

# Continuous Improvements – The Key to Industrial Construction in Practice?

A case study at a large Swedish construction firm

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**KTH Industrial Engineering  
and Management**

Master of Science Thesis  
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En fallstudie i ett stort Svenskt byggföretag

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Examensarbete  
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av

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Examensarbete INDEK 2014:44

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Godkänt 2014-06-16	Examinator Mats Engwall	Handledare Matti Kaulio
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#### Sammanfattning

Byggindustrin har länge tampats med en undermålig produktivitetsutveckling i förhållande till andra industrier och då speciellt processindustrin. Det har gjorts många försök att industrialisera byggandet för att dra nytta av standardiserade produkter och processer, i Sverige mest utmärkande under 60-talets miljonprogram vilket var kraftigt influerat av dåtidens rådande produktionsfilosofi - massproduktion. För närvarande baseras industrialiseringsarbetet på koncept från lean production där fokus ligger i att eliminera alla former av slöserier via det som kallas industriellt byggande.

Syftet med denna rapport är att med hjälp av filosofier från lean production undersöka hur koncept från industriellt byggande appliceras i produktionen av bostäder där prefabricerade betongelement används. Anledningen till att detta perspektiv väljs baseras i att ett konceptuellt ramverk deriverat från lean production lämpar sig ytterst väl för att undersöka och analysera värdeflöden, speciellt i en produktionsmiljö. Ett av Sveriges största byggbolag, NCC AB, använder sig för närvarande av tekniska plattformar och konceptuella produkter för att industrialisera sin process vid upplåtandet hyresfastigheter med minimering av produktionskostnad och tid som huvudmål. En av huvudkomponenterna i produktionen av dessa bostäder är prefabricerade betongelement vilket gör att företaget lämpar sig ytterst väl för en fallstudie.

Några av de huvudresultat som denna rapport utmynnat i är att det studerade företaget och i förlängningen hela byggbranschen dras med ett kraftigt eftersatt förbättringsarbete - continuous improvements vilket kan vara en av huvudförklaringarna till sektorns låga produktivitetsutveckling jämfört med processindustrins dito. Vidare har tre fokusområden tagits fram baserat på den utförda fallstudien som sedan ställts i relation till teori inom industriellt byggande. Dessa tre fokusområden har givits epitetet pelare för industrialisering och det argumenteras för att dessa pelare måste beaktas för att möjliggöra en framgångsrik industriell byggprocess.

**Nyckelord:** Industriellt byggande, lean, ständiga förbättringar, produktion, flow, produktivitet



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Approved 2014-06-16	Examiner Mats Engwall	Supervisor Matti Kaulio
	Commissioner NCC AB	Contact person Kajsa Simu

**Abstract**

The construction industry has during a long time suffered from poor development in productivity compared to other industries, especially the manufacturing industry. Many initiatives for industrialization have been made during the past decade in order to benefit from standardized products and processes, in Sweden most notably through “Miljonprogrammet” in the 1960s. This era was heavily influenced by the prevailing production philosophy in the manufacturing industry at the time - mass production. Today the industrialization initiatives are based on concepts from lean production where the focus is upon eliminating all forms of waste through what is related to as industrial construction.

This report is based on the purpose to, using lean philosophies and tools, investigate how concepts from industrial construction is applied in the production of residential buildings using prefabricated concrete elements. The perspective of lean production is chosen because it is suitable for the study of value flows, especially in a production environment. One of the largest Swedish construction firms - NCC AB, currently deploys technical platforms and conceptual products in order to industrialize the processes used to construct rental housing with production cost and time reduction in focus. One of the key components used are prefabricated concrete elements which means the company is suitable as a case study.

Some of the main results extracted through this research is that the studied company and in extension the entire construction industry performs poorly in terms of continuous improvements. This could be a main explanation for the industry’s productivity development in comparison with other industries, especially the manufacturing industry. Further, three areas of particular importance are derived from the case study and compared to theory within industrial construction. These areas are, in this report, labeled pillars for industrialization and it is argued for that these pillars needs to be considered in order to enable a successful industrialized construction process.

**Key-words:** Industrial construction, lean, continuous improvements, production, flow, productivity

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This report is the result of a research project conducted in a master's thesis in industrial management comprising 30 university credits at the Royal Institute of Technology in Stockholm, Sweden. It would not have been possible to conduct this research without the collaboration with NCC AB and especially professor Lars Stehn and Adjunct Senior Lecturer Kajsa Simu, both employed by the company. Further, we would like to thank every member of the industrial construction project used, in this report, as a practical case for production. The members of this project took us in and, with great patience, helped us in achieving our goals through always answering our questions and allowing us to participate in both the production and the management thereof.

