do the change at their disposal. So why not use them?

Productivity seems to be in the center of many studies, but what if the productivity in construction is not such a big of a problem? What if general opinion is distorted with bad measurement data gained from lacking measurement methods? Opposing viewpoints to the governing spirit where there is a growing need to improve the efficiency of construction processes have also been made. Kalsaas (2010) proposes a viewpoint in which the estimates of value-adding (VA) and non-value-adding (NVA) activities of a project are questioned. The intent of such claims is to question whether low productivity is a real problem or if it is used purely to sway the overall politics in construction towards particular interests.

The goal of this thesis is to conduct a study of the construction processes of a single construction company in Finland through a case study. The aim was to identify *muda*, waste, from a residential construction site and to find ways to minimize those wastes. This research would study the overall division of waste generated on a construction site and find out the affiliations they have with each other so that all possible aspects can be considered. The research is carried out with the production rate of the work in focus and none of the affecting factors such as personal working moral are considered as factors in it since the same persons and their conducted work will be researched throughout this thesis. Of course, a goal was set in the beginning that the studied workers should have at least somewhat medium-high to high work morale so that proper information can be acquired. Also, this thesis does not include study of penchants of small impact of the workers that agreed to take part in this research for they are irrelevant to the study. The larger ones will be included since they might have a large effect on the conducted work. What was considered as a factor for the success of this thesis was the personal competence factors of the participants such as experience and proficiency concerning the studied work phase. These factors can also have a large effect on the result of the study and were therefore considered as important element in the conducted research. Once the wastes and their reasons are figured out, an intervention is planned to deal with the minimization of the biggest sources of wastes and all partial factors of other wastes that are connected to the selected waste. By going through these steps, the hypothesis of the research is that by decreasing the generated wastes there will be savings in schedule and costs but also increase in the quality of the work as well as the speed and well-being of the workers involved.

2 Factors in Project Success

The difference of construction industry and other industries such as manufacturing industry is that even though there have been big leaps of improvement in manufacturing industries the construction industry seems to stand still (Lee et al 1999). Why isn’t everybody in construction taking first steps towards improvements as well? Costa and Formoso (2003) feel that the problem in construction industry is the lack of convenient performance indicators and measurement methods which prohibit the management from seeing the possible positive effects of improvements. Similar discoveries were made by Alarcón and Serpell (1996). Traditional measurement systems for construction process performance are not comprehensive enough to properly integrate lean to processes. Without proper measurement data it is also next to impossible to see the portion of non-value-adding activities in processes. These problems combined do not offer adequate information to the management for them to make corrective actions based on valued data. Lean is a powerful antidote to wastes of any kind (Womack & Jones 2003), but to properly work, commitment from every participant is needed.

In construction processes the dominant drivers for performance are different forms of rewards and punishments which work as the framework for the performance. Instead of striving for glory or evading daunting punishment, the assimilation should be towards finding better ways to perform in daily tasks or processes as Alarcon and Serpell (1996) explain. This would be the first step towards lean thinking. Significant factor in non-progressive way of thinking might be the dominant belief of current measurement of success in construction. Alarcon and Serpell (1996) explained in their study how the overall improvement endeavors are often overlooked while the management is focused more to the singular reasons, often persons, of successful or failed executions of work phases. This kind of thinking can be viewed narrow which leaves much of the actual reasons and possibilities outside the scope.

Zhao & Chua (2003) point out the importance of managerial experience in the processes. Management is prone to find easy ways to do work which can be viewed as a lean approach but is not really that. Costa and Formoso (2003) point out the high probability of managerial decisions made without proper calculations of any kind. This phenomenon is strengthened further when management is mitigated in pursuit of resource optimization. If site managers are prone to minimize the resources used on the site to do the work, Zhao and Chua (2003) point out, that the construction companies are prone minimize the management resources on projects in pursuit of cost savings. Both of these solutions aggravate the problem if the remaining resources are not experienced enough to perform their daily tasks.

Openly and on-time delivered information is also a strong tool in lean philosophy if used correctly. A problem lies in the late information obtaining which feeds the decreasing possibilities of taking corrective actions (Alarcon & Serpell 1996). For the work flow to be efficient, the information must flow alongside it efficiently to all parties involved in the project. Information-related problems in productivity also rise from the deficiencies in the learning processes. Ebbesen (2004) also points out the obvious problems that are the repercussion of undocumented discoveries and improvement-based learnings. When the flow of information breaks between projects caused by the dispersing participants and poor documentation, the learning process must start all over again in the next project. This restart also prevents the efficient harnessing of the accumulated knowledge from the previous projects (Ebbesen 2004). Koskela (1993) describes construction projects as unique projects with their own peculiarities. That being said, every project may contain problems that can be transformed into opportunities for the following projects with similar aspects, if solved. In other words, the solutions generated can have an improving effect on the next project, but the key factor in this is the documentation of monitored information.

3 Productivity of Work

Good productivity of work is a working combination of many factors. Success is dependent of functioning flow of work, information and material, of comprehensive supervision of work and above all else; commitment. The processes between different parties of a project should be in harmony (Aziz & Hafez 2013) and they should offer each other tools to gain best possible outcome in every situation. At the same time all non-value-adding processes should be minimized. In construction it is important to strive towards a situation where value is created with minimal losses, in minimal time and with as little costs as possible; for everyone. Arora (2004) has listed some ways to improve productivity in different processes and that listing can be applied to this research. The list itself is generated to serve industrial processes, but some of the methods can be applied to construction as well. Construction-related or adaptable to it methods from Arora's list are:

1. Elimination of waste
2. Usage of improved technology
3. Better production desing
4. Better management efforts
5. Improved utilization of resources
6. Reduction of inventory size
7. Better leadership management
8. Decreasing wastevity

Many studies (for example Lee et al 1999, Formoso et al 1999, Picard 2002, Zhao & Chua 2003) have been pursuing the identification of value-adding and non-value-adding operations in construction projects, but not so many have been focusing on the production rate and efficiency measurement. According to George (2010) lean methods are effective in waste elimination in processes, but he explains how companies still fail to maintain the gains since the process variation is not directly affected via lean methods. Picard (2002) points out that to improve the productivity of the work, managers should strive towards a situation where the decisions made on the site are made to offer the workers better and easier ways to conduct their work. Picard (2002) continues to add that in order to work the variability of the processes should be decreased drastically. Variability on processes is therefore one critical factor and should thus be minimized to ensure the full capacity of lean methods to function and to enable higher productivity. One tool to variability minimization is to use flow-thinking.

Flow of things can be viewed in many ways such as flow of scheduled tasks or flow of process and of course, also as a flow of information. The point of flow-based thinking is to enable the process visualization in a more logical sense. Flow charts can be made based on the product flow through a system (Lee et al 1999) or process flow through a product (Seppänen & Kenley 2005). Flow of different processes is held in great importance when it comes to process optimization and improvement (Lee et al 1999, Formoso et al 1999, Seppänen & Kenley 2005). The flow of construction projects could possibly be increased quite much by integrating a continuous learning process to it. Ebbesen (2004) found out that one of the reasons suppressing the growth of construction industry is the lack of documented information. When the great potential of previous findings is lost during or after a project or a part of it, it can be hard to compare changes in processes. Another big problem is also the fact that without proper documentation, all possible improvements can be harder to present to the following teams. Of course, if that is not possible nor is the company level learning.

Flow is also particularly important in work planning to prevent unnecessary fragmentation of the work. Kalsaas (2010) explains the consequences of variability from the perspective of a worker as something that force a new beginning in the learning curve of working methods. Long-duration work enables the workers to learn while doing and that can have an accelerating effect on the conducted work. If work is halted before it is finished, the workers are forced to return and start the learning all over again. These changes in projects cause time-consuming actions for the workers and therefore schedule delays for an entire project. Fragmentation of work should be avoided, and it can be prevented by good production planning as well as proper resource and schedule planning.

Comprehensive supervision of the work on the other hand plays a big role in the monitoring of the successful execution of the planned flow and in the merging of the new methods into the general processes; making the new methods as a new norm. Without supervision, there is always a notable risk of working methods to revert back to the old tracks after some time has passed. This in turn will reset all changes made and return the situation back to the original starting point which is not the preferred result. Zhao and Chua (2003) also elevate the importance of communication in any project. They point out the importance of well-prepared designs before the work is started, which usually is left to the responsibility of the responsible manager of the work phase. By planning the work and properly informing all related parties before and during the process major problems can be avoided and the possibility of non-value-adding activities mitigated.

As we later come to see in the case study, the actual productivity of the workers is not always the problem even though much can be made to improve the overall productivity of the work. Managers of the work can play a big role in the improvements and the decisions made by the management play a big role in the execution of single work phases and via them, in the success of entire construction projects.

3.1 Measurement of Productivity

As previously mentioned, one major problem for new improvements in construction is the lack of suitable measurement methods for the performance of different processes (Alarcon & Serpell 1996). Continuous improvement in productivity requires better indicators that those familiar to the construction industry; costs and schedules. As Alarcon and Serpell (1996) explain in their study, the former is not capable of measuring losses in productivity and lacks in quality. Similar findings are presented by Lee et al (1999) who specify in their study the lack of proper measurement methods for waste and value of a process. They feel that the present tools are not sufficient for the distinguishing of value-adding and non value-adding operations.

According to Zhao and Chua (2003) another problem in productivity measurements and the non-value-adding values might be correlated with the experience of the management. Kalsaas (2010) also points out that by analyzing the time consumption habits of skilled workers one can acquire a rough picture of the managerial and organizational skills in construction projects. The most commonly used measurement parameters according to Alarcon and Serpell (1996) are the following:

- Actual cost of the project is compared to the budgeted cost
- Actual man hours are compared to the budgeted man hours
- Actual duration of the project is compared to the planned
- The productivity of labor
- The productivity of equipment
- Overall profit of the project
- Accident frequency rate
- Progress measurement

These parameters can be used periodically or at completion of separate tasks. The problem is that none of the above can be used to monitor the progress in real time or in such way that represents the situation of a single process at any given time.

Alarcon and Serpell (1996) proposed in their study a set of different measurement parameters for the better measurement of different aspects of processes as a set of tools. These parameters contain, among others, the study of cost variation, schedule variation, labor hours, the productivity analysis and amount of rework conducted in a process. The goal of this parameter collection is to allow a generation of vast databases which can later be used to analyze later results with improved accuracy and to generation of further improvement models. All of that information can also be used to analyze the successful and failed sectors of different construction processes.

Lee et al (1999) introduce a process called Construction Process Analysis or CPA as a solution to study and define the reasons for problems in a process. In CPA, a process chart worksheet is used along with a plan view of the flow diagram. This solution is more manufacturing oriented, but it can be adapted to serve the visualization of a construction process.

3.2 Measurement of Value in Processes

There are many ways to measure the work on construction sites, but the most effective ways to gain information depend on the goal of the measurement. The method should be selected with the wished result in mind. Interviews and visual inspections seemed to be quite popular in studies made in the construction sites to research different factors of production in their different forms.

Zhao and Chua (2003) presented a measurement option where they measured the value-adding and non-value-adding operations by interviewing the participants in a construction project and collecting data with weekly log sheets filled by the management on the site. The amount of documented portion of value-adding and non-value-adding varies depending on the measurement method; in some cases, quite lot. Zhao and Chua (2003) presented previous findings of the proportion of value-adding activities in a construction project to fluctuate from 46% to 3% of the working time. The fluctuation is caused by the different viewpoints of what it considered as value-adding activity. In any case, no matter what study is examined the common finding is the domination of non-value-adding activities in processes.

Josephson and Saukkoriipi (2007) found in their studies that the amount of actual value-adding work consisted of only 17,5% of the total time of the work. Contributory (CW) and preparation work had a portion of 45,4% and all the non-value-adding work 33,4%. They studied construction workers in general in a case study. These numbers do not include the time spent in personal matters such as break times. Another study conducted on a construction site in Norway was done by measuring the activities of three different contractors (Kalsaas 2010) with visual measurements during the conducted work. The measurements were made during a total of eleven work days by students marking the activities of each operator every five minutes. The results showed a combined activity time of 49,1% of the total time of work. Study of processes in a processing facility the amount of value-adding work was found to be 29% by conducting work sampling with two observers (Jenkins & Orth 2003). Findings in a construction project proposed the productive time of workers to be 30% (Forsberg & Saukkoriipi 2007).

A mean value for value-adding work can be calculated from the previous studies to be about 25%. There is variation between given values but the differences in the shares of value-adding work can be explained with multiple different ways to divide the collected data. In many studies, the work conducted by the workers is divided into three main groups added with additional groups, depending of the study (Womack and Jones 1996, Lee et al 1999, Zhao and Chua 2003, Jenkins & Orth 2003, Kalsaas 2010, Kalsaas 2013). In many cases the three governing groups are the following:

- Value-adding (direct) work
- Contributory (indirect) or supportive work
- Non-value-adding work also known as waste

These three groups well summarize the measured work into main groups that can later be divided into more accurate groups if necessary; depending on the targeted result.

3.3 Concept of Waste

Shingo (1984) describes waste to be the other half of activities with operations. Operations in general are divided into two separate characterizations; with and without additional value. From these two the latter can be viewed as waste. Waste is described by Shingo to be something that is "entirely unnecessary for performing operation". Shingo (Santos et al., 2006) explains the way to divide waste into seven separate classifications. These classifications have their individual characteristic contents based on the form of waste. Shingo originally classified waste to be caused by

- overproduction
- inventory
- transportation
- defects
- processes
- operations
- inactivities

From this seven-part list, the most important waste to be considered in factories by Shingo is the waste of inventory which is the best way to identify a poorly working factory. In construction projects inventory is something that can be seen as waste, but it can also be a sign of a well-functioning construction site where the work phases have been considered in advance. It is not uncommon to see materials being lifted to the floors even if no one is going to be using them immediately after they have been moved.

Hiroyuki Hirano (Santos et al 2006) describes waste as "everything that is not absolutely essential". All non-value-adding or unnecessary actions are deemed as waste in processes. Hirano (2010) points out the fact that waste can be viewed in multiple ways and is therefore hard to define precisely. The concept of waste can alter between different observers and can therefore complicate the process of identification of value and waste. Hirano (2010) approaches the definition of waste by separating so called useful activities of a process from those that can be considered as non-useful or completely useless. This division offers a possibility to divide everything into activities that are or are not adding value to the end product. Sources of waste are divided in the figure 4 according to their origin and as it can be seen. The figure is constructed based on a viewpoint of manufacturing industry, but it can be used to visualize the waste structure of construction industry as well; with some alterations but maintaining the same topics.

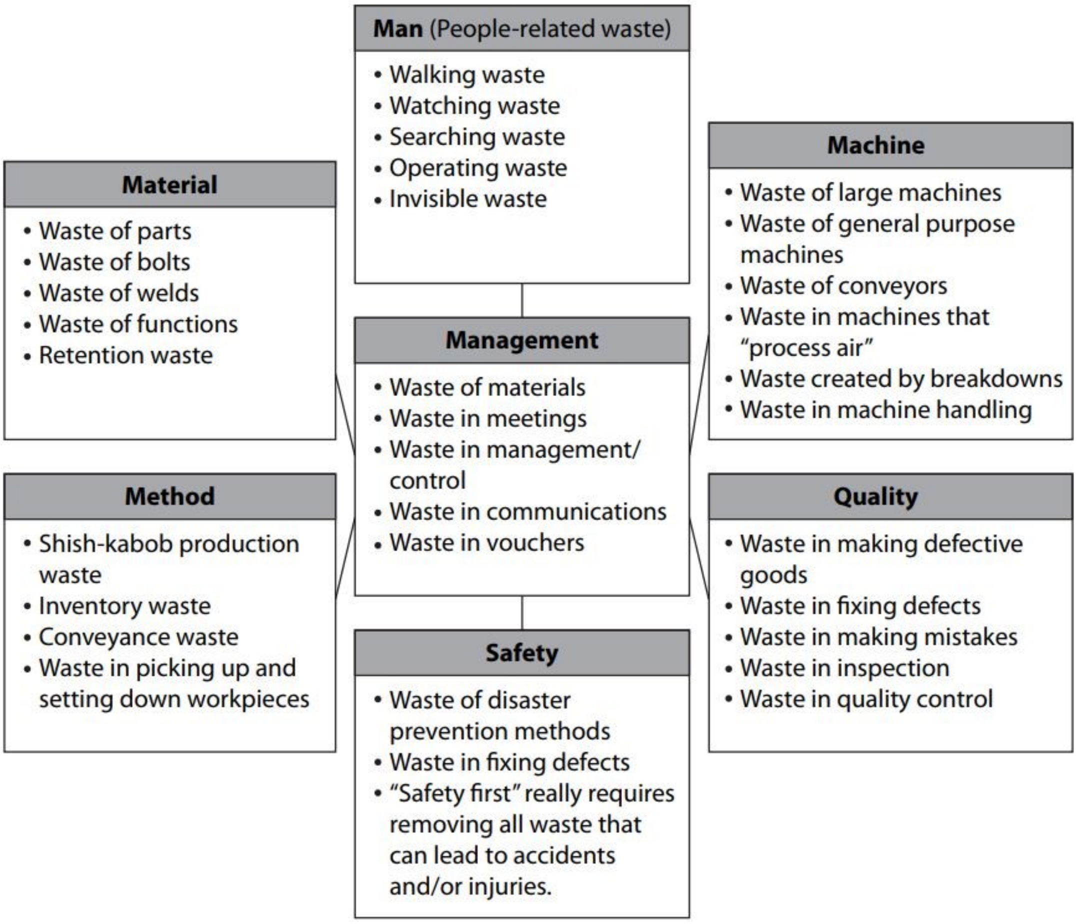

Figure 4: Sources of waste by Hirano (2010)

Lee et al (1999) sums waste in their study to consist of delays in the conducted work, excess costs caused by the desired quality level, shortcomings in work safety upkeep, excess or unnecessary movement of materials and people, unsuitable working method, lacks of managerial actions, bad or faulty equipment and low or lacking constructability of the work itself. One reason for waste is also rework, that is usually caused by mistakes during work. Adding to that, Serpell et al (1995) defines waste as something caused by the deviations from a steady process flow. Waste is mainly generated by mistakes or lacks in the management or conversion actions; or from poor flow management of resources and materials. Waste takes two different forms: inactivity and re-work. These basically follow the same grouping as presented in the previous chapter differing only with the lack of value-adding activities.

Kalsaas (2010) on the other hand divides wasted time into two separate groups based on the source of the waste; have the mistakes been made by others or by the project group themselves. Contributing to the first group are the mistakes made by others, unavailable working areas or lacks in materials, information or tools. The second group contains mistakes made during the work and deficiencies in coordination or planning. Waste is generated differently between different work forms (Kalsaas 2010). Different trades report different problems as their main causes of wasted time according to the findings of Kalsaas' study (2010). All of the reasons can be averted or at least their impact could be decreased with proper managerial actions.

Implementation of lean into construction enables the industry to make great improvements but it also entails big challenges such as better identification wastes and their sources (Lee et al 1999). Measurement of waste in construction has transformed more into the direction of barely measuring purely material waste. Formoso et al (1999) made a notion that waste control before the turn of the millennium was more focused on the measurement of material waste. In many affiliations waste was considered to be something caused by the excess materials or unnecessary costs used to further the objective of the matter at hand. Material waste was studied much in particular (for example Garas et al 2002), but what was dismissed though, was the fact that waste is generated in more ways than just with bad utilization of materials. In later studies the focus has shifted also towards the measurement of other causes of waste when the understanding of the concept of waste has widened.

Alarcon and Serpell (1996) presented a viewpoint to the effort of continuous improvement. To get the different parties better involved, they should be presented with the benefits that can be obtained from the processes when waste is removed. The parties should strive in cooperation to identify wastes on the construction sites so that they could be dealt with. To properly approach the investigation, the participating parties should understand that all of the waste sources do not have the same effect to the productivity. Zhao and Chua (2003) suggest that the available resources should be focused on the most significant reasons of waste on the site and this viewpoint will be considered in this study to some extent.