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**Victor Atterström & Henric Theorin,  
Stockholm, 16th of June, 2014.**

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Appendix 1 – Industrialization evaluation model

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Appendix 3 – Value stream map

Appendix 4 – Time data

# 1. Introduction

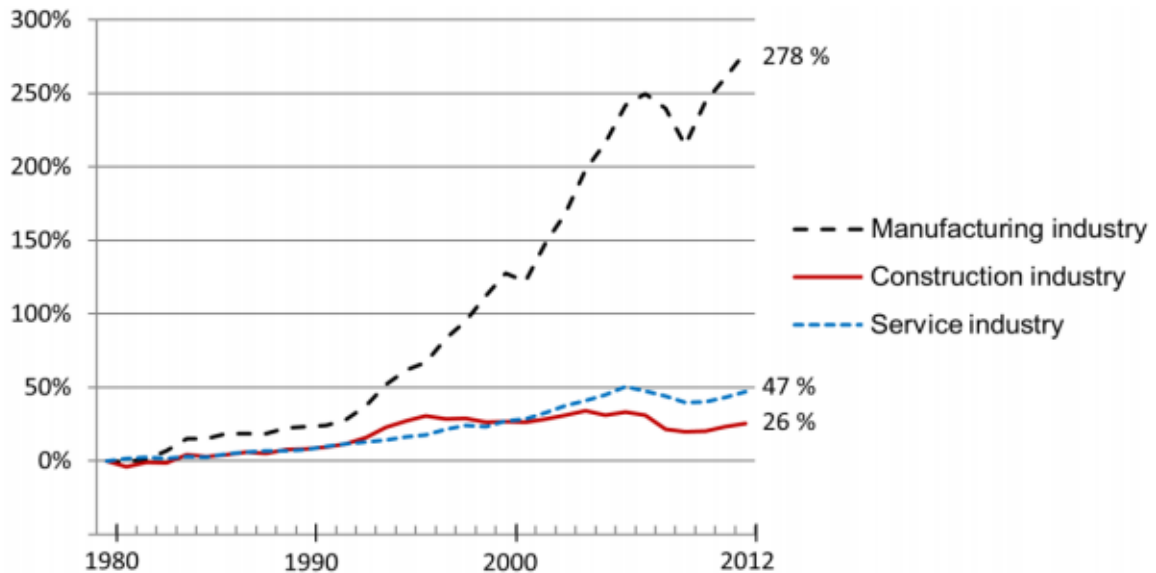
*This chapter presents a general background for this master's thesis. This is followed by the purpose and the research questions that the research handles. In the end of this chapter delimitations are discussed and the structure of the following report is presented.*

## 1.1 Background

Within the manufacturing industry the focus has been shifted from mass-production and economics of scale to resource and flow efficiency of the entire production process. This focus ensures that a competitive advantage can be established and maintained in the market place. A key question for any company dealing with production of goods or services is to provide its offerings at the right price and at a sufficiently high quality in order to meet quickly changing market demand. At the moment (and have been for some time) a widely used concept of production is the concept of lean production (Rother & Shook, 1998) which aims to reduce, for the client, non-value adding work. Further the concept strives to construct a rational production apparatus which is constantly improved through step-wise improvements in order to deliver the right goods at the right time (as demanded by the customer) (Petersson et. al, 2010).

An industry that could take advantage of the experiences from the manufacturing industry's work with process development in general and applied lean philosophy in specific is the construction industry. What is special about this industry is that the production facilities are temporary in nature and assigned to specific construction projects which could span for several years (Bergenudd, 2003). Stemming from the fact that the projects themselves are often relatively unique means that there must be some room for specialization of the, for the project, unique production process.

Studies conducted in the field of construction efficiency show that the typical construction project is associated with relatively large, for the customer, non-value adding activities - so called waste (Josephson & Saukkoriipi, 2005). Further, it has been shown that the productivity in the construction industry as a whole is lagging compared to other industries. For example, the productivity within the automotive industry has been increasing with 7 % per annum between the years 1993 and 2002, whilst during the same period of time the productivity within construction has been decreasing with 0,2% annually. A study performed by the Swedish Konjunkturinstitutet (2014) revealed (see Figure 1) that even the service sector (which is, just like the construction sector, mainly dealing with a non-standardized work environment) outperforms the construction industry in terms of productivity improvements.



**Figure 1** - Productivity comparison, different sectors in Sweden (Konjunkturinstitutet, 2014)

This shows that there is great potential for improvements regarding efficiency which, if dealt with properly, can result in increased profitability for successful companies, and most importantly more affordable residential and professional buildings for the general public. Productivity in this case is defined as production output per spent labor hour (Konjunkturinstitutet, 2014).

Another important reason to industrialize construction and improve the processes used is that the construction industry affects the total environmental burden to a great degree. In the year 2004 a report by the American environmental agency reported that the construction industry accounts for around 39 % of the total energy consumption and 40 % of the total landfill material produced in the country. Industrialized construction, which aims to reduce the waste of resources, is one way to reduce the effects on the environment stemming from construction and is as such an excellent method to ensure sustainability in the future construction of residential and industrial buildings (Nahmens & Ikuna, 2012).

One way to approach the industrialization of construction is to develop well defined concepts where the possibility for product variations are controlled and intentionally kept low (Johnsson et. al, 2011). This approach facilitates the realization of leveled value streams in the entire value chain and to construct buildings at a lower total cost through continuous improvements and standardized work. Further, an efficient production process also provides possibilities to substantially reduce the production time which frees resources and reduces costs associated to on-site construction (Von Platen, 2009).

The research conducted within industrialized construction is predominantly theoretical and in the past decades the research has been influenced by philosophies and concepts linked to lean production (Koskela, 1993). Remarkable for this area of research is, however, that few practical studies with a focus on production and researcher presence exists, especially in a Swedish context (e.g. Dulaimi & Tanamas, 2001; Bertelse, 2004; Salem et. al, 2006; Andersen et. al, 2012). Considering the industry's poor productivity improvements compared to other industries, one possible conclusion is that the gap between theory and practice is relatively large; therefore such a practical study is imperative.

## **1.2 Purpose**

The purpose of this study is to investigate, using lean philosophies, how industrialized construction concepts are applied to the production of residential buildings and how this approach is manifested in practical construction projects based on prefabricated construction parts. Included in the purpose is to evaluate production processes and improve upon them.

## **1.3 Research Questions**

Based on the preceding discussion and purpose the following research questions are formulated.

- How does a large construction firm use industrial construction to produce residential buildings?
- What hindrances arise in the application of the industrial construction concept?
- How can lean concepts be used to investigate and improve the production?

## **1.4 Delimitations**

The empirical data was gathered from investigating a specific industrialized construction project in which the production of a concrete multi story building at one specific company was analyzed. The project is part of a larger initiative in which several similar buildings are constructed in the Stockholm region. The ideal scenario is to analyze the production of several buildings, but due to time constraints and the fact that the buildings are not synced in terms of production times this was not possible.

Another delimitation is that only a part of the entire construction project was investigated. The process investigated was the construction of the concrete skeleton of one stairwell. This delimitation was made mainly due to the fact that it takes around two years to finish a project of this magnitude.

The on-site case studied is part of a case study of the Swedish construction industry and is carried out by a Swedish construction company, and as such the culture and norms of the Swedish construction industry forms the basis for the empirical data for this report. Furthermore, the multi story construction project is budgeted to around 200 million SEK, which results in delimitations being made to the economical scope of the construction project.

## **1.5 Report Structure**

The report is divided into 6 chapters, where at the start of every chapter a brief summary is provided. The summaries for each chapter are presented below.

### *Chapter 1 - Introduction*

This chapter presents a general background for this master's thesis. This is followed by the purpose and the research questions that the research handles. In the end of this chapter delimitations are discussed and the structure of the following report is presented.

### *Chapter 2 - Theoretical framework*

In this chapter a theoretical framework is presented and comprised of research previously done in the field of industrial construction and lean production. The framework is used as a conceptual framework to understand that which is being studied as well as a basis for analysis and conclusions.

### *Chapter 3 - Methodology*

In this chapter a logical exposition of the research methodology and the chosen research methods are presented and argued for.

### *Chapter 4 - Results*

This chapter presents the studied on-site case in depth as well as a discussion of the results, where relevant. Further, observations and interview material are presented here along with other gathered empirical data.

### *Chapter 5 - Discussion*

This chapter contains an in-depth analysis and discussion about the empirical data, and the identified problems are sorted into three main areas of importance. These areas are then discussed in relation to the studied case as well as the construction industry.

### *Chapter 6 - Conclusion*

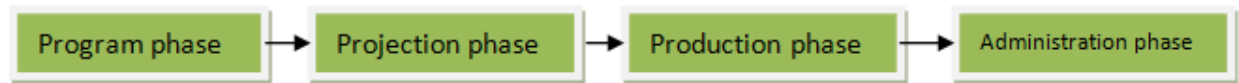
Conclusions and theoretical implications from the discussion are presented here. Further, conclusions about this research's implications on the construction industry are made followed by conclusions regarding three aspects of sustainability. The chapter ends in proposing further research based on the findings herein.

## 2. Theoretical Framework

*In this chapter a theoretical framework is presented and comprised of research previously done in the field of industrial construction and lean production. The framework is used as a conceptual framework to understand that which is being studied as well as a basis for analysis and conclusions.*

### 2.1 Industrial Construction

The major difference between an industrialized construction process and a traditional method of construction lies within the project and its definition. Constructing a building in the traditional way means translating the customer demand into architectural designs, blueprints, construction methods and processes (Callisen, 2008). The work is then conducted in projects unique for the specific customer, the construction is built, the project is considered done, disbanded and its members are engaged in new projects. This process is described adequately in the book “Byggprocessen” by Uno Nordstrand (2000). Simply put the process is comprised of four major phases; The creation of the program, Projection, Production and Administration.



**Figure 2** - The value delivering process in construction (Nordstrand, 2000)

In the program phase the scope of the project is defined in terms of location, size, technical solutions, time and cost constraints as well as financing solutions, in essence this is where the client's needs are defined and sorted in manageable terms (Bergenudd, 2003). This information is then used as a specification during the projection phase where a visualization of that to be constructed is created. Included here are blueprints, calculations, technical specifications, material selections, product description and as of late 3D models of the construction. These aspects are to be as detailed as required to actually produce what is described. Further, the realization of the construction in terms of labor, machines and material distribution are also included in this phase (Nordstrand, 2000).

These two phases are then followed by the production phase, where all the documentation and specifications are used to construct the, until now, immaterial product. This is done by forming an on site organization comprised of leadership functions in the form of officers, and labor in the form of construction workers. The project is disbanded when the construction is finished and the administration phase is initiated (the client is handed control of the construction) and the project members move on to new projects. Ideally the program and projection phase have yielded a detailed construction plan which implies that the production phase is solely a matter of producing, but more often than not changes are made that affects the production due to poor quality in planning, changed client demands or unforeseen issues that hinders the plan from being executed as thought (Nordstrand, 2000; Bergenudd, 2003).