4 The Progress and the Goal of the Study

This study is striving to identify and measure time-waste from a single construction phase. The goal is to enable workers to conduct their work in a more efficient way without too much variation in their work. The study will consist of two separate measurement periods in which the data will be collected and of one break period during which changes will be made and taught to the involving participants of the study. This shifting point will be addressed with a term "intervention" to better describe the nature of it. After the study is finished the goal is to be able to offer the inspected construction company and their workers tools to create a continuous improvement process of their own.

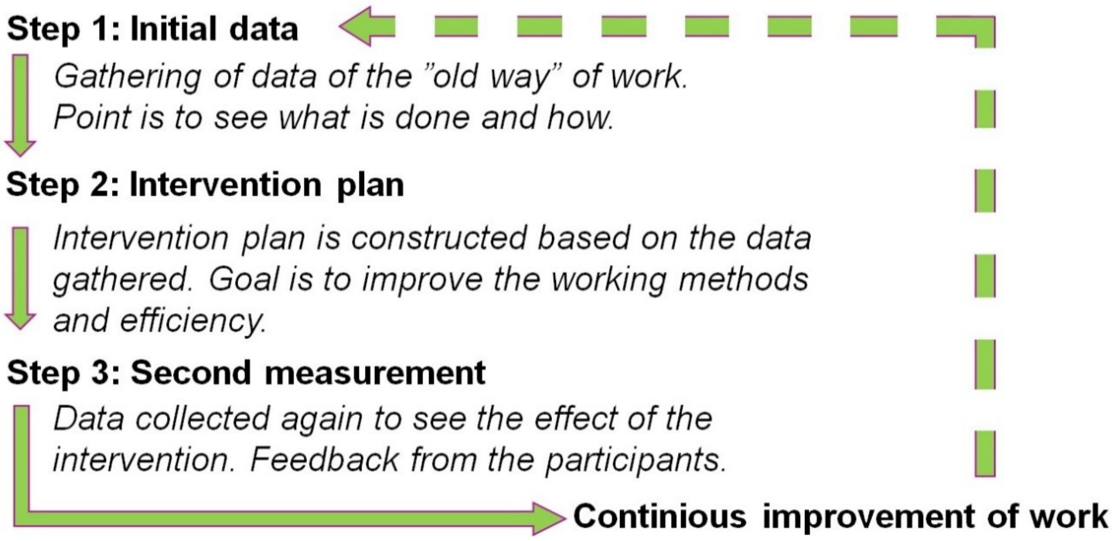

Figure 5: The idea of continuous improvement used in this thesis

The first measurement phase is conducted to record data from the original situation on the site. Considering the viewpoint presented in the study made by Zhao and Chua (2003), the first stage measurement should not be conducted right after the beginning of a completely new work phase, but rather after some time has passed so the initial problems could be set aside and the real problems would emerge more clearly.

The second measurement would take place after an intervention which is explained in more detail in the following chapter, also with consideration of the learning time needed for the workers to fully adapt the new method of working. The measurement technique in the second measurement is to be similar to the first one to ensure the consistency of the two measurements. The studied persons will be the same during the entire study.

4.1 The Intervention

The driving force in the creation of the intervention was the idea similar to a case study conducted by Josephson & Saukkoriipi (2007). They had done waste prevention studies by analyzing what could be done to prevent wasteful actions. The solutions to minimize waste they found were the following:

- Giving training to the participants
- Increasing the amount of planning
- Creating routines
- Supplying resources

In this study these findings were applied with small alterations. The participants were trained to the idea of the improved plan of work and the reason behind every solution was explained while maintaining a two-way discussion to further improve the created solution. An important part of the work phase was emphasized to the management; planning of the work. Planning plays a big role in the overall success of the work and the managerial possibilities in it if necessary, planning is made in the early stages. Without planning there is a risk of decreasing the control possibilities of the work since the work must be planned while doing. This will slow down the process. Through teachings and planning, the hopeful result of the intervention is to create a set of routines for the managers and the workers not only about the studied work phase but also the working manners of each in general. Lastly, the needed resources for the intervention were added from the company management side to assist the managers and the workers in the changes, but in the long run the desire is that the need for external assistance would decrease and through routines the work preparation and execution would improve on its own.

A goal was set for the contents of the intervention plan and that goal was for it to contain needed actions to improve one sector of the researched work. To enable the making of a proper intervention, the data gathered during the first measurement phase should be investigated thoroughly and catalogued with necessary division. By using a proper, clear list of the findings, different waste sources should be identified.

The main purpose of the intervention plan is to offer the management and the workers possibilities to improve their productivity and the control of the studied work phase with lean methods. In lean the purpose is to minimize, if not completely remove, any waste that is generated in the process. Therefore, the identification of biggest sources of waste is crucial for the success of this thesis work. Productivity is a summary of multiple different factors. By increasing one area the total productivity is increased. The input-process-output model is also used to evaluate the cost-effectiveness of the process in the starting point and after the intervention.

The intervention itself is to be carried out as *kaikaku*, which translates into English as a radical improvement. Kaikaku as an action is a contrast to the pursued *kaizen*, or continuous improvement as Womack and Jones (1996) explain. Continuous improvement is targeted to be the overall outcome of this study in the case company's processes after the results are shown to the management of the company, but as for the intervention it will be carried out in short time to ensure an eligible contrast to emerge from the results; as a kaikaku action. Womack and Jones (1996) present a working model for companies to follow to achieve a model for continuous improvement. In their model the companies will repeat a cycle of kaikaku and kaizen. By taking turns in executing each, the companies can improve their operations greatly. This thesis could be the first cycle of that improvement cycle for the studied company.

4.2 Schedule

The starting time for this thesis was originally meant to be during the summer of 2018 but finding suitable working groups for the study turned out to be harder than what was originally thought. This phenomenon is in line with the findings of Koskenvesa and Koskela (2012) about the reluctancy of workers to be part of a learning process. The original plan schedule-wise was that the first and second measurement along with the intervention would have been done during the summer since the weather plays smaller role over the warm season. The variables that must be considered during the winter could cause more work or in the worst-case scenario, distortion in the results. Therefore, the goal was set for the beginning of the fall.

The endeavors of starting the research were started in May 2018 on construction sites located in the metropolitan area. The propositions were made for work groups and companies, but as it turned out the proposition was not well accepted. The problem was that the teams or companies that were asked to join the study misunderstood the point of this research and refused since they thought that the study would have been about their personal working methods and that the results would have been reported to their bosses or that the possible inefficiency of the work would have been blamed on them. This reaction was expected and could have been predicted from previous studies (for example Junnonen & Kankainen 2007, Koskenvesa & Koskela 2012). This of course was not the point of this study, but even if the true point of the study was explained to the workers and to their foremen in detail, they still were reluctant to take part in the research. One big factor in this was that the companies were worried of misunderstandings caused by bad situations on the construction sites and that "the work would not represent their true working methods". In other word, they might have been worried of the possible future co-operation with the case company if their inefficiency was reported to the executives of the studied company even if these bad situations might be the result of bad management of the site managers and not the sub-contractors.

Finally, the chance to conduct this research came later in the fall. On a construction site during September of 2018 the case company's own workers wear asked to join the research. Their work phase in total was meant to last until the next spring so the intervention could be well-planned and executed with sufficient time. The workers happily agreed to take part in the study after the point was explained to them so the research could finally be started in November of 2018.

The first phase of this research would take place during the weeks 41 and 42 in November of 2018 when the selected team would be starting in the first building of the three buildings on the site. The analyze time for the collected material was planned to be two months after which the intervention would be planned and executed on the site. After this another measurement session would be made and analyzed.

4.3 Measurement techniques

Interviews and questionnaires are the easiest way of gathering data, but the techniques contain a large risk of missing or biased information. Even though the target in interviews is always to find answers to possible questions, there is always a risk involved that the interviewees forget certain parts of the conducted work or possibly answer in a way that they think the interviewer wants them to answer. Questionnaires contain a similar problem as far as the reliability of the gathered data would be.

The probability of twisted information could be decreased by asking the questions during the day with mobile devices. This offers the workers to answer the questions further from official organizational environment which can lower the biased approach to the questions (Škec et al 2016). The questions would be asked occasionally during the day in random manner. The amount of necessary questions is calculated from the formula 1 which is also used in work sampling method. The reason this option was excluded from the selection was the low response rate which only at 87,9%. That would leave over a tenth of information outside of the research and as unknown which could alter the overall result in multiple ways.

Another way to measure waste is to observe the conducted work and compile the needed data based on the observations made. The duration of such sampling activity can alter from short duration, as in construction process analysis (CPA), to longer durations, as in work sampling technique. Although CPA can be used to compare similar processes between projects, it is not suitable for construction projects (Lee et al 1999). Though, the basic idea in CPA is similar to that in work sampling method.

Picard (2002) presented a method called 'sampling of work force activity'. In this method random visits are made to the site to see what the productive utilization level of the work force is at any randomly given moment. This method has many aspects that can be used as a guideline for a small-scale measurement of a small team but the technique itself is meant more for measuring the overall productivity of the whole project. Therefore, this method cannot be applied straight to this research.

Work sampling is a measurement technique of activities devised by L.H.C Tippett, an English Statistician, in 1934, is based on the law of probability and is explained by Loera et al. (2013) to be an "indirect measurement technique" in which the measurements are conducted via instantaneous observations. This means that the work that is observed is measured by doing short observations of the work that is done, but in vast amounts. The goal of work sampling is to collect data and amounts of the activities and inactivities of the observed work. By having such data, it is possible to analyze the work from the perspective of observations. The amount of necessary observations can be calculated by using the following formula for relative precision:

$$n = \frac{z^2 * p * (1 - p)}{e^2} \tag{1}$$

in which

- n is the sample size
- z is z-value for the acceptable confidence level
- p is activity use percentage in decimals
- e is the acceptable error percentage is decimals

The z-value is dependent on the selected confidence level of the sampled work and can be derived from mathematics of a standard normal curve. The confidence in general to find the workers doing their work is quite high. Below are listed few confidence levels and their corresponding z-values.

Confidence level	z-value to be used in calculations
75 %	1,15
90 %	1,64
95 %	1,96
99 % (even though unlikely)	2,58

Table 1: Critical (z) values used in calculation of sampling size

Acceptable confident level used is 90% for which the according z-value is 1,64. The error percentage can be set to 5% for this research. The activity time can be assumed to be around 25% which is an approximated mean value of value-adding work time portion based on previous studies presented in chapter 3.2. With these values we get:

$$n = \frac{(1{,}64)^2 * 0{,}25 * (1 - 0{,}25)}{(0{,}05)^2} = \frac{0{,}5043}{0{,}0025} = 201{,}72 \tag{2}$$

This means that a total of 202 observations should be made to gather a comprehensive understanding of the process. This means that for a sufficiently accurate results 202 measurements would be needed from both workers to get an acceptable accurate result by work sampling. Measurements could be conducted during the day between every break

- between 07:00 and 09:00
- between 09:15 and 11:00
- between 11:30 and 13:30 and
- between 13:45 and 15:30

One of the biggest advantages that work sampling can bring is the easy method of measuring widely the productivity of large number of workers (Jenkins & Orth 2003). The information gathered by work sampling method is generated fast and is available immediately after the measurement is done. The problem with the samplings is that it does not function well when the monitored group size decreases since the workers might get the feeling that their work is monitored by a man with a notebook, especially if the monitored team is small. In smaller monitoring groups there is a risk of misunderstandings of the purpose of the measurement. The larger the number of observed workers becomes, the less the workers have a feeling that their individual performance levels are measured and evaluated (Jenkins & Orth 2003).

Kalsaas (2010) suspected the measurement technique where a separate person makes observations during the working day might have an effect on the behavior of the workers. In Kalsaas' (2010) study, observation visits were conducted 96 times per day, every five minutes. Even though Kalsaas (2010) found the workers to be involved and willing, a risk was considered if more than four visits per day were made. More than four visits a day would cause the workers unnecessary distractions in an unnecessarily intense cycle, causing distortion to the results. Of course, the workers might start to wait for the daily visits and stop working effectively after each visit and increase the working rate again just before each visit in each scenario. With lesser visits, the productivity is more likely to stay higher since the workers do not know when the visit will be. With four visits a day the research would require 51 days of sampling and with Kalsaas' (2010) method only three would be needed to gain the same amount of observations.

A far better way would be to combine the previously presented measurement techniques and method to generate a wider selection of data sources. Such solution was the selected approach by Josephson & Saukkoriipi (2007) in their research. They started their research with group sessions and interviews where they identified different sources of waste. The following methods for quantifying the amount of wasted needed adaptation and utilization of multiple different forms of data collection methods; such as interviews, data report studies and visual observations. This approach takes a lot of work and is still not completely comprehensive as far as data collection goes.

A solution derived from the research conducted by Josephson & Saukkoriipi (2007) was to conduct video recordings on the site. Video recordings would not exclude the possibility of interviews, but they would fill in the gaps in information left in the previous measurement methods. Another great aspect with video material is that they could be conducted in much more shorter time frame and in a lot less invasive manner, but still with all the benefits. The only problem with video recordings is the existing knowledge that someone is going to be watching every move of the workers after some time. This knowledge could cause the workers to change their working methods into something they think the viewer wants to see.

Of course, a big factor in conducting video recording is the new EU General Data Protection Regulation (GDPR) which prohibits the video recording without consent and forces the video material to be censored for those parts that are not approved by certain parties. Despite the trouble of gathering consents, the contents of the video material can be used in more ways for their accuracy that this option would be more viable for the research.

With both accurate video and sound it is possible to gather more detailed information to be used in the improvement plan. Without previously mentioned it can be difficult to properly analyze the actions and decisions made by the workers during the measurement periods leaving some of the executed work to guess. With video and sound it is also possible to get closer to the workers when their discussions can be heard. The discussions and the overall speech of each worker can elaborate the decisions made by them before, during or after their work or each part of it. This information can be used to further analyze the video material and to improve the effectiveness of the intervention plan. The use of video material also removes the problematic aspect presented by Kalsaas (2010) where the variation of different stances on what is considered waste is excluded. Video is also one way to avoid possible underreporting of errors made by the workers since everything is visible during the whole time of measurements.

The necessary time for video recordings was based on the conclusions made from the work sampling method. Kalsaas' (2010) method would requires only three days to conduct a proper sample size based on the Tippet's formula. When taking into account that when conducting observations with Kalsaas' (2010) method and even if the observation took about one minute to be written down and categorized it would still leave about four-minute gaps in the gathered information. Video material from the same three-day duration would cover those gaps as well causing the gathered material to cover at least five-time longer sampling duration. Therefore, to cover the calculated sample size of 202 observations calculated with formula 2 the necessary length of video material would be about three and a half hours; assumed the observations take about a minute to make. Of course, the necessary time of video recordings cannot be derived straight with such reasoning, but the number is to offer some perspective between sampling methods and video recordings.

To enable proper data collection, the needed material needed to be more than what would be gathered with work sampling and more accurate to the real situation. The workers should also be allowed to adjust to the fact that they have cameras on their helmets, so the required time of the video recordings was set to be 5 workdays in both sides of the intervention during a two-week timespan. By collecting material for two weeks, it is possible to gain an understanding of the on-going work with analyzable accuracy. This collected data would then be analyzed with precision and categorized based on the actual actions performed by the workers.

The selection between work sampling and video recordings was made based on the accuracy of the gathered information and on the comprehensiveness of it. The video recordings were deemed superior to the work sampling in extent and possibilities but also in the duration of the actual research work.

4.4 Equipment

The equipment for the planned video recordings needed to be small, as least invasive and as light weight as possible to ensure the well-being of the workers. Different solutions were investigated with two suitable options for further study; body cameras or helmet cameras. The camera system needed to be able to film the work from a decent angle so that the material could be analyzed properly. The idea for a body camera came from those used by the police and for the helmet camera from the active sports such as skiing. In both cases the point of a camera installation is to keep it out of the way and allow the user to perform their actions without disturbance from the equipment, but at the same time filming the performance as well as it is possible.

A major problem with the video recordings came up with the duration of battery life in most cameras. The searching for a camera with more than eight (8) hours of battery life turned up nothing. The best filming time with decent quality with the smaller body and action cameras was only 2 hours after which the battery would have been needed to change. This was something that had to be avoided since the goal for the use of cameras was that the workers should not have to perform any actions with or for them.

The next step was to find suitable solutions to enhance the duration of the battery life. This also turned out to be harder than what was thought. Most of the camera manufacturers had not planned the cameras to be charged during the use of them. After multiple phone calls and e-mails a solution was found with a decent price. Garmin® produces small action cameras that can be charged during filming. These cameras were then equipped with 12 500 mAh external power supplies ensuring a filming time of 14 hours.

After all technical problems around the video recordings were solved it was necessary to construct a proper setup for the worker equipment. The weight of the cameras was countered by the weight of the battery when placed on the opposite sides of the helmets generating an installation that was functional but also ergonomic. Another important factor was that the height of the installations should not exceed the regular height of the helmets since it could cause the workers problems, especially in narrow spaces. Therefore, great care in the installations was used to produce a setup that causes as little of disturbance as possible while minimizing the awareness of the cameras in everyday work. The finished product that was used in the video recordings is presented in the figure 6.

Figure 6: The camera system on workers' helmets during the video recordings

4.5 Division of gathered information

The information of the measurements must be divided into different categories in order to get comparable information from each day separately. The categories should represent the gathered data sufficiently and they should offer a possibility to reliable data comparison. The division of data clarifies the data for a proper analyze. As others (Womack and Jones 1996, Lee et al 1999, Zhao and Chua 2003, Jenkins & Orth 2003, Kalsaas 2010, Kalsaas 2013) had divided their gathered data according to the studied process, so was the goal in this study as well.

The video material of each day needs to be inspected carefully and divided in Excel-tables based on the tasks done. The accuracy of the data division is not completely in the aspiration of lean philosophy since such categorization would require enormous work and that would be beyond the scope of this thesis. Alternatively, the accuracy was dialed down to a level that would still offer acceptably accurate data for this study and would conform the limitations of lean philosophy. A decision was made to divide the collected data into fourteen (14) separate groups; all based on the viewed actions or work. Though, the division of the groups were quite accurate, each of them still contained some additional actions such as small movements or operations. The exactness of each measured task was acceptable for the requirements of this thesis. The data was divided into the following topics to function well on a construction site:

1) Actual work
2) Inspections
3) Measurements
4) Work preparations
5) Working with materials
6) Planning
7) Work related discussions
8) Installations
9) Cleaning
10) Movement
11) Maintenance
12) Re-work
13) Searching and handling
14) Non-work -related (excluding break times)

With this division of gathered information, the information is divided according to the conducted work and is easily understood by all participants. Also, with clear contents and limitations this division is considered valid for this study. The topics are elaborated in the following chapters.

The division was divided into three main groups as were presented in the chapter 3.2; value-adding work, contributory work and non-value-adding work. The division was based on the evaluation of the value-adding activity in each topic and their division is presented in the figure 7. The two value-adding activities in this study are the actual work itself but also the inspections that are made of the finished work. With inspections the probability of unnecessary actions is reduced, and the quality of the work can be improved. The topics from three to nine can be considered as supportive tasks and as Jenkins & Orth (2003) point out supportive, or contributory, work is defined as something that maintains the productive work. Lastly, the topics from eleven to fourteen were considered as non-value-adding work for their deficiencies in value-adding capabilities.

As can be seen from the figure 7, one topic is regarded as something that is contributory work but also non-value-adding work. Movement is considered as one topic in this thesis, but it can be divided into two topics; movement with or without materials or tools. The first one of the two is considered as contributory work and the latter as non-value-adding work.