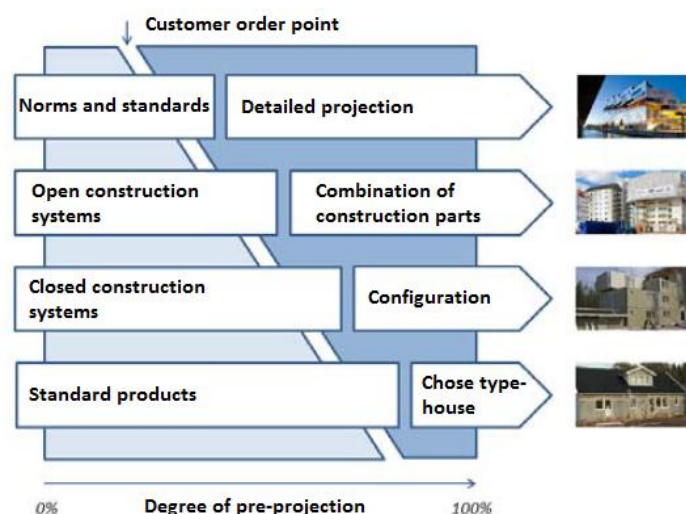
As presented in the introduction of the report the construction industry is lagging in terms of productivity compared to other industries. It is possible this poor productivity is linked to its general methods of delivering customer value (Von Platen, 2009; Lundkvist & Martinell, 2009), especially that of focusing the production to the specific construction site of the project, which means that the production apparatus

is limited in time. This hinders standardization and important process improvement initiatives (why invest in improvements for something that will be abolished in the relatively near future). Lately the industry has focused on moving parts of the production to dedicated and rational production facilities where the components making up a finished house is, to different degrees, prefabricated and later transported to the construction site for assembly. This strategy is part of the concept industrialized construction, which rests upon a new production philosophy, and some of the differences between this philosophy and the conventional philosophies can be seen in table 1 below.

**Table 1** - The conventional and the new production philosophy (Koskela, 1993)

	<b>Conventional production philosophy</b>	<b>New production philosophy</b>
<b>Conceptualization of production</b>	Production consists of conversions (activities); all activities are value adding	Production consists of conversion <i>and</i> flows; there are value adding and non value adding activities
<b>Focus of control</b>	Cost of activities	Cost, time and value of flows
<b>Focus of improvement</b>	Increase of efficiency by implementing new technology	Elimination or suppression of non-value adding activities through continuous improvements and new technology

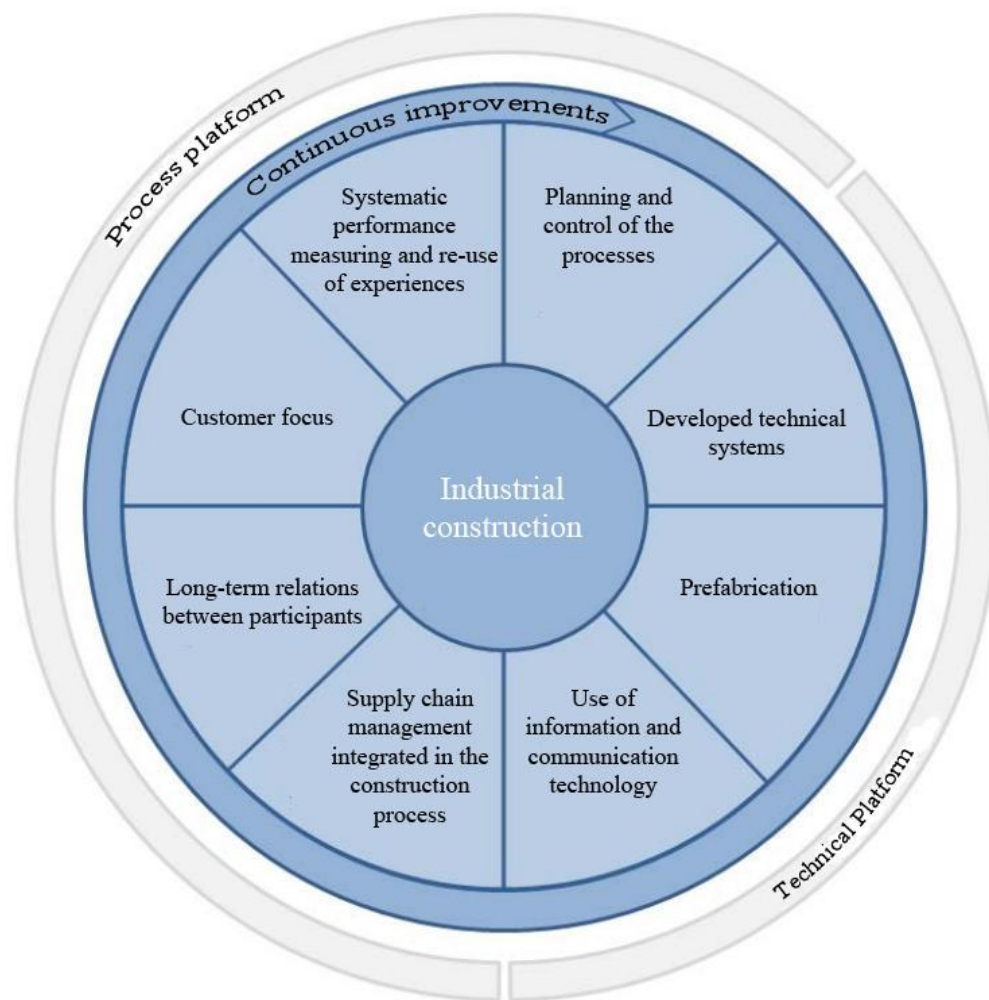
Considering that industrialized construction strives for long-term process improvements it can be concluded that the more specific and predefined the project is, the higher the extent of possible industrialization. This is because the processes can be shared between similar projects and utilized during a larger time-span. The disadvantages with an extensive pre-planning strategy is that the offering to the market naturally becomes more limited, and as such, variation in customer demand is harder to cope with. Figure 3 below illustrates the implications on the production methods based on the point of customer entry compared to the extent of project pre-planning. The industrialization of construction is ideally focused on situations where a moderate to high project pre-planning is possible (Johnsson et. al, 2011).