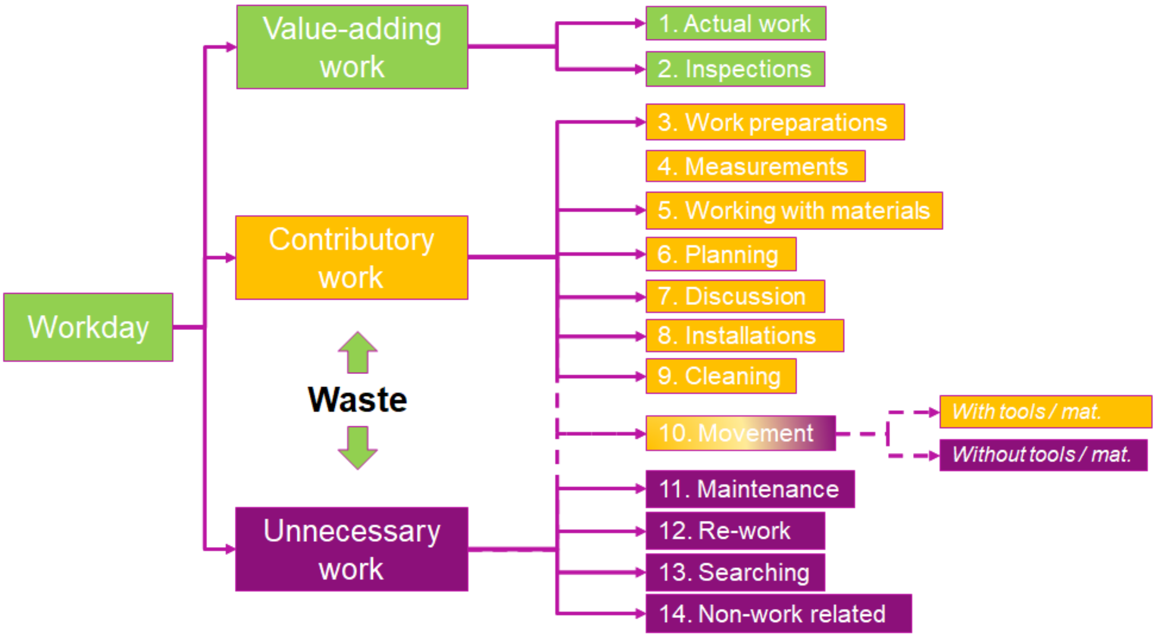

Figure 7: Division of workday time in respect to Shingo and Hirano

4.5.1 Actual work

Shingo (1984) classifies operations in processes into two separate segments; one that can be considered as value-adding action and another that is not adding anything to the value. In processing sense of the construction industry, the first one can be perceived as actions that are participating to the transformation of materials into something that can be held in value in any way. In construction value-adding actions are those that increase the value of the end product; a building or a structure of some kind. The latter of the two classifications in construction is basically all the rest of the actions made by any worker on the construction site. From these two classifications, the first is considered to be the most valued part of the process. Therefore, it is necessary to try in every way to increase the quantity of the value-adding work in every process by decreasing the rest. By doing so, the actual amount of the value-adding activity is not increased, but the wasteful actions are decreased. Therefore, it is important to strive towards decreasing of the different wastes in construction processes; although the process of decreasing waste can be a tricky project to take on.

Hirano (2010) takes a somewhat more drastic approach and explains value-adding activities through an example of fastening a screw. In his example the only part of the value-adding activities in the fastening process is the last turn that tightens the screw into its base; everything else is considered as waste. This viewpoint is too specific for the scope of this thesis and therefore alterations had to be made to classify the class of "Actual work". This class was decided to keep the value-adding work as its own topic to collect everything that can be viewed as such, although, the frame of value-adding work was extended from Hirano's definition to a slightly wider definition.

In this thesis the value-adding work is considered to consist of all the work that is made to increase the value of the target building or a building part. To keep the scope of this thesis within reasonable limits, the following work phases that are conducted during the suspended ceiling and drywall assembly were considered to be part of value-adding activities:

- The final fitting of the part to its place
- The fitting of a screw to the drill head
- The attaching of the screws into the parts
- The checking of the laser lines with hand when fitting the part to its place
- Tiny adjustments made to the material while working
- Small movements to get to the place where the next fastener is to be installed, movement with work platform included during screwing and attachments
- The assisting work with the teammate if the work at hand requires two pair of hands

I decided to include the tasks mentioned above since the accuracy and the purpose of this thesis are fulfilled with this kind of definition of the term “actual work”. The accuracy of the actual work compared to the exact interpretation of value-adding work is considered to be close enough to actually offer useable information for the intervention and the post-intervention study of the work phase.

4.5.2 Inspections

Inspections were divided into a separate topic for they do affect the outcome of the productivity. Josephson & Saukkoriipi (2007) determined checks and inspections as a waste, but in their study this term has a slightly different meaning. In addition, in this thesis the inspections are made to ensure the quality of the work and remove the re-work risk, thus upholding if not improving the productivity of the work. Inspections allow the workers to learn from their work as well which has a positive effect on the work. Although the effects might be visible only after a longer duration, the immediate results are the minimizing of the unnecessary visits to re-do something previously done. Also, inspections allow the management to conduct their inspections with better success rate which also minimizes the re-work and movement required to ensure that the qualification requirements are met. Managerial inspections after the workers are done might be considered as waste but in the case company’s case these inspections are made with the following contractors to officially approve the areas to be ready for their intended work. Therefore, in the company’s sense this is acceptable waste that has schedule and quality effects in a longer run. Managerial inspections are not measured in this research.

Inspection is considered to happen when the workers are clearly inspecting the rigidity or the quality of their work after an installation. Inspections might happen with tools or by visible checking.

4.5.3 Measurements

A topic was needed for the work that precedes the actual work and the material work. Necessary actions to enable these are the measurements made by the workers from the structures. Measurements are usually made by using steel ruler, but they can also be made by using other instruments such as laser measuring device. Measurement as a topic contains also the necessary writings that are made in a notebook or similar to help the worker in the following actions. This topic also includes the necessary small movements to allow the worker to properly measure larger assemblies of needed materials. Measurements are considered as the first topic in the contributory work section since this topic contains actions that can be considered as preparations for successful installation. Also, to point out that with more accurate designs the amount of measurements can be lowered to a certain extent. In the case project, the only premeasured parts were the verticals of the drywall frames.

Planning actions were not included into this topic since they are completely different kind of work and should be inspected separately from this division. The separation between planning actions and pure measurement actions were made based on the determination of the worker and the fact that while the workers were doing measurements for certain parts, the destination for their actions was clear from the videos. The difference between planning work and planned measurements can be seen from the videos clearly enough to separate the two.

4.5.4 Work preparations

This topic contains all the required preparations needed to allow the workers to start their work properly. Work preparation actions were included in this topic since they can be considered, along the measurements that are made, to be part of the preparing actions needed for successful installations. Josephson and Saukkoriipi (2007) included every type of preparatory work happening in the near vicinity of the actual work place into a topic such as this, but for the accuracy offered by the video material and the time that can be used to analyze the videos, the definition of "work preparations" was chosen to be more specific to the name.

Work preparations includes all the small movements, tool gatherings and material handling in the immediate vicinity of the workplace so that the worker is not actually moving more than couple of steps to pick up tools or materials. If the worker has to move longer distances, work with materials to make them fit or to, for example, take measurements to ensure the fitting of the part, they are included in different topics. This topic contains only the actual preparatory actions taken by the workers just before the actual, value-adding work can begin.

4.5.5 Working with materials

This topic was constructed to include all the work that is put to the materials before they are installed. Since the project was not using any BIM-models, it was next to impossible to order the needed materials pre-measured and pre-cut. Therefore, the site had made a decision to order bulk materials which were meant to be cut to the right size on site along the progress of the work. This category contains the following actions:

- Acquiring of the material from a storage area
- Measuring the necessary parts at the place of material work
- Marking the cutting places to the parts
- Cutting the material to the right size
- Finishing the edges of the material if needed
- Making necessary inlets or holes to the parts
- Trimming the edges after the material is attached to the designated place

This category will inspect the amount of work put to the material before it is possible to attach it to the designed place. The steps presented above are included into this topic to keep the scope of the thesis similar throughout the research work without going into too much detail. Material work does have multiple different steps that could be divided into more accurate topics, but for this thesis, this subject was decided to be wider yet accurate to the ideology of lean.

4.5.6 Planning

Even though Kalsaas (2010) had defined planning as a value-adding activity, in this thesis another viewpoint is used. Planning is considered something happens that should be done before the work phase can start as much as possibly can and it should not happen that much during the work. In this research planning is considered as a contributory work that offers no direct value to the product but is necessary for successful execution of the work.

Planning is a topic that was added to offer information on how much planning is made at the place of work or outside of it and how. The point of this category is to figure out all the extra planning the workers must do on site and how much of it could be avoided by managerial activities. Another factor that can be uncovered is the information from the perspective of the workers about things that could or cannot be planned in advance.

One content of this topic was also the information about the comprehensiveness of the designs that were at the worker’s disposal and the effects of them to the conducted work. Another factor that is included in this topic is to see how the workers inform the managers about anything involving the designs. Such things might be the need for extra information or to plan the work with the managers if the needed information is lacking from the designs. The involvement of the managers is also something that is of interest in this topic.

By having comprehensive information at hand, it is possible to generate alleviating work methods to the workers so that they would have the necessary information where they need it, when they need it. Of course, this goes both ways. If the management is expected of offering information properly to the workers, it is also expected from the workers to informing the managers about any changes they have made that deviate from the designs they were given.

4.5.7 Work related discussion

Discussions happen all the time; on the site and off the site. This topic contains all discussions had by the workers between each other or with other contractors and with the management concerning anything that is related to the work at hand. To simplify the research, not all discussions were considered as work-related even though there might be a sentence or two made about the work during breaks. Those discussions were not included into this topic but were a part of the last topic. Discussions about the work at hand play a big role in guiding the work towards the desired outcome, but also offer crucial information to avoid unnecessary mistakes. This topic summarizes the amount of time that is used by the studied workers to discuss about their work with other workers or managers or ask questions about it from another party.

4.5.8 Installations

Installations as a topic was created to separate all the additional device installations or additional part installations of different tools as their own section. By doing so, it is possible to see if there are factors affecting to the work that have something to do for example the lighting of the work area or the capabilities of different tools. This topic contains all light installations, laser device installations and changes of drill bits or such. The workers should not spend too much time on various installations of machines, but if they do, the reason for them should be investigated.

4.5.9 Cleaning

Cleaning activity was separated as a topic of its own to calculate the amount of cleaning the workers do. Cleaning does not directly generate value to the end product and is therefore considered as a supporting task that allows the workers to maintain a proper and safe working space.

4.5.10 Movement

This category was constructed to contain all the movements made by the workers; with or without materials. These movements do not include those small movements made at the place of work, but this will include all the movements from one area to another; however small they might be. The purpose of the movement is to be researched in order to gain understanding as to why the worker is moving and where is he going. Movement is something that happens in many forms on the site and some of it can be classified as waste straight away, but on the other hand some movements can be deemed as necessary and in some ways the necessity can alter from the viewpoint. The opinions and explanations might vary between the management and the workers if inquired. There are possibilities to divide movement between complete waste and supportive actions by determining if the workers are moving without tools or materials or if they are indeed carrying something with them.

Movement is usually a result of fragmented work when the necessary tools, materials, plans or equipment are not in the needed place. Kalsaas (2010) names the lack of materials and equipment as the single largest cause of fragmentation in work, especially in carpenters' work. Management plays a big role in the de-fragmentation of the work since they can plan the work in such manner that as little variation happens in the work as possible. By meeting the demands of the work area set by the work phase, the work itself can be conducted in a more productive manner and at the same time the workers do not have to move around to find missing materials, tools or information if they all can be found in the work area.

4.5.11 Maintenance

Maintenance as a category was created from the need of segregation of various maintenance actions such as battery changes, screw clip changes and fixings of broken machines. This category was created to see the effect of battery life and proper tools to the work. In the case company's operations, the tools that are offered to the workers in general are in good quality when they come to the site, but the maintaining of them is left mainly for the workers during their usage. Problems may arise from dust and temperature, but in this category different reasons causing maintenance need will be measured.

4.5.12 Re-work

Re-work is considered as the most unwanted of the waste types since re-work contains every step of the process that is repeated. Repetition can be caused by multiple different reasons, but in this thesis the focus is on the following subjects to keep the extent of the study within the scope of this thesis:

- Attachment mistakes
- Measurement mistakes
- Fitting mistakes
- Re-fitting caused by a forgotten preceding phase
- Work method mistake
- Mistakes in the material work
- Unnecessary attachments

As the list points out, the focus is on the mistakes made by the management, designers, workers, other sub-contractors or the measurer. The reason for the mistakes can vary, but in this thesis, the effect of the concentration of the different workers is studied.

4.5.13 Searching and handling

A whole category was set to include all the searching and handling activities made by the workers on the site. To gain better understanding of the work and to offer a possibility to construct a proper intervention, the reasons behind every search and tool or material handling event are to be figured out. Searching of tools and materials is a waste that could be avoided with better planning of work and logistics, but to elucidate the main causes for searching activities, this topic is necessary. By having the reasons clarified it is easier to counter them with solutions. The reasons of material handling are also an important factor since in many cases the materials can be seen stored in a pile or tools may be in random order on shelfs or boxes. This search-like action is considered as “handling” in this thesis to include such actions to this topic.

4.5.14 Non-work -related activities (including break times)

Non-work -related actions is a vast topic which contains basically everything else that is not mentioned on the sections 4.5.1 – 4.5.13. This topic was created to see what amount of time is spent during a workday to other activities besides to the work at hand. This category includes also the breaks held by the workers even though that time can be considered to be a part of work time. The video clips of breaks will not be studied accurately since that time is meant to be off-time from work and therefore the matters discussed during breaks will be considered as non-work -related activities. The study of the contents of each break time was out of the scope of this study and would have needed separate measurement system.

This category also includes any discussions made during the workday that have nothing to do with the work phase the workers are doing. In addition, this category will include all additional breaks, such as cigarette breaks. An important notion concerning this category is that the possible improvements discovered from this category will be left as such since it can be considered as a violation of personal space by some if, for example, additional cigarette breaks would be denied from the workers. This has a potential to cause bad morale on the site and therefore, should be avoided.

5 Selection criteria of the work phase

For this thesis different work phases were inspected from the point of research possibilities. The work phase that would be inspected must have measurable content so that the work could be measured in multiple ways if possible. This is really the most important factor in the selection. One important factor was set out to be that the work phase should not have too many adjoining phases linked directly to it. Those phases that rely too much on the success of the previous phase or have too big of an effect to the following phases are ruled out since the investigation of the following effects will require vast amounts of work to be properly analyzed. One example of such phase is the element assembly phase that can have effects affecting the finishing phases of the site. Such phases require remarkably accurate measurements making them ineligible for this research.

The work phase can nevertheless have some aspects that can be taken into consideration concerning the previous or following phases, but these effects should not be too substantial. The acceptable aspects were decided to be the following:

1. The work phase can be one of the finishing phases, such as painting or tiling, but it can be one of the previous phases as well
2. The work phase can have adjoining phases but the effects of those preceding should not have crucial effect on the studied phase
3. The subsequent phases should not be crucially affected by the examined phase if errors are discovered
4. The work phase should be a long-term phase which can be observed during a longer period
5. The observed team should stay the same during the research if at all possible

The closer to the finishing work the selected phase is, the easier the research becomes since the errors made during the work can be examined promptly. The finishing works also remove the need to observe the effects to the following phases. Of course, finishing works do have some long-term effects, some of which cannot really be observed before years have passed, but to sustain the scope of this thesis, these after-effects could be ignored.

Since the selected phase might have adjoining phases it still can be examined with the effects towards both ways in mind. The scope of this thesis does not support the examination of long-term effects of specific phases. Even though, everything has something to do with everything, this thesis will focus on the close proximity of different phases and their effects on each other. There will still be remarks concerning the possible improvements in specific phases to avoid problems if any are found during the research weeks.

What this thesis will also examine is the effects specific work phases have on each other and how one stage could be finished in a better manner to avoid re-work or extra work in the following phase. If the selected phase is a mid-way phase, such as drywall or masonry wall construction phase, the research will cover the analysis of the after-effects of errors, if any are found. If in turn the phase is one of the finishing phases, the examination will be made from the point of view that how much re-work has to be made so that the work is accepted with no remarks.

The longer the duration of the work phase, the more information is possible to acquire from that particular phase. This thesis will focus on a single phase and it is therefore crucial to have a single phase last longer that one week. The work should also be continuous so that the effects of the learning of the workers can possibly be observed. Consecutive work is also better to examine since the workflow is steady and the variations in it can be observed more easily. This of course emphasizes the last point of having same workers all the time during the examination. This is a way to minimize unrelated variations in the research and to maximize the accuracy of the results.

5.1 Selection of work phase

After some research, few work phases were selected for closer examination. These phases all fulfilled the requirements set for the work phase earlier and were deemed fit to be examined in more accurate manner.

5.1.1 Bathroom and kitchen tiling

This phase has a lot of easily observable work phases that can also be easily measured. The effects of the previous work phases can be seen in the preparation work made for the success of this work phase since tiling requires somewhat excellent level of preceding work quality before the tiling can actually begin. Multiple measurable aspects can be found concerning this particular work phase which makes it alluring phase for the study. Tiling is usually also quite time-consuming and is in many cases made by the same team since the quality of the work should be homogeneous.

According to Rakennustieto (2013) tiling has demands not only in the quality and finishing of the work but also requirements set by the temperature and moisture levels of the underlaying structures which makes it rather diverse work phase. In other words, tiling is not only driven by the site management’s ability to control the tiling work phase but also the ability to control adjacent factors as well. Temperature and moisture control are not only the problem for a tiler but also for the entire construction site schedule-wise. Therefore, this could be one of the most interesting and multi-functioned research possibilities.

Material logistics in this work phase have certain aspects that must be considered. The tiles should be from the same batch to avoid color faults. This is something that can be avoided by a proper pre-planning of the work phase. The material itself is easily transported to the areas they are needed since the work requires little work that needs to be made to the material itself; apart from the mixing of the filler.

5.1.2 Drywall assembly

Figure 8: Drywall assembly with steel frame, one side of the sheeting done

This stage has a lot of potential to be examined in this thesis. The phase has relatively few requirements and not too many parts in the actual assembly making it simpler than, for example, tiling. The phase itself is interesting since there are still quite many things that need to be considered and the effects from previous phases and the effects caused to the following phases can be observed easily to a certain extent. This phase also has two separate work stages that both are easily observed and examined as well as measured. Both of these work phases can have an effect on the following phases that might raise interesting observations. Also, the preceding work can have catastrophic effects on this phase since undone preceding work can actually stop the progress of this work.

In larger scale drywall assembly does have large number of factors that should be thought of. One big part of the work phase is the need of work with the materials if they are not ordered pre-cut to a certain measure. Pre-measured parts require vast knowledge of the spaces they should be installed to. For the best outcome building information models (BIM) should be used, but with those the requirement for a closer observation of work is needed. In the scale of this thesis the use of BIM models is not considered, and the material work is therefore necessary.

For this work phase the placing and the logistics of the large pieces of material need to be well-planned before the work can begin. The material needs to be transported close to the area where they are needed but away from all the adjacent structures of the spaces. The amount of material needs to be well thought since extra material can cause unnecessary need for re-transporting the materials. Material consumption should also be monitored so the necessary adjustments can be made to the following material deliveries.

5.1.3 Suspended ceiling assembly

Figure 9: Framework for a gypsum suspended ceiling with electric installments done

Suspended ceiling assembly has multiple different forms of which a study can be made. Different versions vary from gypsum ceilings to wooden or, for example, acoustic ceilings. Each version has some similar stages such as frame assembly or attachment of the sheets, but they also have their unique aspects which can make this alternative interesting to study. The progress of suspended ceiling assembly is also easy to measure and follow as it progresses from one space to another as it is finished in the previous areas.

The success of suspended ceiling assembly is highly dependent on the activity of other contractors and especially of the accuracy of measurements. If something has been forgotten by, let us say, electrician, the work can stop for the time that the necessary or lacking installments are made. Therefore, this work phase requires much monitoring from the managers to avoid such problematic situations.

The material logistics for suspended ceilings are somewhat similar with the drywall assembly since the necessary materials need to be in the right place at the right time. Also, what is important, and possible, is the monitoring of the consumption of materials during the work phase so that every delivery of material is adjusted according to the preceding attainment to avoid unnecessary material waste; but also, to plan the necessary steps and requirements for the possible material storage needs on the site. Even though, storage is viewed as waste in lean philosophy, Shingo (1984) points out that from the process' viewpoint storage is necessary for smooth operation success.

5.1.4 Concrete masonry interior walls

The building phase for concrete masonry interior walls is one work phase that is quite simple, yet it can have a large effect on the preceding phases when it comes to the dimensional accuracy of the finished work. Laying of the concrete block is easily measured work phase with few actual work stages and is thus a tempting work phase for the study. The progress of the work is clear, and the effects of logistics and planning are easily seen.

The logistics for the concrete masonry walls must be made during the concrete element assembly phase to be efficient and so it requires planning well before the actual beginning of the work phase. Another way to execute logistical needs is to lift the materials to the storeys with a telehandler or similar but this solution requires strong movers since the blocks can be quite heavy. The moving of concrete blocks also exposes them to the danger of material damages and should therefore be avoided. Early need for logistics would require the study to start well before the actual beginning of the work phase and makes this phase therefore harder to study than the other three.

5.1.5 The selected work phase

After some interviews with some possible candidates for the study it became clear that a lot of skepticism was involved with the interviewees. Even though the scope of the research was explained well to the possible participants, the answers were more or less vague ways of saying no. The main reason seemed to be that the candidates thought that the research would point out their possible individual problems in working which would then be reported to their foremen. The company representatives of sub-contractors that were interviewed thought that the research would point out problems in their operations that would possibly weaken their status in the eyes of the case company. This was not anticipated in the beginning of the planning of this thesis.

Luckily, a team of workers were found from a construction site in the metropolitan area. Two of the case company's own workers agreed to participate in the research after two-minute discussion and they were very interested to do so. Another two-man team was also interviewed to be the back-up for the original team in later stage in case of problems and they agreed to do so. This proved that the original problem of not finding suitable participants relies much on the personal attitudes of individuals. The workers were working on suspended ceilings and drywall assembly as an hourly basis contract work for the whole site. The schedule for their work phase was concurrent with this study and the selection was made to study a combination of the work phases presented in chapters 5.1.2 and 5.1.3.

6 Introduction of the case company

The case company is a family-owned Finnish construction company with history starting from year 1996. The company focuses on residential building mainly in the metropolitan area around Helsinki, but it also has a sister company which focuses on residential building in Tavastia Proper. The case company has been growing its production steadily which can be seen from the growing revenue. The case company also have an ISO 9001:2015 quality certificate. In its operations the company strives to improvements with production quality but also with cost-effectiveness and effective schedule control and to support this the company has developed a completely own Quality Management System (QMS) which offers the managers a set of tools to manage their work on the construction site and outside of them. The case company has built the QMS to support the work of the site managers but has also added separate applications to support the functions of the QMS. These systems offer tools for different phases of the processes. Even though the systems have proven effective in previous utilizations, the use of these was quite scarce before this research. Part of the company's strategy is to improve its cost-effectiveness via development of the QMS and the Operations Management System (OMS) of which the latter consists of cost-management, schedule management and quality management. The requirements set by the QMS and OMS are met by training the employees in a systematic way.

Even though the hopes of ever decreasing of lead times in different projects might be considered to be in the primary hopes of construction project developers (Junnonen & Kankainen 2007) and even though the case company is not a developer itself, it was still in their interest also to decrease the lead time of any new or ongoing projects if any new ways were to emerge with potential to do so. This meant that the case company was very accepting about the new suggestions and philosophies, such as lean, that were introduced to them in order to improve their operations.

6.1 Inspection of operations in the case company

To properly gain a comprehensive understanding of the processes in the case company's operation inspections were necessary of the operation of different functions in the case company's construction processes. To maintain the scope of this thesis, only construction sites and the most important functions involving their actions were inspected, though the focus was mainly in the differences and similarities between different construction sites around southern Finland. For the starting data, eight different residential building sites were investigated to achieve a proper understanding of the general situation that was in the company at the time. The used methods for inspections were visual investigations, interviews and study of documented information from the sites.

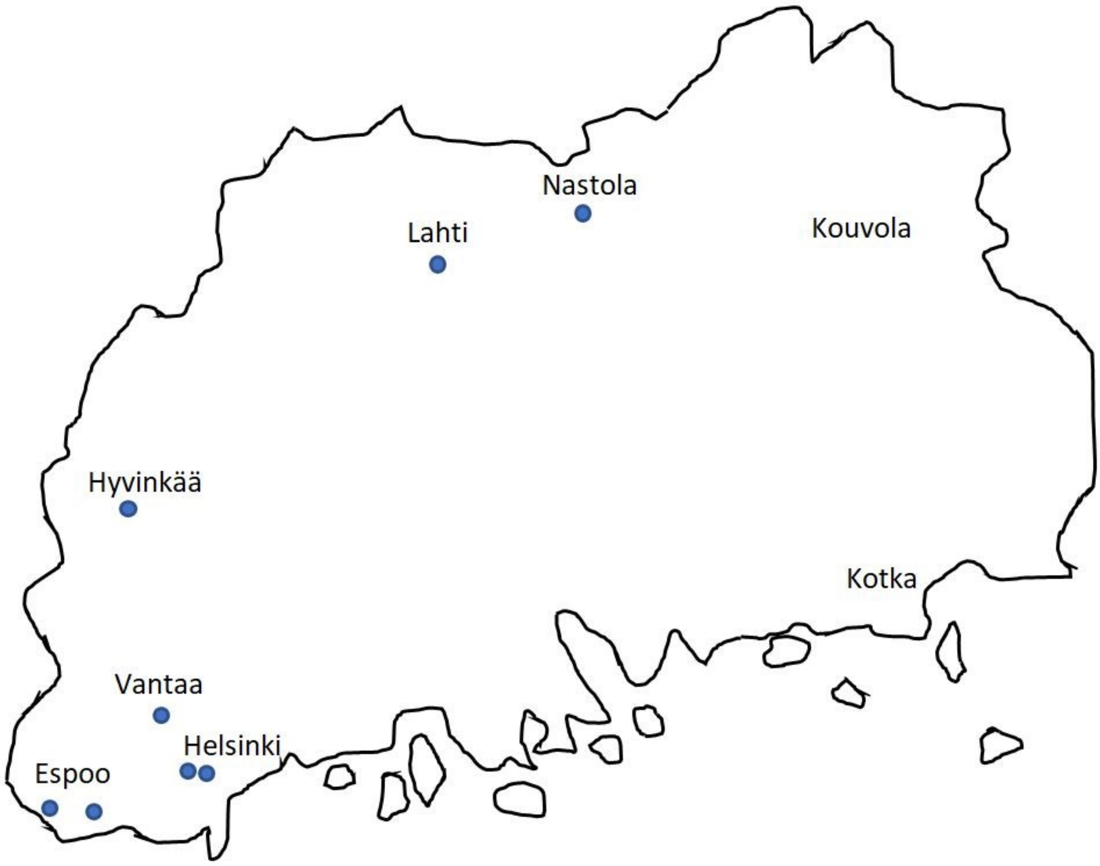

Figure 10: A map of southern Finland with the locations of the sites that were included in the investigations

During the investigations it became clear that the construction sites functioned in a quite similar way compared to each other even though there were many site managers that have transferred from other companies to the case company; some just recently. These managers were still working mainly in a way they had learned in the previous companies. Those that were educated in the company's way of thinking and had embraced it were operating more in the way the company intended.

The regular workday was from 07:00 to 15:30 with typical break times at 09:00, 11:00 and 13:30. The managers usually did their work between the site office and the site. The most used tools were their computers and mobile phones which were mostly used to place material orders, to design inspections or the controlling operations of the sub-contractors. Although, the managers did have proper equipment to manage their work, there was still problems with the transferring of information in efficient manner between different parties of the project.

The first notable aspect was that none of the inspected managers had constructed comprehensive plans of their responsibilities, but instead they controlled the actions by making many decisions on the go when a problem became visible or someone presented it to the site management. When managers work with mentality of making-do with what they have at the moment the need becomes visible, it will reflect to the workers as well and they will start to adapt to that kind of thinking. Making-do is something that might be perceived as a useful approach schedule-wise (Kalsaas 2010), but it can decrease the productivity of the work when the work is not planned well enough beforehand. Precautionary planning was mostly lacking from all the sites that were investigated to find problems on the site.

Another clear shortcoming was the production of schedule follow-ups. The managers did have an idea of where their work was proceeding but simplified and clear monitoring of the progress of work was not done. In many cases on the sites when asked about planning or schedule tracking, the answer was that the situation happened to be hasty and the managers did not seem to have time to sit down to think about their works. Of course, this was not the case on every site, but where the reason was not the lack of time it was lack of knowledge.

A need was set to identify problematic operations from the sites and to construct an improvement plan how to remove some of the problems or improve the efficiency of them and simultaneously offer tools to the workers and the management to increase the productivity of work phases. The data from the sites was investigated from the point of view that what could be done to offer the management on the sites more time to actually plan their work better and by doing so, to improve the production rate of different work phases. When this point of view is selected it becomes clear that what needs to be done is to remove waste from the processes on the construction site. This waste takes on many forms, but they all can be affected with proper planning.

7 Introduction of the selected site and work phase

The selected site was the case company's own design-build -project that took place in Vantaa, Finland. The site consists of three separate buildings that each have 4 storeys and in total they had 102 apartments. An area plan of the site is represented in the figure 12 below. In figure 13 there is also a picture of buildings A and B in which the study was conducted; building A is on the right side and the building B on the left. The intervention was carried out in the building B between floors 3 and 2.

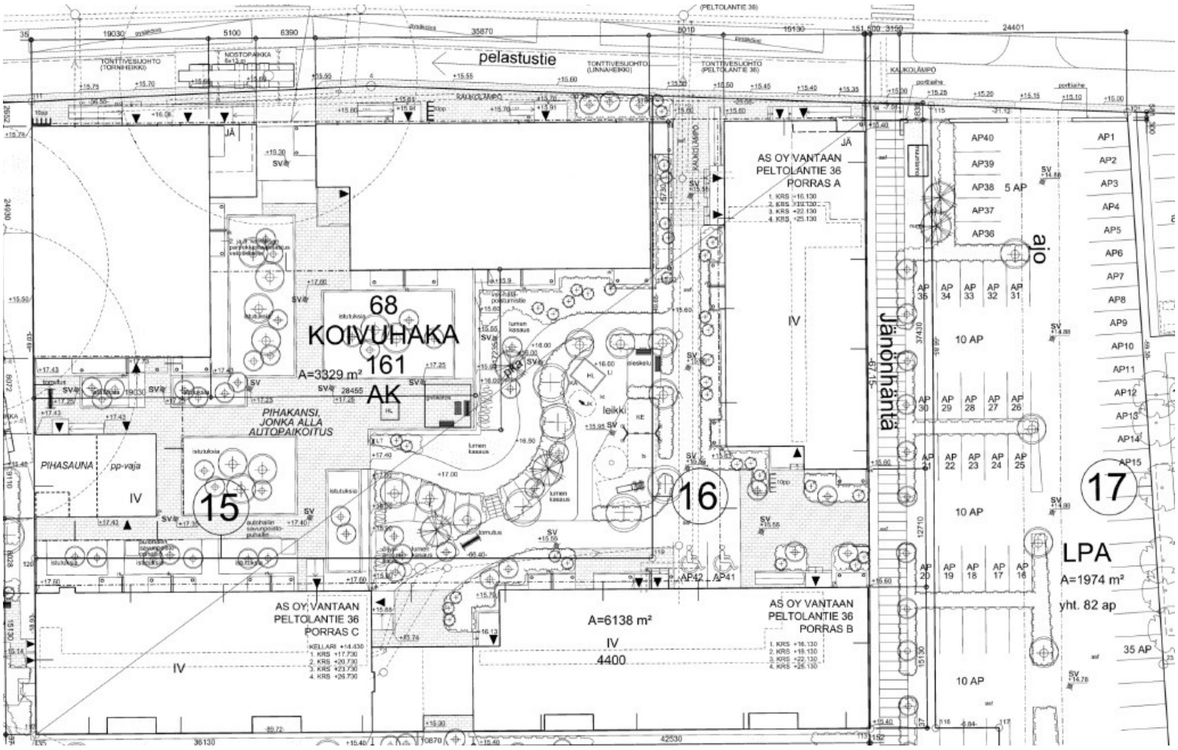

Figure 11: Site plan of the studied site "Peltolantie 36"

Figure 12: Picture from the site with buildings A (on the right) and B (on the left) visible

The drywall and suspended ceiling assembly was carried out with a single team in the building A by working from fourth floor downwards to the first floor, but in the building B another team joined to assist in the work. The work was divided in two; the researched team started working in the third floor and moved to the first floor after the third was completed. The other team started from floor four and moved to the second floor after finishing. This same routine continued in the building C.

The assembly itself was quite straight forward. The teams built the frames of the walls and sheeted one side of them in the first round followed by the electrician who installed necessary cables and parts behind them. After finishing the first round the teams continued with doubling of the drywalls and simultaneously finishing the drywall work. In the casings and the suspended ceilings, the work was simpler as the work phase consisted of building a necessary framework to the casings and suspended ceilings according to the installations made by the HVAC and electric crews. In both cases the necessary holes and inlets were constructed as necessary during the installation of the drywall sheets. Attachment of the materials were made using necessary screws and nails suitable for the underlaying material.

There were no pre-cut materials on the site; except the frame steel material for the wall that was ordered according the height pictured in the designs. The measurements of the drywall were 9x900x2600 in all three buildings making them movable and installable by one man according to the regulations. The needed amounts of materials for the work phase were calculated based on the quantity calculations made of the total site, but also by using the related 2D-designs of the buildings.

There was no task program produced for the studied work phase, but a start meeting was held with the studied team where the quality demands, schedule and costs were discussed and planned. All necessary information concerning the work was written in the minutes. Of course, the regulations set in the general quality demands collection “SisäRYL” were considered in the executed work.

8 The participants of the research

The participants for this research were all working for the case company on the site that was researched. The manager came to work for the case company in the middle of the assembly in the building A and was therefore not present during the first stages of the research. Although, she did take a good control of the phase later in the building B and C after she got around to familiarize herself to the site and to her responsibilities on it.

The manager responsible for the studied work phase did not have that much experience of the researched work phase but she was extremely co-operative during the whole research. She had a good attitude towards the goals of lean philosophy and therefore played a big and important role in the research.

The workers that took part in the research were all experienced men in the field of construction. The two studied workers were both co-operative during the whole study, and both showed interest to take part in the work conducted on the site to improve their productivity. The other worker had experience of drywall and suspended ceiling installments for a total of three years and the other for a total of two years. The men have experience of construction work for fourteen and sixteen years making them well-experienced in the overall working methods of a construction site. Of course, long experience in the industry increases the possibility of drifting into a habituated way of work. Signs of this were visible, but since the possibility of working better was accepted by the workers the old habits had not much place in the flow of work. A positive thing to notice was the willingness of the workers to adopt new approaches to the old ways.

The best observation that was made during the three steps of research was that both workers gave good ideas during the work. In building B another team joined the research of improved work and with their ideas both teams gained maximal benefits to improve the work conducted as a group.

9 Research plan for the study

This study is carried out in a three-step manner where the first step is to gather initial data for the problem identification, then an intervention plan is created and carried out on the site; and after these steps the results of the intervention are observed and researched. The last step also aims to identify possible development subjects that might arise from this study. The process used in this thesis can be thought in an illustrative way as it was described in the figure 5 presented in the chapter 4. This thesis presents a new learning process to the selected construction site along with the improvements. As the thesis only approaches the problem by conducting steps one, two and three; the process should continue on the site to maintain continuous improvement cycle which is the core idea of lean. In each cycle the process should be making itself more and more efficient and with each cycle the process should be improved in some way to fuel that development onwards.

9.1 The first step

The first step is always the hardest and that was the case in this thesis as well. The initial situation with the drywall and suspended ceiling assembly on the site was that there were many things that could have been affected in some way. The problem was to try and keep as neutral attitude towards everything as it was possible since even a smallest participation in this step could have altered the totality of the initial situation. The point in the first step was to approach the work in such a manner that would be as least invasive as possible. For this, the camera system was optimal since the equipment on the helmets was very light and by collecting the information from a video recording would need no interaction with the workers during the day.

It became clear that to make this three-step process as efficient as possible the problem should be somehow known and identified before taking the first step. This study was made from the starting point of not having one therefore making it an example of a situation where the management wants to find out the problems on the site. There is nothing wrong with that, but what was discovered was the fact that there is a lot of information that will be gathered if the research equipment is not chosen according to a singular problem. With no main research goal except the one to find different sources of waste, this step gathered more information than really was necessary and by doing so, made it harder to pinpoint the biggest problems with a quick glance of the material. While the vast amount of information might have made some aspects more complicated, it also offered many possibilities since there was a lot to work with.

One thing that was also hoped to find out, was the amount and nature of events that occur and cause waste that could have been avoided with proper planning. Even though, everything cannot be controlled, some precautionary actions can still be made to avoid bigger problems with matters that cannot necessarily be controlled. In many cases these precautionary actions are not made, and the result can be a devastating rush that causes uncontrolled waste since the managers are trying to control the on-going work phases with small, quick and sometimes un-planned actions. The impact and the importance of planning, management and controlling in the value-adding capabilities of a project are something that should always be focused on by the site management (Harris et al 2013) during the whole construction process. The lack of proper pre-planning can cause more problems even though the initial impression might give the managers a distorted feeling of lighter workload during the work phase. In the initial studies conducted on the work sites it became clear that the managers took little actions to properly plan the work phases ahead; of course, there were some exceptions to that as well.

Construction projects do have multiple tools available to minimize the emergence of waste. There are tools for each phase of a large-scale project, but also tools that focus on the details of a single construction phase. The tools are usually planned to serve certain parts of the project and as such they are effective is used right. It is important to plan everything that can be controlled and to prepare for everything that is not; and for the latter, construct a plan to manage the probability of the uncontrolled.

10 Phase 1 research

The overall situation on the site was good at the start of the first research part. The management of the site consisted of the responsible site manager, one site engineer and two foremen; both with their own responsibilities to tend. The selected work phase, drywall and suspended ceiling assembly, was led by the responsible site manager at this point since the additional foreman who was supposed to take the management of the drywall assembly over at a later point. The first phase of research took place in the fourth floor of the building A which was the first floor under construction for this particular work phase.

The responsible site manager had made calculations of the necessary materials based on the target cost estimation of the project. These calculations were made for each of the three buildings but only as a total amount. There were no calculations for each apartment separately leaving the hauling of the materials to the workers along with the progression of the work.

The logistics concerning the drywall and suspended ceiling assembly materials could have been done in a better way. Now the materials had been delivered to the site and left outside to wait for the lifting machine to be free. After few days, the material was lifted to the floors via the balconies by telehandler in a manner where the drywall material was lifted to a single apartment in each floor and most of the frame material was lifted to another. Some of the frame material was left outside.

The workers had all the necessary tools with them, but they were carrying them around in a large, wooden box which could be moved only by two men. The work areas that they were working on were extremely clean which was a very positive factor thinking about the work. The overall cleanliness on the site was much better than what it was on the other sites. This is a clear advantage and should be viewed as such. There were only few other work phases going on at the same time in the same areas that were meant for the drywall assembly team, so the schedular solutions were showing positive signs for the success of the drywall and suspended ceiling assembly. After some discussions with the sub-contractors' workers on the site, a somewhat coherent opinion emerged; the responsible site manager had arranged the work so, that everyone has the possibility to finish their work with proper time and area management before the next teams enter the area. They had very positive experience from the first building with this management method.

10.1 Results of the first measurement

In the first part of the research a total of 69 hours of video material was filmed and of that amount about 22 randomly selected one-hour clips were analyzed and categorized; including at least one full day. Both workers held the helmet cameras for total of five (5) days each during the weeks 41 and 42 of the year 2018. All the analyzed material was divided into 14 separate categories that were presented in the section 4.5 of this thesis. An example of such list is presented in the figure 14.