**Figure 3** - Building systems based on the customer order point (Johnsson et. al, 2011)

Utilizing a strategy with a high degree of project pre-planning can thus be seen as an enabler of, both practically and economically, long-term process improvements and continuity across a firm's industrialized project portfolio.

In order to achieve this continuity the literature suggests that two aspects be developed in a firm striving for industrialized construction - a process platform and a technical platform. The process platform contains information about *how* (e.g. planning, process control, knowledge reuse etc.) things should be done and the technical platform contains information on *what* (technical solutions, construction system, prefabrication etc.) should be done (Johnsson et. al, 2011). The different aspects of these platforms and its relationship to industrialized construction are depicted in Figure 4 below.



**Figure 4-** The different areas of industrial construction (Johnsson et. al, 2011)



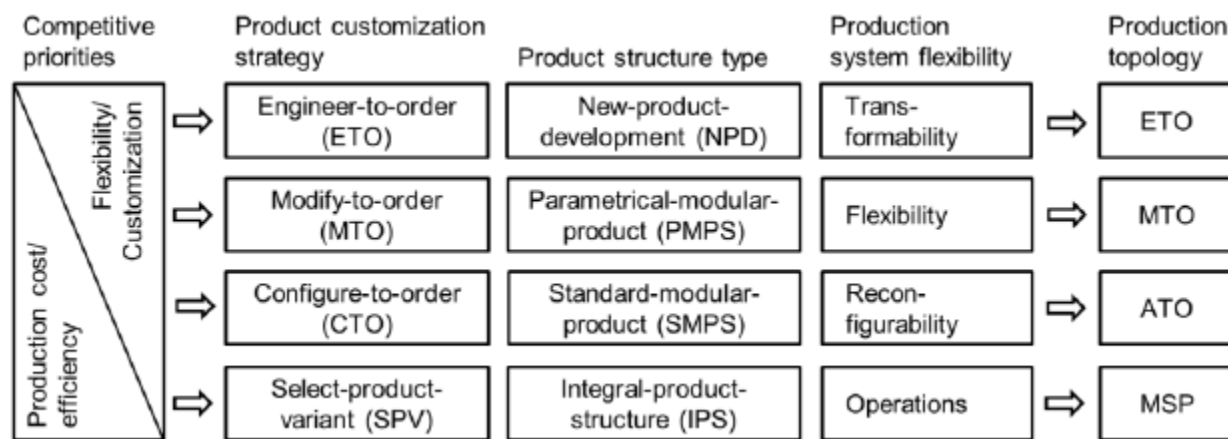
An extensive description of these aspects is available in the publication by Johnsson et. al (2011), this is summarized by the authors of this report in table 2 below.

**Table 2** - Description of the eight areas of industrial construction

Area	Description	Outcome
Planning and control of the processes	In depth planning from project cradle to grave, the whole project should be planned before construction starts.	Reduces waste and increases quality
Systematic performance measuring and reuse of experiences	Measuring process performance and including input from all involved parties (including suppliers)	Important in order to create a process which continuously improves
Customer focus	Systematic market surveying to capture market and customer demands	Ensures that the right products with the right quality is being produced. Useful for market segmentation and development of specialized product offerings.
Long-term relations between participants	Choosing suppliers should be methodical and should strive towards co-developing the organizations.	Saves time in production, improves quality and product function through feedback loops.
Supply chain management integrated in the construction process	Value flows to the construction site should be coordinated with flows from the construction site. Flows should be based on the Just in time principle.	Moving activities from the construction site to rational production facilities saves production time and improves quality.
Developed technical systems	Technical solutions for different aspects such as frame, façade, installations etc. and the compatibility between them.	Essential part of industrialized construction, facilitates development of subsystems which in turn means an improved product.
Prefabrication	Construction parts is produced in an environment suitable for rational production and is then transported to the construction site for assembly.	Reduces the number of on site work activities as well as product variations.
Use of information and communication technology	Structured usage of Information and Communication Technology systems.	Supports processes, especially in the pre-planning processes through 3D visualization and financial calculation.

To assess the degree to which a (construction) company is industrialized, Lessing et. al (2005) have developed a model that categorizes the eight different areas described above and assigns a score of 0-4 on a Likert Scale to each one (See appendix 1). This model can be used as a tool for both self-evaluation as areas which lags behind are brought forward and can be improved upon and further industrialization can be achieved as well as a tool to compare the degree of industrialization between different projects.

As mentioned in the introduction to this report the concept of industrialized construction comes with implications on the value proposition to the market. The industrialization is related to the degree of pre-planning and that, in turn, affects what can be offered to the customer in terms of customization. Specifically, different production typologies (how to deliver value) imply different degrees of pre-planning. In a doctoral thesis by Gerth (2013) four typical production typologies are presented and their relationship to construction and organizational strategy is discussed. This is show in figure 5 below.