13:53	14:09	0:16	16	Actual work	Attaching the missing piece
14:09	14:14	0:05	5	Searching: for materials	Picking up the lower corner steel
14:14	14:45	0:31	31	Measurements and work preparations	Fitting the corner steel to its place
14:45	16:18	1:33	93	Actual work	Attaching the corner steel
16:18	16:25	0:07	7	Searching: for materials	Picking up the next corner steel piece
16:25	16:37	0:12	12	Measurements and work preparations	Fitting the next piece to its place
16:37	17:24	0:47	47	Actual work	Attaching the corner steel
17:24	18:09	0:45	45	Installations	Uninstalling the laser from the pole, installing it to the floor
18:09	18:15	0:06	6	Searching: for materials	Picking up the bottom pieces off the floor
18:15	21:08	2:53	173	Actual work	Attaching the bottom pieces of the frame
21:08	21:10	0:02	2	Re-work	Lifting a fallen piece from the floor
21:10	23:34	2:24	144	Actual work	Attaching continues
23:34	23:44	0:10	10	Movement	A29 MH - A29 K
23:44	23:49	0:05	5	Maintenance	Battery ran out of the drill, took it off
23:49	23:59	0:10	10	Movement	A29 K - hallway
23:59	24:03	0:04	4	Maintenance	Getting a new battery from the loader
24:03	24:17	0:14	14	Movement	Hallway - A29 K
24:17	24:25	0:08	8	Movement	A29 K - A29 MH
24:25	24:36	0:11	11	Searching: for tools	Collecting the tools from the bedroom
24:36	24:42	0:06	6	Movement	A29 MH - A29 K
24:42	24:54	0:12	12	Movement	A29 K - A29 MH
24:54	24:55	0:01	1	Searching: for tools	Taking the laser
24:55	25:03	0:08	8	Movement	A29 MH - A29 K
25:03	25:19	0:16	16	Planning	Thinking about the next phase
25:19	25:29	0:10	10	Movement	A29K - A30 OH
25:29	25:42	0:13	13	Movement	A30 OH - hallway with the design board
25:42	26:03	0:21	21	Planning	Looking at the designs
26:03	26:10	0:07	7	Movement	Hallway - A30 OH
26:10	26:12	0:02	2	Searching: for materials	Picking up some frame pieces (trash?)
26:12	26:24	0:12	12	Movement	A30 OH - A31 MH vas
26:24	26:27	0:03	3	Searching for materials	Picking up a single piece of corner steel
26:27	26:48	0:21	21	Movement	A31 MH vas - A29 OH with materials
26:48	26:58	0:10	10	Movement	Within the OH and K
26:58	29:08	2:10	130	Measurements and work preparations	Measuring the frame lines to the floor
29:08	29:34	0:26	26	Installations	Installing the laser to the floor
29:34	30:17	0:43	43	Measurements and work preparations	Making markings to the ceiling along the laser line
30:17	30:37	0:20	20	Installations	Moving the laser on the floor
30:37	31:18	0:41	41	Measurements and work preparations	Making markings to the ceiling along the laser line
31:18	31:49	0:31	31	Installations	Moving the laser on the floor
31:49	32:18	0:29	29	Measurements and work preparations	Making markings to the ceiling along the laser line
32:18	32:26	0:08	8	Installations	Uninstalling the laser, moving it to the side
32:26	32:33	0:07	7	Movement	Within the K
32:33	32:42	0:09	9	Searching: for materials	Picking up the corner steel piece off the floor
32:42	32:50	0:08	8	Searching: for tools	Picking up the needed tools
32:50	33:12	0:22	22	Measurements and work preparations	Fitting the corner steel to its place based on the markings made
33:12	36:55	3:43	223	Actual work	Attaching the piece to its place
36:55	37:14	0:19	19	Searching: for materials	Searching for a piece of cardboard to use as a notebook

Figure 13: An example of the division and color coding of the researched video material

All the data was clearly marked to the extent that could be figured out from the videos. Even though, the basic color-coded categorization of the work would have sufficed an additional information column was added to offer more information and making the tracking of the work easier. By doing so, the possible needs for improvements were easier to spot and analyze. Another possibility that the more accurate information gathering makes possible is the continuous improvement of work based on the extra information that can be discovered from this information since the collected data is easier to divide and more precise comparisons are easier to make.

All the data was calculated to a visual chart presented in the figure 16. The time workers spent on the planned functions during the day was about 80% of the total time. The portion of value-adding work of that active time was found to be around 22% which is somewhat in line with the findings of Josephson and Saukkoriipi (2007) from a Swedish housing project who found that the directly value-adding activities constituted only for about 17,5% of total time. On the other hand, the amount of actual work differs quite much from a Norwegian study conducted by Kalsaas (2010) in which he found that the portion of direct work conducted by the workers during wallboard mounting which is like the studied phase in this study. The total time measured in that project was 56,6% for the time of carpenters' work. This amount can be caused by the differences in measurement techniques since it can be visually seen from the videos that a lot can happen in 5 minutes if the situation is compared for example to a work sampling method measurement.

In this study, the value-adding time consisted of about fifth of the overall working time. Somewhat similar amount of time was spent on non-value-adding operations by the workers. The biggest portion was consumed by the contributory work. The division is represented in figure 15 below.

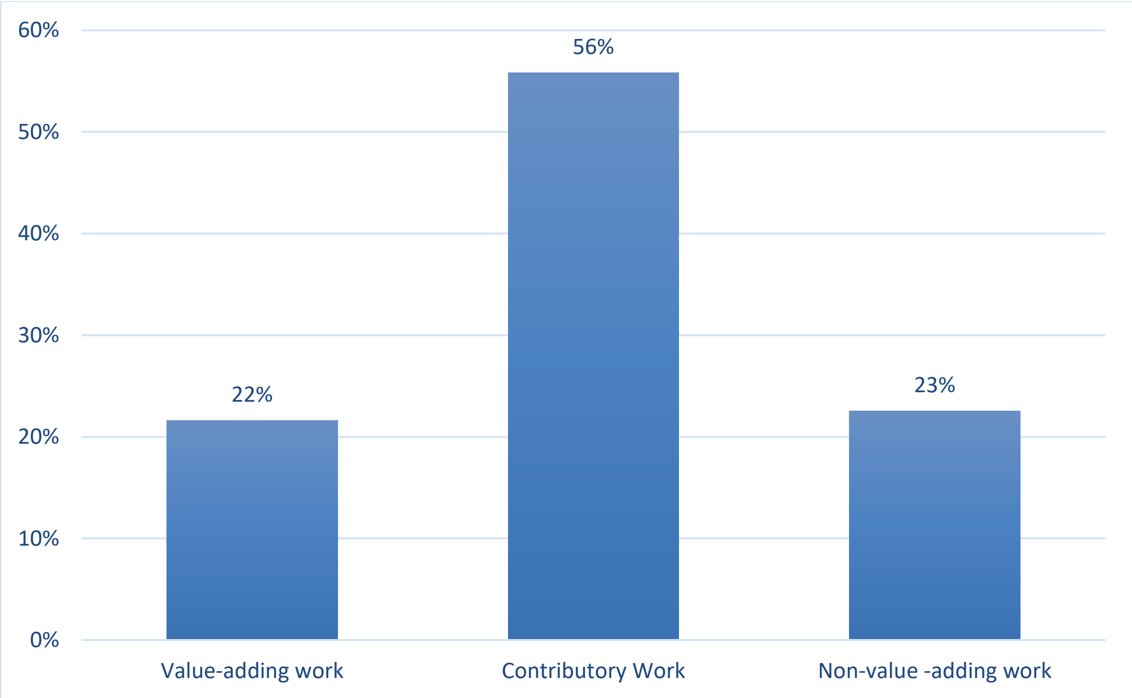

Figure 14: Distribution of work time (not including non-work -related time)

From this data the biggest time consumers could be seen. In the first section, the actual work time consisted of about fifth of all the daily time spent. On the other hand, biggest time consumers discovered were the time spent to movement (20%), material work (18%) and preparatory functions such as work preparations and measurements (total of about 17%). What was interesting to see also was the amount of planning (5%) and searching and handling of materials and tools (5%) that together consist of about a tenth of all the time and that were needed by the workers to successfully carry out their daily work. A decreasing impact for all these supportive work or waste categories was needed to improve the portion of the actual work made during the days.

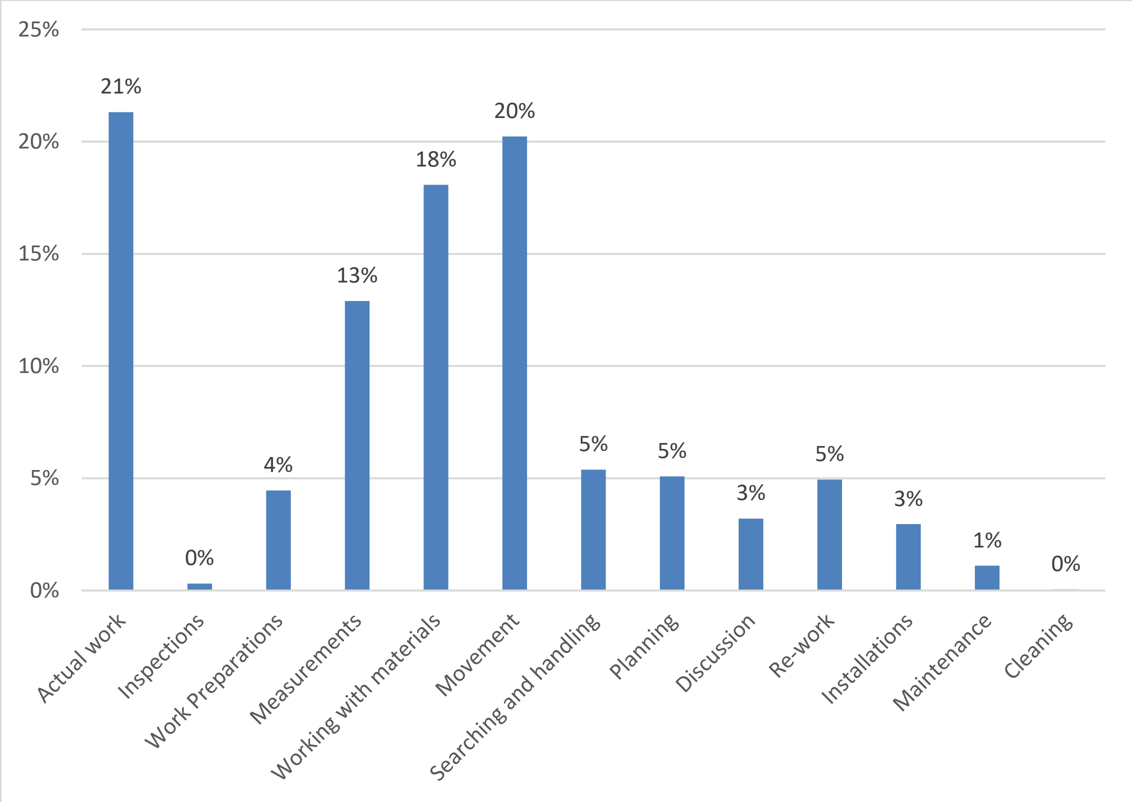

Figure 15: Division of data gathered in the first measurement

Movement seemed to be caused by the poor planning of the work and the material logistics. The workers had developed an interesting approach to the work they were doing. The floor plan of the fourth floor of building A is presented on the figure 17. The material storage areas (left side of the building), the material work area and the tools storage areas (right side of the building) are marked in the floor plan. For some reason the workers used multiple different areas to do one work phase in an apartment. They did try to optimize their work by carrying some of the material to an apartment, but the result in their opinion was that the work did not get any faster even though in reality it did and quite much.

There were multiple signs of lacking management and missing of planning of work in sight that could have been affected with proper plans and discussions with the workers. One example of such is the fact that much of the needed frame material was piled up outside and the workers had to take them inside in small batches when they happened to walk by whenever they ran out of material. Of course, a significant factor could have been at this point the lack of a designated foreman for this work phase and the fact that the responsible site manager had multiple things to attend to causing his attention to be less than required for the beginning of this phase. It is obviously expected that the management will get better after a foreman is designated to oversee this work phase.

The decisions of the workers can be affected with a properly planned intervention where the workers are taken along with the planning so that every decided change is accepted by the workers and their commitment to them is easier. It is crucial in the long run to make such changes that are easily approached, accepted and easily explained to the workers and to the foremen, but that also have clear advantages to the previous methods. Controllability is also an important factor in any change for its persistence in the processes of the case company.

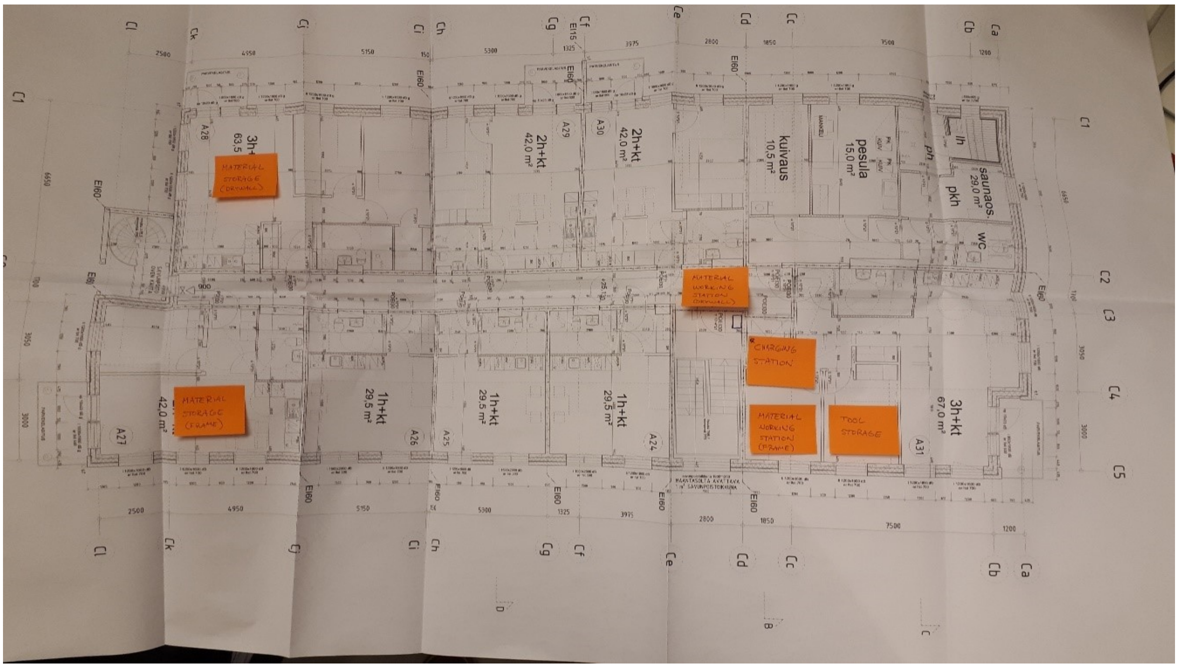

Figure 16: Floor plan of the fourth floor of building A

The other categories showed relatively small amounts of time with factors that can be hard to affect. Discussions and re-work are affected largely by the experience of the workers and thus they can be harder to steer towards a better result; except with time. In this thesis work there was not enough time to wait for the workers to gain enough experience of the work made so that they could be told what to do and how in a more precise manner. Installations were something that are made during the day and the duration in those does have a lot to do with the personal matters since for example, the adjustment accuracy of a laser liner depends much on the workers will to be more accurate. Of course, they could be told not to do their work so accurately, but this is not recommendable at this point. On the other hand, pre-cut and pre-measured materials require less accurate measurements decreasing the need to use laser liners and such, but that is a completely other topic and outside of this thesis. A notable thing that was discovered was the small amount of inspections made by the workers. A category was added to see how the workers avoided possible re-work later in the work phase by conducting proper inspections after the work was finished.

11 Intervention time

During the finalization phases of the intervention plan, there had been some changes in the conducted drywall assembly work. A separate foreman took over the work phase from the responsible site manager and another team had been brought to assist the first team in the assembly phase from the beginning of building B. The plan was that the other team would construct drywalls and suspended ceilings in the 4th and the 2nd floor of building B and the original, investigated team would construct the 3rd and the 1st floors. This change had been made to speed up the work and to catch up with the schedule.

The situation in the fourth floor was quite hasty since a painting team had caught up with the other team. Therefore, the intervention could not have been carried out in a better time than when it was. Both teams assisted in the finishing of the fourth floor and by doing so offered the painters a finished floor just in time. The next day both teams and the work phase manager were invited to a meeting where the intervention plan was presented to them.

Both teams were interviewed together with the manager to find out the best working methods to optimize the conducted work. By doing so, the workers were taken along with the planning of the work phase which turned out later to be very effective to the production rate of the work. The two teams had been working in different ways before the intervention but after the meeting everyone had similar working methods and all good ideas were combined into one well-planned and optimized plan of actions. The importance of compliance to the plan was explained and the workers did commit to working as agreed upon.

The intervention took place in the mid-part of the building B when the investigated team and the other team changed from floors four and three to floors two and one. The 2nd and the 1st floor were prepared with pre-calculated materials in each apartment. Also, an iCONS-positioning system grid was set up in the third and first floor to offer a way to ensure the conformity of the success of the intervention along with the video material.

11.1 Minimizing the movement

In this thesis a main goal was set to decrease the amount of excess movement as low as it was possible. It became clear in the first set of videos that the movement was one of the biggest wastes generated by the workers. Much of the daily movement was caused by the work necessary with the materials and the lack of materials at hand at the place of work. Another major reason was the poor placement of tools and attachment materials. The main goal was set to optimize this section.

Movement can be decreased in multiple ways and the intervention plan did contain many ways to do just that. The first and foremost factor was to move all the required materials to where they were needed and in right amounts. A study conducted on a Finnish construction site showed that much can be affected by proper material placement and logistics (Kalsaas 2010). The working time necessary for single work phase was reduced a lot when the necessary materials were delivered to their intended installation areas. In this study, this was conducted by installing wall mounts that had the ability to carry the weight of the drywall and frame materials of each separate apartment. These mounts, that are presented in the figure 18, were the company's own production. A previous experience with these mounts on another site showed the potential of the mounts when well used and organized. On that site, the drywall material was lifted to the first and second floors of 76 separated two-storey apartments during the concrete and wood frame assembly. After the lifting the material was covered with plastic to protect it against the weather conditions.

Figure 17: Drywall and frame material wall mount with some materials in it

The best aspect of these wall mounts really is the fact that all the materials can be placed on them in the early stages of concrete element assembly if they only are covered with plastic to protect the underlying materials against the weather and moisture. The wall mounts also leave the floor open for work and offer ease in cleaning work since nothing is stored on the floor. The only extra work generated is the need for filler in the wall mount bolt holes. These mounts can be installed with the consideration of the workers height in mind to offer them ergonomic work stance while lifting the drywall sheets to a working table.

Movement will also be minimized by giving the workers a toolbox of their own. This way all workers should have their needed tools and necessary attachment materials at hand all the time. The contents of the bag should be checked at the end of each day and refilled if necessary. Furthermore, the management should be informed immediately if one of the workers notice anything running low. The management will be responsible of acquiring the needed materials in time and delivering them to where they are needed. The information of the lacks and needs will be made by mobile application to the management. A separate Whatsapp© -group will be created for the information of suspended ceiling and drywall assembly.

Furthermore, when the work is done in a certain sequence the need for unnecessary movement between apartments will be decreased. The work must be planned by the management in co-operation with the workers so that the need for discussions, planning and teachings between the two workers should decrease remarkably. With a proper planning and informing the work should flow better and in a more productive manner.

To further study the impact of the changes and to support the hypothesis an icons network was set up to the site in the third and first floors of the building B. The two workers with cameras were given the beacons as well as the work phase manager. The goal of using icons was to see the workers stay in certain apartments for longer periods of time instead of moving around the floors for different reasons. A more sedentary way of work was expected with the upgrades. The icons gateways were located in each apartment separately to ensure a more accurate measurement of time spent in each area. The setup of the first floor can be seen in the figure 19.

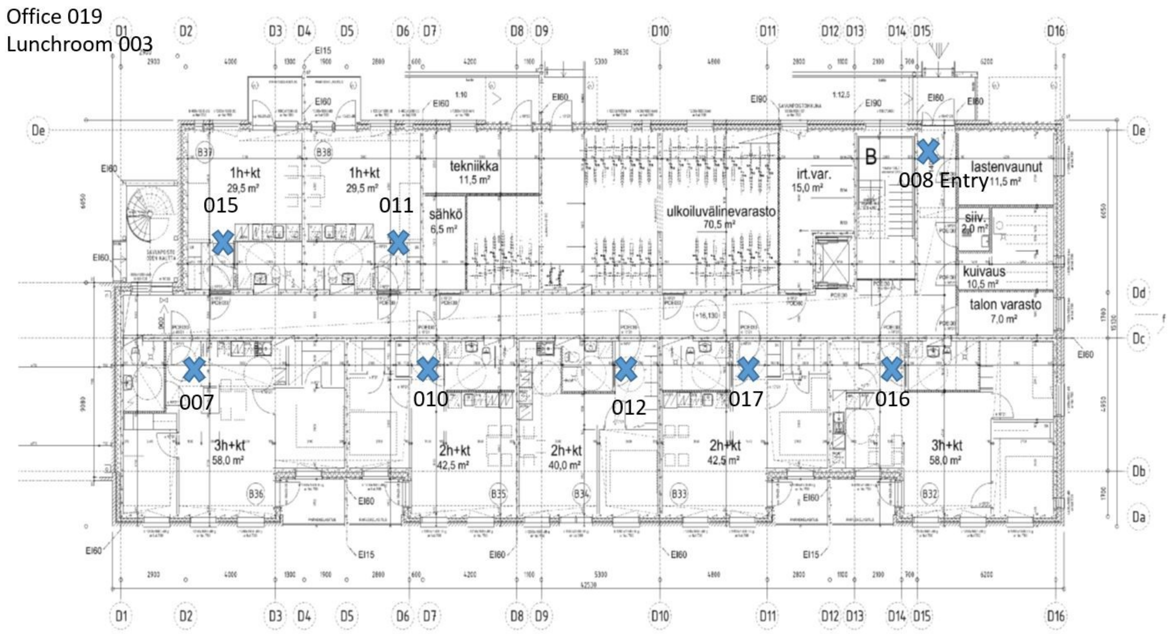

Figure 18: Icons networks in the first floor of the building B

11.2 Adding controlled inspections

A section was added to see how much quality inspections the workers were doing while working. The workers were given quality inspection sheets for them to use before moving to another space. The inspections were used to decrease the need of returning to the finished apartments because of mistakes that were not seen by the workers even if they should have been. A discussion with the work phase manager revealed a need for improvement in this section. Numerous re-work visits had been made previously to apartments that were reported as finished by the workers. The reason for the mistakes were that the workers did not have a decent check list for the finished spaces, and they had to remember most of the agreed topics from the work phase starting meeting from memory. The most alarming thing was that the other team had no knowledge of the quality requirements set in the initial meeting since they did not attend it. They worked according to their overall knowledge of the drywall and suspended ceiling assembly.

The amount in this section will be improved. Since this is the section that minimizes the need for re-work afterwards, the goal is to improve the effect of the inspections made by the workers themselves. This is gained by producing an inspection sheet for the work phase and explaining it to the workers. This way it is possible to shift some of the responsibility of the inspections to the workers who are actually doing the work.

11.3 Improvements to increase the amount of actual work

The amount of this section will be improved by minimizing the overall amount of all the rest. By allowing the workers to do more work it is possible to gain schedule and waste benefits.

Changes were also made to the methods of work. The other team was conducting the work in a differing manner from the other one. Both teams were inspected from the perspective of good execution methods and functioning ideas. As a result, changes were made to remove unnecessary working phases such as excess frame from the HVAC-casings. The cases could have been constructed without extra frame. The site manager was also surprised of the manner the other team was building the casings. The framework was not really needed for the rigidity of the case. Therefore, the excessive work conducted can be considered as waste and should be avoided by adjusting working methods and going through the detail plans of the work with both teams.

11.4 Minimizing measurements and work preparations

This section is minimized by offering the workers note sheets with certain detail pictures already made in some of them. By having such sheets, the workers can more easily measure and calculate the need of different parts in advance without the need to sketch them on a piece of paper or a piece of gypsum. With this information it is possible to produce larger amounts of parts at the same time which in turn decreases the unnecessary movement made by the workers involving the material processing. The efficiency impact of such notebooks was to be inspected in this study. An example of such sheet is in the figure 20. The point is that the workers are offered pre-planned detail designs so that the need of planning actions could be decreased.

Measurement demand will also be decreased by having decent designs at hand with the certain measurements set in the designs. This allows the management and the workers to read the designs more efficiently. The designs of each apartment will also be delivered to each apartment with necessary adjoining designs. This way there is information at hand in each room if needed.

The preparation work involving the work will be decreased by having certain meeting with the workers so that they both are on the same page concerning the work. This is a way to minimize the effects of different visions in building the work. Also, the work will be done in certain order to minimize the need for extra planning or thinking. By doing similar work in a repetitive manner, it is possible to optimize the work on a worker level. Therefore, the workers were instructed to properly finish one work phase in one apartment before moving to the next apartment.

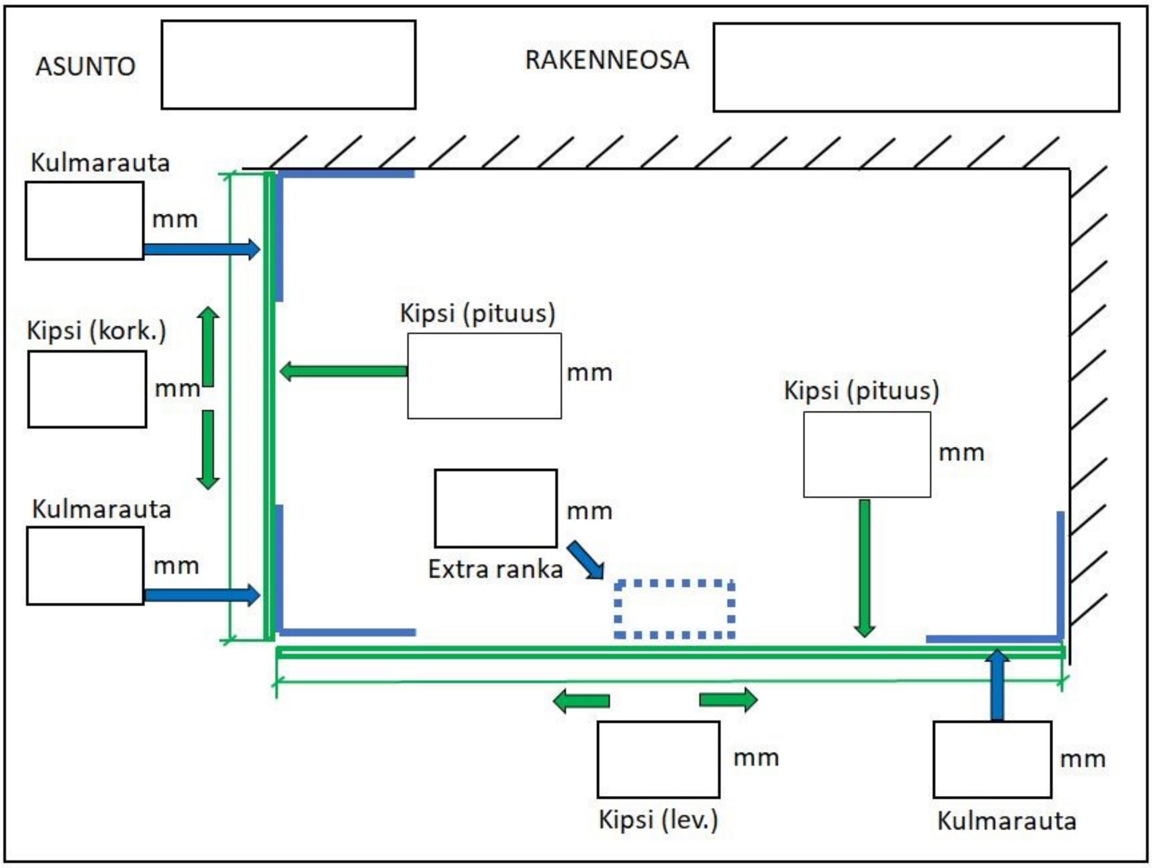

Figure 19: Measurement sheet for gypsum casings

11.5 Working with materials without movement

Materials will be brought to the room where they are needed, and the workers will have proper ways to measure the necessary parts. The workers are instructed to make measurements of as much of materials as they can make on one sitting to allow themselves to cut multiple parts simultaneously since producing of numerous parts simultaneously is more efficient than working with singular parts separately. The goal of guidance in measurement and cutting was that the workers could focus better on the assembly of the materials, but also the work should be speed up by the fact that the required measurements are there in total when the work with the materials begins.

Pre-cut materials will be used only in the vertical frame structures of the drywalls since that measure is the only one that is repeating from one floor to another. The site did not have BIM-models to work with so the use of pre-cut materials can be too much work with only 2D-desings at use. This improvement was left out of this thesis based on the lack of necessary designs. The process could also be made more efficient by going through the work phase with the adjoining work phases to ensure they also do the work in uniform manner making the use of pre-cut materials even more possible. In the scope of this thesis, this change of working method for the sub-contractors could mean that all the sockets and lamps etc. are in similar places and with similar measurements so that the need for planning the work can be minimized and the material work made more efficient for the suspended ceiling and drywall assembly teams.

Materials should also be worked with on a proper worktable to ensure an ergonomic work stance. Instead of doing the cutting etc. on the floor, the workers will have a moveable worktable at their disposal. This way the materials can be lifted from the rack and placed on the table while standing in a good posture. A proper working height also minimizes the risk of muscle tiredness and sore muscles that both have a decreasing effect on the productivity.

11.6 Less searching and handling

This section will be minimized by giving the workers their own tool bags. When all the workers have an option to store their own tools in their own manner, they should find the needed tools quicker when needed. In addition, the workers were instructed to store the necessary attachment materials in the bags or at least in a separate, light box which they must keep in the same area as the bag. Also, the workers will be instructed to keep the tools in that toolbox when they are not needed. These changes will decrease the unnecessary movement as well as the unnecessary searches for certain materials or tools.

The materials should also be stored in a uniform manner so that the workers can more easily find the materials they need. The workers seemed to have a good system in place where they move smaller pieces along with the work on the corridor so that whenever there is a need for small parts, they all know where to look. The materials were kept in a neat pile so the required work to search for certain parts was minimized. This was decided to be kept as it is since the system was quite efficient and it really worked already.

At the end of each day, the workers gathered their materials and stored them in a designated area to minimize the need of searching for them the next day. Also, with a proper storage use, it is possible to avoid unnecessary searching and handling caused by someone else if they have moved the tools or materials while, for example, cleaning.

11.7 Plans where they are needed

The time spent to planning activities is to be decreased by offering the workers decent plans where they need them. Each apartment will be equipped with proper room cards which contain necessary floor plans and detail designs along with the present furniture designs. This way the workers can easily visualize the totalities of the different structures and their work should become easier and less confusing. The designs will be located near the doorways of the apartments which were least invasive and least on the way of the suspended ceiling and drywall assembly but also of the following work phases. Therefore, this improvement is not intended only for the drywall and suspended ceiling teams but also for the other teams that follow.

11.8 Adding information channels

Earlier, the workers discussed mostly about the work they are doing or some teachings they had to do for each other if the work was unclear for the other. Discussions were mostly caused by a lack of information and the lack of managers presence. The biggest flaw that was found in the investigations was that the workers seldomly contacted the management and they did not have a controlled channel to approach the management with questions or needs; except when meeting with the management face to face.

Harris et al. (2013) mentions from ICT-perspective that "the exchange of construction information is seen as one of the critical tasks in the construction-management process." This is something that should be improved and to remove this problem the workers were given the opportunity to approach the management via mobile application Whatsapp©. The workers were added to the same group with the manager responsible for the drywall and suspended ceiling work phase. The idea is to use this new channel to inform the manager about lacks or flaws, ask for materials that are running low and to request clarifications to possible questions considering the designs. Foremost, the reason behind this addition is to remove the need for movement for instructions and to eliminate the unnecessary interruptions of the work.

11.9 Decreasing re-work

In their own inspections the workers will utilize the information given them in the work phase inspection sheet ("työvaiheen tarkastuskortti"). The inspections will be made in each apartment separately right after the work is done. If any flaws are found by the workers themselves, they should be addressed before any work can continue. The idea with this procedure is to produce finished areas without the need of going back. After the work is completed and the workers have gone through their inspection cards, they will inform the management with a mobile messaging application.

After the notification of finished work is sent to the management, the manager of the work phase will go and do the necessary inspections. If any flaws are found, they will be documented, and the workers informed. Management is also responsible of taking the foremen of the following phases to inspect the areas after certain, pre-decided areas are finished so that the foremen can accept the areas ("mestan vastaanotto") as they are to continue their work after the drywall team has finished. This will also be documented. This procedure is used to improve the flow of the work and to adapt a certain learning process to the work.

Re-work caused by the lack of information and the non-uniform working methods will be minimized by going through the requirements of the work with both teams. They must understand the requirements of each phase in the complete work phase so that there is no need of moving already installed parts because the measurements are off.

The re-work caused by the wrong tools will also be removed by giving the workers their own toolsets and the possibility to ask for certain materials or tools from the management in an easier manner. This way the workers will have the right tools, right materials and the right methods at hand all the time and no re-work is caused using wrong methods.

11.10 Work-related actions vs. non-work-related actions

The workers do have their own routines and they do discuss different matters with each other and with other workers on the site. This is a difficult part of the daily routine to decrease since the short discussions do have an impact on the overall morale of the workers. If the discussions are minimized by denying the workers the possibility of having non-work-related discussions, the overall morale of the workers is in a risk of decreasing. Of course, there are ways to decrease time spent on these. For instance, the cigarette breaks could be held at the same time as the breaks are held. Total denying of having cigarette breaks is also something that will not be done in this research for it can cause problems with the willingness of the workers.

12 Phase 2 research

The second measurement took place on the site during the weeks 2 and 3 of the year 2019; eleven weeks after the first measurement. In the second measurement visit about 90 hours of video material was collected and for closer analysis about 20 hours was randomly selected; including at least one full day. The analyzed amount of video material was aimed to be about the same as in the first measurement phase. Not much had changed in the overall situation on the site between the two visits. The state of cleanliness was similar, and the working methods of most contractors followed the same routine as previously. The weather was colder than what it was during the first research weeks, but it had no impact since now all the necessary materials were carried inside the building to wait for the teams to use them.

An important effort was made by the foreman when she calculated the necessary amounts of materials for each apartment so that everything could be carried inside and divided between the apartments accordingly. During the distribution of materials, a compromising lack was discovered in the first floor where there was only half of the needed drywall sheets. This situation was caused by a need of materials in the previous building. The workers had carried most of the first-floor sheets to the building A during the work there, but the information about this had been forgotten by the different parties of the work. The workers did inform the management when they took the sheets, but after that the information had not moved. The workers do trust the management to know these things and probably therefore did not bring the information up later.

Of course, this near problem was a sum of many factors, but in this case, it was avoided. By having comprehensive plans and calculations made before the work phases, it is easier for the management to control their work when the information is easy to see from the situation on the site. If the materials are not divided in the apartments but are left in a single, or in building B in two apartments, it is hard to know where the problems might be hidden. What was clear in the second measurement, was the simplicity of the work controlling with well-thought tactics and calculations. It was also easier for the workers to keep the management informed about needs and discoveries on the site. One major factor in the planning of a work phase is the experience of the managers and in the second measurement it was clear that the foreman was not as experienced in drywall and suspended ceiling assembly than what the workers were. She needed some guidance but was very willing to adapt to the new way of work and eager to gain more experience. Still, the lack of vast experience was not a crucial problem for the study although, it was more one more thing to account for in the analyze of the results.

The workers seemed happy about the changes made and they utilized every advantage they had at their disposal very well. Although there were some symptoms of the bad habits and the old, learned ways still visible, the work was made more or less the way it was planned and speculated. The workers started to use the message group in great amount and the information delivered though it was comprehensive and added with photos. This information is easily used by the management to control the work efficiently. The workers had their tools where they needed them, and they let the management know whenever something was missing or if they had trouble with something. Also, the management did inform the workers about the things that were concerning them. In short, the interaction between the workers and the foreman was much more active and effective in the second measurement. One thing that did not find a foothold in the daily work was the measurement sheets offered to the workers since they preferred their own sketches and did not find additional value in the given sheets.

12.1 Results

The second measurement offered a lot of information in terms of positive observations, but also in terms of surprising results. Overall the intervention was considered as a success and the work became more efficient, but what was the most important observation was the satisfaction and endorsement of the changes made by the workers and the management. Another significant discovery was the fact that one measurement method alone does not necessarily tell the whole truth.

The comparison between the data gathered in phases one and two gives a result which is presented in the figure 21. As it can be seen, the targeted segment of movement was affected quite much with an overall decrease of about three percentage points. This can be considered as a successful execution of lean intervention in the sense of this thesis.

What can also be seen from the data are the changes happening in other segments. The changes can be explained by comparing the data collected from both measurements.

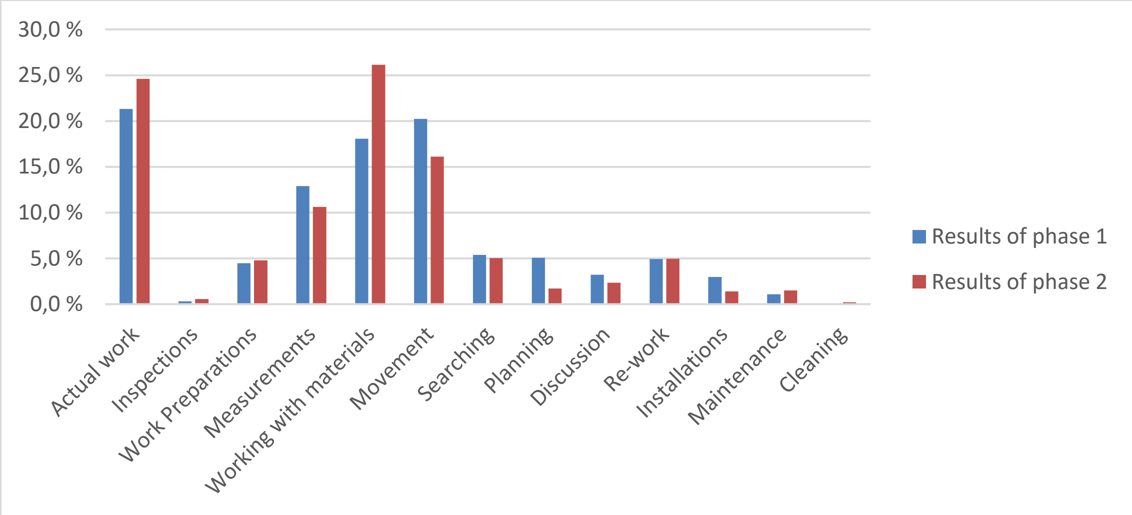

Figure 20: Comparison between the data collected on phases 1 and 2 (NWR-time not included)

Topic	Phase 1	Phase 2	Change (pp)
1 Actual work	21,3 %	24,6 %	+ 3,3 %
2 Inspections	0,3 %	0,6 %	+ 0,3 %
3 Work preparations	4,5 %	4,8 %	+ 0,3 %
4 Measurements	12,9 %	10,6 %	- 2,3 %
5 Working with materials	18,6 %	26,1 %	+ 8,1 %
6 Planning	5,1 %	1,7 %	- 3,4 %
7 Discussion	3,2 %	2,3 %	- 0,9 %
8 Installations	3,0 %	1,4 %	- 1,6 %
9 Cleaning	0,1 %	0,2 %	+ 0,1 %
10 Movement	**20,2 %**	**16,1 %**	**- 4,1 %**
11 Maintenance	1,1 %	1,5 %	+ 0,4 %
12 Re-work	4,9 %	4,9 %	+ 0,0 %
13 Searching and handling	5,4 %	5,0 %	- 0,4 %

Table 2: The changes in every topic per percentage points (NWR-time not included)

The studied topic "movement" decreased over four percent points which was the goal of the intervention. Positive changes can be seen in other topics as well. Actual work time increased as was anticipated in the planning of the intervention. The need for planning had also decreased quite much since in the intervention the plans of the work were clarified to the workers and an information channel opened for the workers to quickly gain information in problematic situations. The workers also started to focus on the necessary inspections that needed to be done to avoid unnecessary re-visits to finished areas. The longer durations in single spaced were also confirmed by analyzing the iCONS data gained from the movements of the workers in the building B. The workers seemed to spend longer times in the areas they were working and there was not that much moving around than there was in the first measurement phase, which was one of the goals of the intervention.