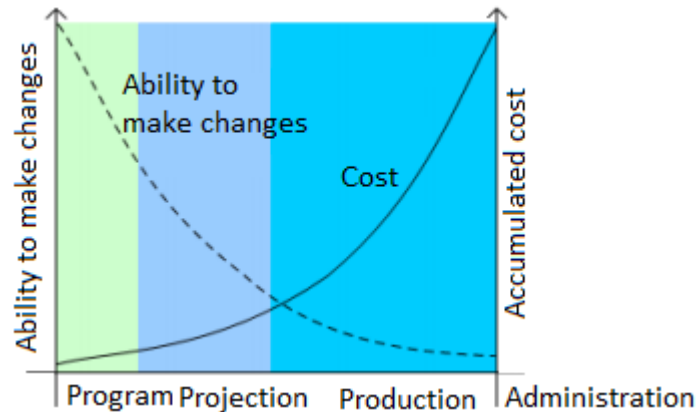


**Figure 5** - The four generic production typologies (Gerth, 2013)

Here engineer to order (ETO) is best suited for projects that are delivered with unique solutions to a unique product. Because of the tight link between standardization and the capture of repetitive methods and industrialization it comes as no surprise that the production typology MTO (Modify-to-order), ATO (Assemble to order) and MSP (Make standard products) are, in increasing order, more suitable for industrialization. Further, the picture becomes clearer if these typologies are looked upon in the light of the definition of industrial construction brought forward by Johnsson et. al (2011), i.e the MTO, ATO and MSP typologies' interlinkage to industrial construction.

Important to note is the organizational implications these production typologies present on an organization, e.g. how an organization should be structured to deal with the chosen or implied production typology. Apart from the organizational implications these typologies have on any one producer, the different production typologies are also linked to certain production philosophies. For example, the ETO typology is typically linked with a project-to-project based production, and the usage of stored information is quite low. The further down the model one goes, the higher the relevance of industrial production concepts. Since the CTO and SPV typologies incur lower customization, industrial concepts can be applied on the production of such typologies with greater success (Gerth, 2013).

One reason for this lies, inherent, in the methods and processes of which customer demand is realized in a building, bridge or any other type of construction project. Callisen (2006) proposes that changes made during the process, like in any kind of project based business, incur costs based on where in the project life-cycle the changes are being made. Typically, changes made in production cost a lot more than changes made pre-production (program or projection phase). This relationship, along with the possibility to influence the project, is illustrated in Figure 6 below.



**Figure 6** - Cost and influence based on the different phases (Callisen, 2006)

This relationship means that, in order to perform well in an economical sense the production should be dedicated to producing rather than dealing with changes, as that leads to unnecessary cost connected to something that could be done beforehand.

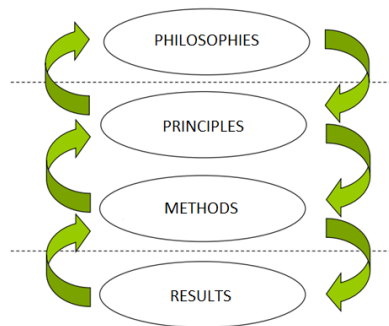
In order to understand the area of industrial construction, it is relevant to investigate the source from which the concepts came. In this case, the manufacturing industry has served as a source of inspiration for initiatives dealing with industrializing construction (Ballard, 2000). Below, aspects from the manufacturing industry relevant to this report are presented.

## 2.2 Lean Production

The processing industry has been developing vastly over the last century, starting with the introduction of the mass-production philosophy initiated by Henry Ford through the use of the conveyer belt and breaking up the realization of a product in discrete processing steps. Prior to this revolutionizing shift in production philosophy the processing industry was similar to that of traditional construction, e.g. specialists performing work in a more autonomous way i.e. utilizing the ETO product philosophy (Womack et al, 1990). Henry Ford shifted an entire industry from this ETO philosophy to a philosophy revolving around MSP and mass production, manifested as the T-Ford. The mass production philosophy was the dominating production philosophy for several decades adopted by many industries, including the construction industry, in Sweden most notably in the Miljonprogrammet in the 1960's (Johnsson et. al, 2011).

Currently, the dominating production philosophy in the automobile industry is the lean philosophy derived from the Toyota Production System (TPS). The basic principles within lean are to eliminate all types of waste and to always strive towards perfection through continuous improvements (Petersson et. al, 2010). The lean concept is based on philosophies, principles and methods, and according to Reich et. al