There were those segments that had changed into the unwanted direction. The biggest one of them was the topic "Working with materials". After a closer study and with some reasoning the increase in this topic can be explained by the fact that the workers were working in a more efficient way, which meant an increased need for necessary parts. This naturally means also that the amount of material work would increase. But to widen the view to this, the positive effects around the work contained the decreasing in the topic "Measurements" since the workers had proper tools at hand, they were working in a more logical manner and they were more confident with what they were doing.

Re-work segment was not affected in this study. This would mean that the human error factor was still very much present causing some re-work. This can be considered acceptable in the scope of this study. One event was found from the videos that could have affected a possibly improving work phase; an intervening of the work phase management to the quality of the work which made the workers work in more precise manner with the attachments. One clear initiative for such actions was the work phase manager's remark of a quality issue of elevated screws in the drywalls which was probably causing extra work with later work phases and therefore had to be removed as well as possible. The workers started to pay more attention to the attachments after the manager's involvement and started fixing the imperfect attachments along with their work. The same re-work has probably been happening outside the collected video material in the first areas too, but the execution might have been left to the filler and painting team. That is still re-work, but it could not be measured in this study. The solution for this unnecessary re-work would be to improve the performance of the attachment equipment since such re-work should not occur with proper equipment.

The gathered data was also compared in the level of the three main groups presented in chapter 3.2. The division of data used in this thesis is presented in figure 7 in chapter 4.5. When the data was divided into the three main topics the result was somewhat in the direction the study was aiming for with the intervention. In figure 22 are visualized the results between the two phases and based on the figure the results would be as hoped. But, as it was stated previously, the results should not be viewed purely based on the measured data since there are variables at play that affect to the results.

One example of such variables was the working method of the workers in the phase 1. The workers constructed structures that were unnecessary and also over scaled in terms of necessary durability in some cases. The work they conducted was still calculated into the actual work -topic even though the time used on the unnecessary structures would be considered as wasteful overproduction. Over-production is the first topic presented in

Shingo's (1984) list. The workers themselves were in the mindset of rightful production method in the first study phase and thus, the work was not waste from their point of view. The reason for the wasteful actions was the lack of information at some point of the work.

This waste of over-production can be removed from the value-adding work and contributory work segments of the first phase measurement and added to the non-value-adding segment. For the simplicity of this study and to remain loyal with the original division of data, the addition of over production was left out in this thesis work since the vast investigation of understanding which of the conducted work phase were caused by over-production and which were not. Though left out, the effect of the over-production did not affect the success of the intervention, but if calculated in it would generate even larger difference in each sector than what is seen in figure 22.

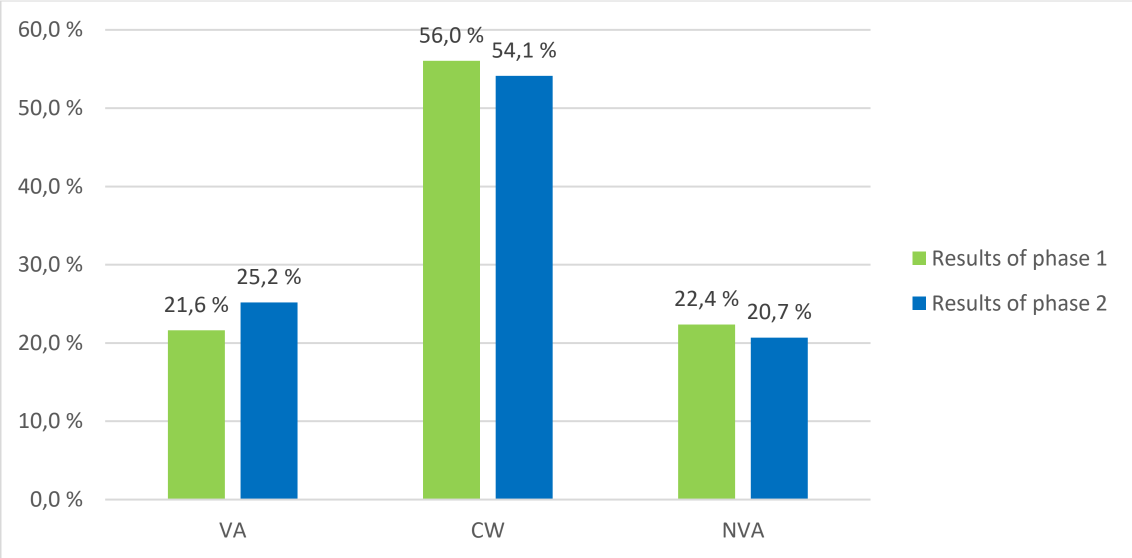

Figure 21: The division of data in the three main groups (VA, CW & NVA) in both phases

12.2 Cost effectiveness of the intervention

Of course, to gain another viewpoint, a decision was made to compare the data in terms of schedule and costs to see the effects of the lean-intervention since the extent of the successful intervention cannot be seen purely from increase in value-adding work and decrease in rest. A calculation was constructed based on the values before and after the intervention. The results from the building B measurements and analyzes are presented in the table 3 below. An approximated hourly wage of 24,50€ of the professional carpenters is used for these calculations which is multiplied by 1,73 to gain a complete sum of 42,39€ for the hourly wage of a single worker with social costs included.

Content	4th floor	3rd floor	2nd floor	1st floor
No. of apartments	9	10	9	7
Amount of suspended ceilings (m^2)	60,30	66,20	62,60	45,00
Framework (h)	11,46	12,58	11,89	8,55
Sheeting (h)	10,25	11,25	10,64	7,65
Amount of drywall (m^2)	471,60	539,60	519,90	432,10
Framework (h)	75,46	86,34	83,18	69,14

Sheeting (h)	108,47	124,11	119,58	99,38
Total are of drywall structures (m^2)	531,90	605,80	582,50	477,10
Theoretical hours in total (h)	205,63	234,28	225,30	184,72
Theoretical days in total (d)	25,70	29,28	28,16	23,09
For two-man team (d)	12,85	14,64	14,08	11,54
Theoretical production rate (m^2/d)	20,69	20,69	20,68	20,66
Actual duration, pre-intervention	24	27	(26,28) *	(21,3) *
For two-man team	12	13,5	(13,1) *	(10,6) *
Actual duration, after intervention			20	20
For two-man team			10	10
Theoretical duration for two-man team (d)	12,9	14,6	14,1	11,5
Scheduled duration (planned), for two-man team	6	6	5	5
Difference in duration vs. planned, pre-intervention (d)	+ 6	+ 7,5	+ 8,1 *	+ 5,6 *
Difference in duration vs. planned, after intervention (d)			+ 5	+ 5
Reduction after intervention (d)			- 3,1	- 0,6
Actual production rate	22,16	22,44	29,13	23,86
Actual production rate compared to the theoretical value	107,10 %	108,46 %	140,81 %	115,46%
Increase in production rate			*+ 31,48%*	*+ 6,44 %*
Efficiency (man-h / wall-m^2)	0,41	0,40	0,31	0,37
Saved days compared to the planned duration (d)	-3,7	(For two-man team)		
Saved hours compared to the planned duration (h)	59,2	(In total for two men)		
Saved costs in total, assumed with hourly wage of 24,50 €	2509,19 € (soc. costs incl.)			

Table 3: Calculation of durations and saves in building B

The gains in building B had to be compared with the needed costs to make the improvement possible. By including work phases such as installations of the wall mounts, distribution of the materials and the use of telehandler to do so, a calculation can be made to summarize the cost of the improvement. Each work phase, such as moving the drywalls, an extra 10% was added to include the effect of a less motivated worker carrying the materials instead of a motivated professional. This way the calculation can be constructed more reliably. The results for the approximated costs of moving the materials in the whole building are presented in the table 4 below.

Content	Costs and durations
Telehandler cost, estimate	70,00 €/h
Rental worker cost, estimate	26,00 €/h
Number of apartments	35
Amount of drywall sheets	606
Duration of drywall moving, 1 sheet	0,018 h (65 s)
Duration of drywall moving, in total	10,94 h
Duration of wall mount installation, 2 mounts per apartment	0,2 h
Duration of wall mount installation, total time	7 h
Duration of moving frame materials to apartments, 1 apartment	0,25 h
Duration of moving frame materials to apartments, total time	8,75 h
Need for telehandler	6 h
Need for rental worker	26,69 h
Total cost of preparations in building B (theoretical)	1113,98 €

Table 4: Calculation of costs in building B

As it can be seen from tables 3 and 4 the difference between the costs of distributing the materials, offering the workers better ways to do their work and with a closer control of the work, it was possible to save a total sum of 1395,21 €. This sum is a total of only two storeys and could have been increased by about 2500 € if the whole building would have been upgraded with the methods used in the lean intervention. Therefore, the intervention can be deemed successful also from the cost perspective.

12.3 Schedular success of the improvements

Calculations were made to support the claim that the lean-intervention was successful on the researched site. For preliminary study the learning process of the workers and the management was investigated. In figure 23 a progressive development of the work on its own in the building A can be seen. This was anticipated to happen even though there might have been some managerial actions taken that were not reported. The willingness to improve the work might have gotten a spark in the baseline measurements after which the reason for the study was explained to the workers and the management.

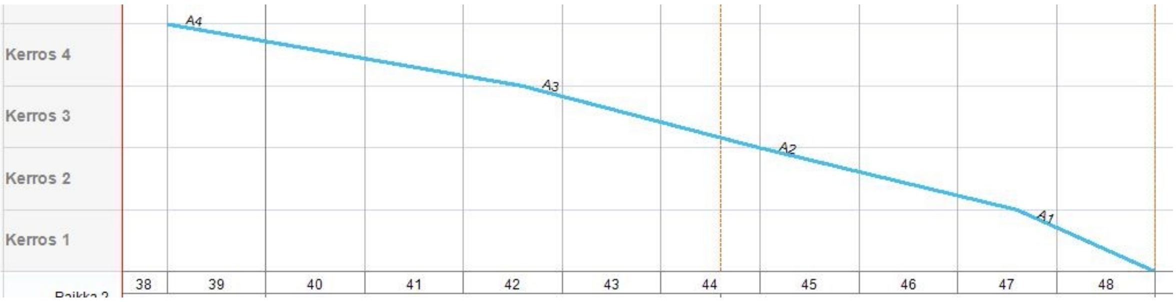

Figure 22: The actual duration of the work in building A

A notable remark in building B was that the workers were already doing their work a little more efficiently than what the standards are for the scheduling process in the floors four and three since the management had taken some initiative and divided the materials to two separate apartments instead of only one; as the situation was in the building A.

The changes in the production rate were clearly visible from the schedule as can be seen in the figure 24. The work was scheduled quite close to the theoretical production rate even though the schedule made by the site manager was done with previous experiences rather than based on calculations. As it is shown in the figure the change after the intervention is quite large.

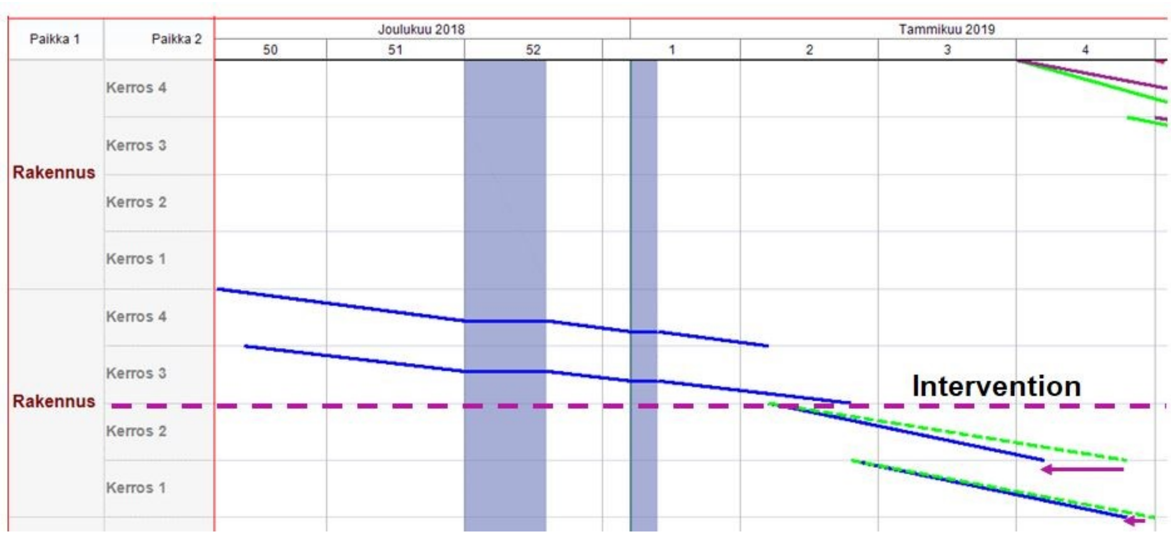

Figure 23: The actual duration of work in building B

In building B, the intervention actually saved over a 1000 euros compared to the original schedule and plan. This claim is based on the actual production rate gained from the schedule.

12.4 Projection of improvements for the last building

To further analyze the success rate of the improvement, a projection was made to the last building in which the foreman had the option to use the newly learned methods for improved working. The calculations for the projection are based on the production rates measured from the different floors of building B.

After first inspection, it was clear that the schedule was made much too tight to be possible to maintain in the building C. The production rate was over double of the theoretical levels mentioned in the scheduling book by Wind et al. (2014). The result was that the intervention functioned to minimize the damage caused by the inaccurate original schedule. The calculations were made to calculate the true duration of the work in two ways. One calculation for duration was made with the production rate from building B; specifically, that of floors one and two. The other calculation was made based on those production rates of floors three and four. These calculations are shown in tables 5 and 6.

Content	4th floor	3rd floor	2nd floor	1st floor
No. of apartments	9	10	10	8
Amount of suspended ceilings (m^2)	57,70	66,30	66,30	47,70
Framework (h)	10,96	12,60	12,60	9,06
Sheeting (h)	9,81	11,27	11,27	8,11
Amount of drywall (m^2)	374,40	439,70	439,70	324,20
Framework (h)	59,90	70,35	70,35	51,87
Sheeting (h)	86,11	101,13	101,13	74,57
Total are of drywall structures (m^2)	432,10	506,00	506,00	371,90
Theoretical hours in total (h)	166,79	195,35	195,35	143,61
Theoretical days in total (d)	20,85	24,42	24,42	17,95
For two-man team (d)	10,42	12,21	12,21	8,98
Theoretical production rate (m^2/d)	20,73	20,72	20,72	20,72
Duration approx. (pre-interv.)	19,50	22,55	22,83	16,58
For two-man team	9,75	11,28	11,42	8,29
Duration approx., (improved)	14,84	21,21	17,37	15,59
For two-man team	7,42	10,61	8,69	7,80
Scheduled duration (planned), for two-man team	6	6	5	5
Difference in duration vs. planned, pre-intervention (d)	+ 3,75	+ 5,28	+ 6,42	+ 3,29
Difference in duration vs. planned, improved rate (d)	+ 1,42	+ 4,61	+ 3,69	+ 2,8
Reduction with improvements to the original situation (d)	- 2,33	- 0,67	- 2,73	- 0,49
Production rate in building B	29,13	23,86	29,13	23,86
Efficiency (man-h / wall-m^2)	0,32	0,39	0,32	0,38
Production rate set by the schedule for 2-man teams (m^2/day)	*27,00*	*42,20*	*31,60*	*23,2*

Days saved with improvements compared to the original (d)	-6,22	(For two-man team)
Hours saved with improvements compared to the original (h)	99,52	(In total for two men)
Saved costs in total, assumed with hourly wage of 24,50 €	4218,16 € (soc. costs incl.)	

Table 5: Projection for the improvements in building C

A similar cost estimation was constructed for building C as it was for building B earlier. As it happened, some values were similar between the two buildings. The calculation used the same logic as was used in the building B calculations.

Content	Costs and durations
Telehandler cost, estimate	70,00 €/h
Rental worker cost, estimate	26,00 €/h
Number of apartments	37
Amount of drywall sheets	606
Duration of drywall moving, 1 sheet	0,018 h (65 s)
Duration of drywall moving, in total	10,94 h
Duration of wall mount installation, 2 mounts per apartment	0,2 h
Duration of wall mount installation, total time	7 h
Duration of moving frame materials to apartments, 1 apartment	0,25 h
Duration of moving frame materials to apartments, total time	9,25 h
Need for telehandler	6 h
Need for rental worker	27,59 h
Total cost of preparations in building C (theoretical)	1137,38 €

Table 6: Projection of costs in building C

The most important notice made from these calculations was that the site was not aware of the excess in the real duration of the work and based on these calculations the last building would have been delayed over four weeks compared to the original schedule. This means that even though the work could be started right after the previous building, the complete work phase with two simultaneously working teams would be delayed by three and half weeks. In other words, instead of being ready at the end of week 10, the phase would be ready during the week 14 if only the planned one team is used. Instead, what could be done is to use the two teams as they were used in the building B and with improved production rate great gains are possible. The schedule for building C with a projected improvement schedule (green) along with the original schedule (pink) is represented in the figure 25.

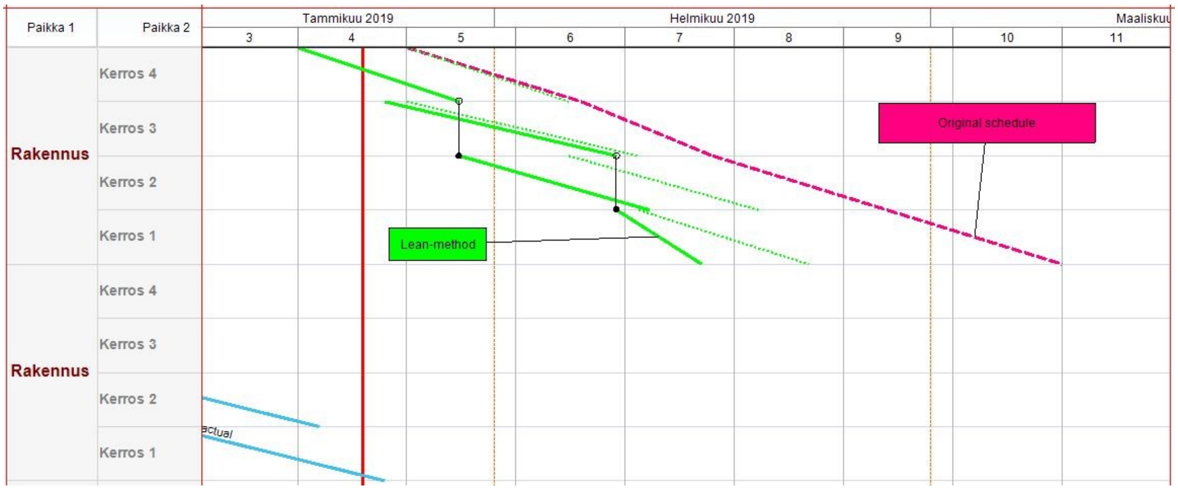

Figure 24: Schedule projection of building C comparing the original and improved methods

The intervention made it possible to find a way to remove the threat of delay completely but only if the workers are used accordingly. This in turn means that if the management can get the workers to start with building C right after the building B, there is a real possibility of finishing the complete work phase well ahead of schedule even though the last building was scheduled wrong. This time saving could be used to plan the following work phases better and to prepare to them with more time, after all, time is something that each site seemed to be lacking in the initial studies of different sites.

13 Analysis of the improvements

After the changes were made, the greatest success was to notice the enthusiasm of the workers to participate in the research. The researched team and the second team were both interested in the changes and very open minded towards the improvements that were presented to them. They also incorporated the upgrades and changes presented in the intervention to their work instantly after they were explained to them. In a long run this is a beneficial factor to the operation of the company. The workers were pleased with the results. The spirit within the two teams working with the management was improved by having the workflow and function better. The workers started to find solutions to develop the work even further. This is an addition that was not seen in the hypothesis of the research.