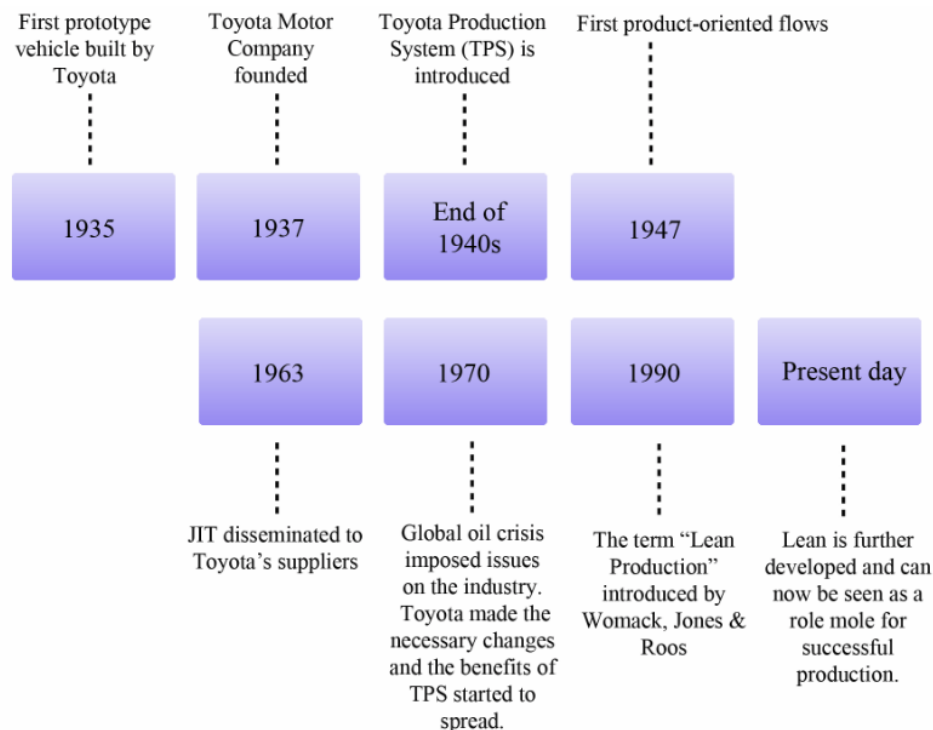
(2014) it is important to understand the relationships between the applied philosophies and its connection to expected results. This is illustrated in Figure 7 below.



**Figure 7 - The Lean concept (Reich, 2014)**

During a seminar (Reich et al., 2014) where Reich was one of the lectures it was stressed upon the importance of these relationships; in order to achieve the desired results from striving towards lean it is of outmost importance that the philosophies are anchored within the organization. From the philosophies and the actual working environment guiding principles should be derived and from these principles work methods should be established. This will, according to Reich et. al (2014) as well as Petersson et. al (2010), lead to the desired results of a more effective organization through the reduction of waste.

The history of lean production is not trivial as it is a production philosophy developed during a relatively large time span, this is described by Petersson et. al (2010) and is summarized, by the authors of this report, in Figure 8 below.



**Figure 8 - History of TPS and lean production.**

What is important to realize here is that the TPS and the lean manufacturing philosophies have been developed, through continuity and continuous improvements, during period of 40 years until it could compete with the, at the time, prevailing production philosophy of mass production. It took another 20 years to become a concept to reckon with, meaning other companies in the motor industry started to question their production methods based on mass production (Womack & Jones, 1990).

In common for the entire motor industry is, however, that it is based around having a *dedicated* production which sole purpose is to produce according to specifications and that the industry excels through *continuity* and *continuous* improvements. For this study lean is not only interesting in the sense of production, but more importantly due to the concept's philosophies and useful definitions regarding the observation and understanding of any given value-flow, i.e. it serves as a framework for process analysis. In the following chapter, the relevant concepts of lean production are presented and described.

### **2.2.1 Five Lean Principles**

According to literature (Womack & Jones, 2003; Petersson, 2010) lean production rests upon five distinct principles referred to as the lean principles. These principles are, in essence, definitions of physical and immaterial aspects of a production process. These principles are utilized, in this report, as basis for analysis and understanding of the investigated processes. Below the principles are presented and elaborated on.

1. Value - The first principle of lean thinking is to specify the value of the product from the customer's perspective. Within lean the value can and should be defined from the customer perspective, and describes what activities the customer is willing to pay for.
2. The Value Stream - The value stream deal with understanding the entire stream of required activities to produce a specific good or service. Within the value stream, value flows in the form of products, material and / or information.
3. Flow - The next principle of lean thinking is flow, where the product, its components and information should move uninterrupted along the value stream. Part of this is to eliminate any kind of batches or queues in the production.
4. Pull - Lean is built upon a pull rather than a push system. This means that the production reacts to the customers' demands, and only produces what is needed by the customer. A push system on the other hand uses a forecast which likely results in unnecessary inventory build ups which creates waste.
5. Perfection - In the end, the aim is to strive for perfection. Through continuous improvements all types of waste should be eliminated so that all activities in the production are value-adding. This state is seen as unreachable and thus one strives toward lean rather than implements it.

### 2.2.2 Waste

Activities within a production system are, within lean, categorized either as value-adding or as waste (muda). Based on the five principles, activities in a lean production environment should be value adding, otherwise they are considered waste. The waste is categorized in two different forms, type one and type two (Womack & Jones, 2003).

- Value-Adding: Activities that unambiguously create value
- Type one waste: Activities that create no value but seem to be unavoidable with current **technologies** or **production assets**
- Type two waste: Activities that create no value and are immediately avoidable

The types of waste are further categorized into eight different areas summarized, by the authors of this report, in table 4 below (Petersson et al., 2010).

**Table 4** - The eight categories of waste

Category	Description	Note
Overproduction	Producing items that is not demanded. Too large batches are also considered overproduction	Considered the worst kind of waste as it renders other sources of waste.
Waiting (idle)	Time spent waiting for production to be possible, typically waiting for upstream processes to finish.	May be caused by a lack of material or information.
Transport	Internal transports that the customer is not willing to pay for. Typically <b>all</b> transport.	Unnecessary transport is often linked to production site layout.
Inappropriate processing	Producing to a higher quality or complexity than the customer demands.	Usually comes in the form of using excess material in production. Also, quality inspection are included in this form of waste.
Inventory	Storages of raw material or work in progress.	Not only costs money but also degenerates the stored material and can obstruct the production.
Motion	Moving material or resources more than necessary.	Unnecessary movement is a work environment risk and decreases productivity.
Producing defective products	Producing or processing defective products incurs unnecessary processing.	Typically caused by poor design on processes, avoided through finding the root cause of the defect.
Untapped competence	Not capturing and using competitive knowledge that staff possess.	Caused by not having a structured system to capture and transfer knowledge between employees.