Another positive thing that was noticed was the participation and activity of the managers on the site. The foreman responsible for the drywall work had not previously done calculations for materials or work before so this intervention was really a good thing for her as a learning experience. The understanding of work was improved, and the managerial options widened which in turn offers the managers ways to better control and manage their work in future projects.

As the previous studies (Jenkins & Orth 2003, Josephson & Saukkoriipi 2007, Forsberg & Saukkoriipi 2007, Kalsaas 2010) had shown, the amount of value-adding work consists only of about one quarter or one third of the active time of the workers and so it was in this case as well. The effect of managerial decisions in improving the productivity of the work is high since there are many solutions to not only decrease wasteful actions from occurring but to also obviate some of the contributory work.

The importance of analyzing the data from multiple viewpoints was also emphasized in this study. By purely trying to identify value-adding and non-value -adding activities, the information might be lacking crucial hints of which can be later used to improve the processes. Therefore, the data should be viewed with more detail than just from the viewpoint of the three main groups. In addition, it is necessary to know the sources and the core of the problems before any improvements can really be made (Santos et al 2006). These factors cannot be found purely by viewing the studied work from a too narrow perspective. By combining different information sources, it is still possible to determine the reasons behind problematic situations. Another factor that needs to be taken into account in measurements and viewpoints is the variation of the work (Santos et al 2006) since a non-planned gap or shift in a steady, on-going work phase can cause surprising problems and changes in the overall flow of the work.

The collected data contains measurable data in forms that need to be evaluated not only based on the numbers, but also based on the work itself. Such information can be gathered reliably only by analyzing video material and with perfect understanding of the work that is studied. If the data is viewed through too narrow perspective, important factors may pass the viewer by and affect the data quite much. The more accurate the division of the data is, the more realistic the data became. With lesser accuracy the data became distorted and the results were pointing to the wrong direction at some sections.

The video recordings offer an effective, yet laborious, way to analyze the conducted work but at the same time there were many things that could not be answered by viewing the video material alone. In many cases a question of “why” was raised to figure out the reasons behind the decisions made by the workers and the solutions of the managers. The managerial actions also do have a large effect on the work since after going through the work phase in greater detail with the workers and explaining the objectives of the work the work started to flow better and there was less uncertainty in the actions of the workers. Of course, there is always the problem of time, but one should not forget that the work should be well planned before hand and be gone through well with all the executing parties before the actual start, but also with proper information channel in use between the two sides. This in turn can reduce the amount of “why”-questions since the workers should be working in a more determined manner and avoid making strange decisions during the workdays.

One aspect to supplement the previously mentioned is the reduction of fragmentation in work that was raised as a factor by the workers in an end interview that was conducted after the second measurement was completed. The varying work forces the workers to start their learning curve, or “flow-state” as they themselves stated, from beginning and thus causing a slowdown of the productivity. Such activity was happening during the work phase later and is completely up to the managers and their plans of time consumption. As it was stated earlier in this thesis, lean cannot directly help with this (George 2010), but it can offer tools to minimize the time consumption of singular work phases and thus offering the managers possibilities to better coordinate different tasks and to minimize variability of the work (Picard 2002).

The lack of certain, specified goal in the beginning of this study made it harder to focus the measurement efforts to a certain segment of the work since the problematic areas were not yet known. The collected data offers many possibilities, but it can also be overwhelming if the goal is not clear at the beginning. Another important finding was that with proper data division, problematic, or functioning, areas of work may arise. If the division of data is too indefinite or lacking the necessary specificity to properly analyze the video material, the collected data will not offer accurate information and can be misleading.

What was also discovered during this research was that the changes do not necessarily need to be complicated and vast, but they can also be quite simple and logical. The most important thing that was discovered was that almost everything from measurement, studies to successful execution of work itself is based on proper planning. By planning the possible propositions, they can be altered into simpler models that are easier to explain to every party whoever the planned changes might affect. One should not also forget the input of the workers in planning; especially in cases where the workers are experienced. A situation where the work is planned in functioning cooperation and where the information is going in both ways actively, should be strived towards. Such harmony between two processes that have the ability to support each other should be strived towards (Aziz & Hafez 2013). Functioning cooperation on a construction site offers tools for the workers to work in an efficient way, for the managers to offer the necessary assistance and for the company, learning possibilities on a wider scale.

14 Summary of the work and further suggestions

The research showed that there is a lot of information available on the construction sites if only one knows how to collect and use it. Although, information is easily gathered, it became clear during the video recordings and their studies that it is important to have some kind of idea of the desired data that is to be collected or measured. This study showed that without precise idea of the subject of closer study, the amount of the information can come as a surprise and as such can cause trouble finding the certain factors one might be looking for. Furthermore, this study showed that with appropriate combination of different measurement techniques it is possible to gather data through multiple sources that have certain areas complementing or reinforcing each other. Also, if the chosen measurement techniques are selected well, the problematic areas might rise above the other data in a clearer way.

Even though, the gathered video material was only for five days in both measurement phases for each worker, the amount of analyzed data was enough to conduct the study for this thesis. Adding the sound to the videos proved to be useful since it is not possible to figure out all the decisions and solutions made by the workers by just watching video feed. Furthermore, the video recordings made from the person's own perspective allow the researcher to see and almost experience the actual daily work as the worker would experience it. This helps in the process of improvement generation.

A significant factor that rose from the analysis of the video material was the fact that even though the studied work phases had similar aspects to them with frame structures construction and the drywall sheet work, they should have been divided into separate groups. This emphasizes the need to accurately divide the data into smaller fractions and analyze them separately; even if they are part of a bigger work phase totality. This offers the researcher more information about what is really happening. In this study, the focus was on a larger scale of things making the study less accurate on smaller changes but offers reliable information about changes made in a bigger picture. To analyze the problematic areas in greater detail, the study should have needed to go deeper into detail of the conducted work, though, that was out of the scope of this thesis.

It also required multiple views from time to time of same sections of the video material to really get a proper grasp of what was going on in the video material. Even though the video contained voices, it was really hard to determine the reasons behind every move of the workers. Sometimes the actions were even made against common sense, but to further analyze these factors, the workers themselves should be involved in the analysis of the video material for every second; not only through an interview since it does not offer the full information that might be missed by the researcher from the video as it was found in this case. This would offer answers to the multiple "why" -questions rising from time to time.

It also became quite clear that in the case company's actions there is a quite large lack in planning of the work which presents itself as a rush for the foremen. Without proper planning the work is planned on the go and it has an effect to the everyday work. From the workers' perspective the lack of plans usually represents itself as missing materials, poor information and changing work. The last of the previously mentioned was not liked by the workers when interviewed since the flow of work is interrupted and the work might be changed to a completely different type of work for a period of time. Of course, the reason for such happenings might not always be the lack of planning, but still it should be avoided or at least planned to a point where one phase of the other work is finished, and the workers are forced to move to the next area. This would be the optimal situation from the workers' perspective, but also from the managerial side since there would be finished areas for possibly other contractors to use.

There are no reasons why the results and methods presented in this thesis could not be implemented on other construction sites of the case company or any other. The changes do not require vast knowledge of lean philosophy, even though it does help if the idea of lean is known. Still, everything can be simplified and taught, but the general idea should be something considered self-evident: everything can be made better and more efficient. One should still recognize the fact that the workers might be working better than the literature values of construction work consumptions given by Wind et al (2014), but that does not mean that there is still room for improvements as was shown in this study.

There are problems that must be overcome before any improvements can be made, as it was discovered in this research. The researchers may run into some suspicion and disbelief on the construction sites when such studies as this are presented and especially if the management is presented with ideas such as investing money to gain more savings. Another problematic factor that was found was that even if the improvement of the productivity and the extra time offered by it should seem as tempting, it can be seen on construction sites that even though something better is presented to workers or managers, they seem to drift back to the old ways gradually if they are not monitored and tutored properly. This anchor, as it can be viewed, is something that is hard to lose, but can be lost if there is enough of commitment on the site to integrate new methods and improvements to the processes. In this study, arguments to support lean thinking were presented in chapter 12 and its sub-chapters, but even with solid results that show the potential of improvements, the change might still be hard to achieve. Of course, there are multiple factors that affect that, but one cannot exclude the great effect of personal attitudes towards new things (Junnonen & Kankainen 2007, Koskenvesa & Koskela 2012).

One major project for the case company in further implementations of lean philosophy would be to have few construction sites follow the lean philosophy and use the tools offered by it in a controlled manner and measure the changes that happen. They need to find ways to get the workers and managers on the site to commit to the improvements and new ways of working and the best way to do so, is to show them just what can be done to improve the productivity of certain areas of work but also to show how the work of the different parties of the construction site can be made easier. The case company itself has all the tools to do just that, so it would not require large changes in their core operations. These projects could then be used as examples to the other projects that are on-going or those that follow since it would seem also on construction that the power of example should not be underestimated.

One should always keep in mind the distinctive differences between the manufacturing and construction industries in the sense of the flows of processes. There are limitations in the automation of construction work still present today causing inevitable variation in the different processes of construction. These variations can only be affected so much, but what should be considered is the point made by Serpell et al (1995) that not all factors can be controlled, but they should still be taken into consideration to avoid bigger problems. Therefore, complete removal of waste might not be possible in construction, but the minimizing of waste can be maximized by good planning and proper execution along with on-going supervision. The continuous improvement is supported by the comprehensive documentation of the work, which unfortunately is often neglected in different processes and for some parts this phenomenon could be seen in the operations of the case company as well.

This intervention to improve productivity by lean philosophy was a success for every party that was involved, and it offered something new to the case company that hopefully will be used for many improvements during the coming years. The case company was pleased with the results on this small-scale research. The benefits gained from this research have shown the actual numerical values of the improvements and the practical approaches to the improvement of the work in general. This newly discovered knowledge was what the company was looking forward to in the planning of the work making the research successful for the case company.

15 Sources

Alarcón, L.F. & Serpell, A. 1996, 'Performance Measuring Benchmarking, and Modelling of Construction Projects' In: *4th Annual Conference of the International Group for Lean Construction.* Birmingham, UK.

Arora, K.C. 2004. *Comprehensive Production and Operations Management*. New Delhi, India. Laxmi Publications (P) Ltd. pp.2-11, (662/865). ISBN: 81-7008-581-0.

Aziz, R.F. & Hafez, S.M. 2013. 'Applying lean thinking in construction and performance improvement', In: *Alexandria Engineering Journal (2013) 52*. Structural Engineering Department, Faculty of Engineering, Alexandria University, Egypt. 25 Feb 203. pp. 679-695.

Costa, D.B. & Formoso, C.T. 2003, 'Guidelines for Conception, Implementation and Use of Performance Measurement Systems in Construction Companies' In:, *11th Annual Conference of the International Group for Lean Construction.* Virginia, USA, 1-.

Ebbesen, R.M. 2004, 'A System for Evaluating the Ongoing Building Process - Theory and Practice' In: Bertelsen, S. & Formoso, C.T., *12th Annual Conference of the International Group for Lean Construction.* Helsingør, Denmark, 3-5 Aug 2004.

Forsberg, A. & Saukkoriipi, L. 2007, 'Measurement of Waste and Productivity in Relation to Lean Thinking' In: Pasquire, C.L, C.L. & Tzortzopoulos, P., *15th Annual Conference of the International Group for Lean Construction.* East Lansing, Michigan, USA, 18-20 Jul 2007. pp 67-76.

Formoso, C.T., Isatto, E.L. & Hirota, E. 1999, 'Method for Waste Control in the Building Industry' In: *7th Annual Conference on the International Group for Lean Construction.* Berkeley, CA, USA, 26-28 Jul 1999. pp 325-334.

George, M.O. 2010. *The Lean Six Sigma Guide to Doing More with Less, Cut Costs, Reduce Waste and Lower Your Overhead*. Hoboken, New Jersey, USA. John Wiley & Sons, Inc. pp.1-50. ISBN: 978-0-470-53957-6

Goldsby, T., Martichenko, R. 2005. *Lean Six Sigma Logistics: Strategic Development to Operational Success*. USA. J. Ross Publishing. pp.3-59. ISBN: 1-932159-36-3.

Haapasalo, H. 2011. 'Lean-filosofian ja menetelmien soveltaminen Suomessa', *Rakentajain kalenteri 2011*, Rakennustieto Oy. pp.178-183.

Harris, F., McCaffer, R. & Edum-Fotwe, F. 2013. *Modern Construction Management – 7th edition*. West Sussex, UK. John Wiley & Sons, Ltd. pp.7-116. ISBN 978-0-470-67217-4.

Hirano, H. 2010. *JIT Implementation Manual, The Complete Guide to Just-In-Time Manufacturing*. Boca Raton, FL, USA. Taylor & Francis Group, LLC. pp.145-153. ISBN-13: 978-1-4200-9025-3 (eBook – PDF).

Jenkins, J. L. & Orth, D. L. 2003. Productivity improvement through work sampling. *AACE International Transactions,* CS51-CS57. Morgantown, WV, USA. Retrieved from https://search.proquest.com/docview/208178476?accountid=27468

Josephson, P-E. & Saukkoriipi, L. 2007. *Waste in construction projects: call for a new approach*. Report. The Centre for Management of the Built Environment, Building Economics and Management, Chalmers University of Technology, Göteborg, Sweden.

Junnonen, J.-M. & Kankainen, J. 2007. ’Rakennusalan muutostrendit Suomessa’, *Rakentajain kalenteri 2007*, Rakennustieto Oy. pp.504-509.

Kalsaas, B.T. 2010, 'Work-Time Waste in Construction' In:, Walsh, K. & Alves, T., *18th Annual Conference of the International Group for Lean Construction.* Haifa, Israel, 14-16 Jul 2010. pp 507-517.

Kalsaas, B.T. 2013, 'Measuring Waste and Workflow in Construction' In:, Formoso, C.T. & Tzortzopoulos, P., *21th Annual Conference of the International Group for Lean Construction.* Fortaleza, Brazil, 31-2 Aug 2013. pp 33-42.

Kartam, S., Ballard, G. & Ibbs, C.W. 1994. ‘Construction models: A new integrated approach’, *Lean construction*, pp.379-389. Rotterdam, Netherlands. A.A. Balkema. ISBN 90-5410-648-4.

Koskela, L. 1993. ‘Lean production in construction’, *Lean construction*, pp.1-9. Rotterdam, Netherlands. A.A. Balkema. ISBN 90-5410-648-4.

Koskela, L. 2000. *An exploration towards a production theory and its application to construction*. Espoo, Finland. Technical Research Centre of Finland, VTT Publications. pp.3-73. ISBN 951-38-5566-X

Koskenvesa, A. & Koskela, L. 2012. *Ten Years of Last Planner in Finland – Where Are We*. 10p. In:, Tommelein, I.D. & Pasquire, C.L., *20th Annual Conference of the International Group for Lean Construction.* San Diego, USA, 18-20 Jul 2012.

Lee, S., Diekmann, J.E., Songer, A.D. & Brown, H. 1999, 'Identifying Waste: Applications of Construction Process Analysis' In: *7th Annual Conference of the International Group for Lean Construction.* Berkeley, USA, 26-28 Jul 1999. pp 63-72

Loera, I., Espinosa, G., Enriquez, C. & Rodriquez, J. 2013. ‘Productivity in Construction and Indtustrial Maintenance*, *Procedia Engineering 63*, pp.947-955. Mexico. Elsevier Ltd. DOI: 10.1016/j.proeng.2013.08.274.

Lohilahti, O. 2017. ’Rakennusalalla työn tuottavuus ei ole juuri kasvanut 40 vuodessa – ongelmana on ollut vuoropuhelun puute’, *Helsingin Sanomat*, 2 Sep 2017, Available: https://www.hs.fi/talous/art-2000005350624.html

Manninen, S. 2011. *Rakennusalan hukkien priorisointi ja eliminointi*. Master’s Thesis. Oulu University, Department of Industrial Engineering and Management. Oulu.

Picard, H.E. 2002, 'Construction Process Measurement and Improvement' In:, Formoso, C.T. & Ballard, G., *10th Annual Conference of the International Group for Lean Construction.* Gramado, Brazil, 6-8 Aug 2002.

Rakennuslehti, 2019. Available: https://www.rakennusteollisuus.fi/Tietoa-alasta/Tyoelama/Tietoja-tyovoimasta-rakennusalalla/

Rakennusteollisuus, 2013. *Rakentamisen yhteiskunnalliset vaikutukset 2012*. Available: http://www.rakennusteollisuus.fi/globalassets/suhdanteet-ja-tilastot/rakentamisen-yhteiskunnalliset-vaikutukset-2012.pdf

Raval, P.A., Bhavsar, J.J. and Oza, D.K. 2017. ‘Categorization of Construction Waste’ In: *International Conference on ‘Research & Innovations in Science, Engineering & Technology’ ICRISET-2017*. Anand, India, 17-19 Feb 2017.

Santos, J., Wysk, R.A., Torres, J.M. 2006. *Improving Production with Lean Thinking*. Hoboken, NJ, USA. John Wiley & Sons, Inc. pp.1-165 ISBN 978-0471-75486-2 (cloth)

Shingo, S. 1984. *Study of ‘Toyota’ Production System from Industrial Engineering Viewpoint*. Osaka, Japan. Shinsei Printing Co., Ltd. pp.13-298. ISBN-13: 978-4820702658.

Škec, S., Štorga, M. & Ribarić, Z. T. 2016. ‘Work Sampling of Product Development Activities’ In: *Technical Gazette 23,* Jun 2016. pp.1547-1554. ISSN: 1848-6339 (Online)

Seppänen, O. & Kenley, R. 2005, 'Performance Measurement Using Location-Based Status Data' In: *13th Annual Conference of the International Group for Lean Construction.* Sydney, Australia, 19-21 Jul 2005. pp 263-269.

Serpell, A., Venturi, A & Contreras, J. 1995. ‘Characterization of waste in building construction projects’, *Lean construction*, pp.67-77. Rotterdam, Netherlands. A.A. Balkema. ISBN 90-5410-648-4.

Souraj, S., Rahim, A., Carretero, J.A. 2010. ‘The integration of Six Sigma and lean management’, *International Journal of Lean Six Sigma*, Vol 1 (no. 3) pp. 249-274. Brunswick, Canada. Emerald Group Publishing Limited. DOI: 10.1108/20401461011075035

Statistics Finland, 2017. *Apartment prices, appendix 3: Index of old and new apartments* [web publication]. Helsinki, Finland. ISSN=2323-878X. URL: http://www.stat.fi/til/ashi/2017/12/ashi_2017_12_2018-01-30_kuv_003_fi.html

Statistics Finland, Productivity 2018. https://www.stat.fi. Visited 29.12.2018.

Statistics Finland, 2019. *Construction Cost Index* [web publication]. Helsinki, Finland. ISSN=1795-4282. URL: http://www.stat.fi/til/rki/2019/02/rki_2019_02_2019-03-15_tie_001_fi.html

Vihmo, J. 2013. *Tilastot ja* suhdanteet, Rakennusteollisuus. Visited 13.4.2019. Available: http://www.rakennusteollisuus.fi/Tietoa-alasta/Talous-tilastot-ja-suhdanteet/

Wind, N., Kivimäki, C., Koistinen, L. Lahtinen, M. & Koskenvesa, A. 2014. *Rakennus-töiden menekit 2015*. pp. 93-112. Tampere, Finland. Rakennustieto Oy. ISBN 978-952-267-077-9.

Womack, J.P. & Jones, D.T. 2003. *LEAN THINKING. Banish Waste and Create Wealth in Your Corporation*. London, UK. Simon & Schuster UK Ltd. pp.15-89. ISBN: 978-0-7432-3164-0.

Zhao, Y. & Chua, D.K.H. 2003. 'Relationship Between Productivity and Non Value-Adding Activities', In: *Proceedings of the 11th Annual Conference of the International Group for Lean Construction*, Virginia, USA. 1-.

Rakennuslehti, 2019. Available: https://www.rakennusteollisuus.fi/Tietoa-alasta/Ty-oelama/Tietoja-tyovoimasta-rakennusalalla/