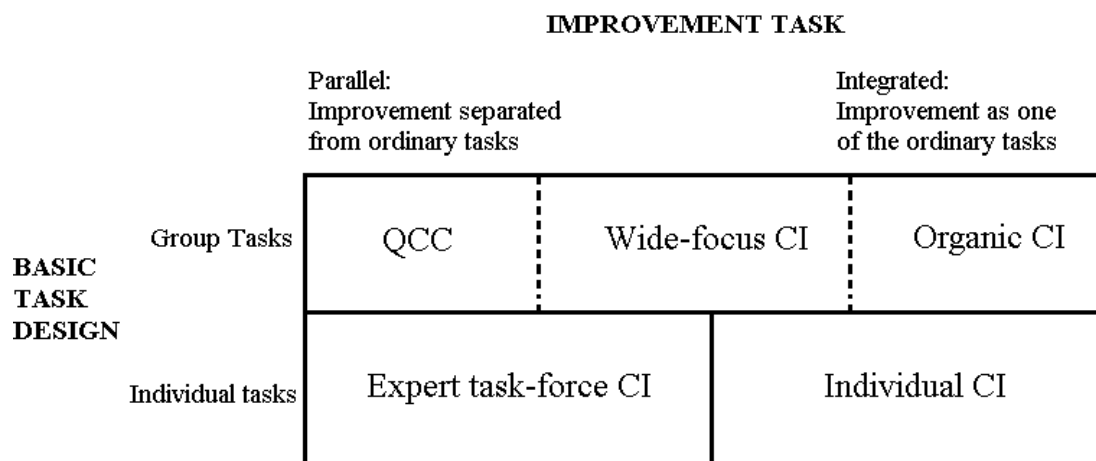
### 2.2.3 Continuous Improvements - Kaizen

Within lean production a prime activity is to continuously improve the value stream utilizing a structured approach - strive for perfection. Based on the five principles presented above and the focus on value within the lean concept improving the value stream means eliminating all forms of waste within it (Petersson et. al, 2010). This activity of improving through waste elimination is motivated through competitive advantage and increased overall business performance and is, by some, considered a key success factor for the Japanese manufacturing industry (Berger, 1997 & Womack & Jones, 2003).

Continuous improvements, within lean, is tightly related to improving the processes rather than the products, i.e. there should be a distinction between the product and the process. Improving the process leads, according to e.g. Petersson et. al (2010), to an improved product. This standpoint is also supported by for example Sandkull and Johansson (2000, pp. 97):

*“It is not the product itself but rather the process of producing the product that brings long-term success. Good products do not create winners. Instead, winners produce good products.”*

In literature regarding lean production and Kaizen in specific (Petersson et. al, 2010; Womack & Jones, 2003; Berger, 1997) it is said that Kaizen should primarily come from within the process itself as it is in the processes waste can be identified and dealt with. In order to achieve satisfactory Kaizen it is therefore important to deal with information flows from production to upstream processes and, as there are people involved in the process, the managing of their knowledge. This can, according to literature (e.g. Bhuiyan & Baghel, 2005; Berger 1999) be achieved through five distinct organizational designs for working with continuous improvements (CI) in practice. According to these authors continuous improvement tasks can be divided into two categories related to the degree of standardization within the processes. A high degree of standardization implies that CI should be of an integrated type and stem from individuals, whilst in an environment with low degree of standardization working with parallel improvement processes are implied. These relationships are presented and explained in Figure 9 below.



**Figure 9** - A typology of organizational designs for CI (Berger, 1999)

This model is explained by Bhuiyan & Baghel (2005, p. 767)

1. **“Quality control circles (QCC):** a group of people in the staff who meet regularly to discuss problems and issues related to quality so that they may examine them and come up with solutions.
2. **Wide-focus CI:** a blend of organic CI and expert task force CI (described below). It is used for temporary operations and for CI in self-managed work groups by combining continuous improvement process teams.
3. **Organic CI:** multifunctional work groups are integrated with improvement activities. Organic CI is different from other CI models since the improvement activities are not left to the experts for design and planning and the decision-making is not left to the authorities outside the group.
4. **Expert task force CI:** this form of CI is based on the reliance on temporary expert task force consisting of professional from quality, engineering and maintenance and therefore the span of improvement tasks requires considerable time and investment.
5. **Individual CI:** improvements are set off by individuals and generally organized in the form of a suggestion system. Individuals come up with ideas and the implementation of the ideas is left to the specialists.”

Based on the traditional way of conducting business in the construction industry it can be assumed that improvement work, if existing, is done in a parallel fashion on a high level of aggregation. Within industrial construction, however, a high degree of standardization is strived for, and as such CI work should be integrated in the processes. Further, Josephson & Björkman (2011) argue that CI conducted in projects should be communicated to upstream processes if applicable through utilizing feedback systems in order to improve the value stream.

#### **2.2.4 Lean Tools**

In order to facilitate an organization's journey towards lean through eliminating waste which is done through continuous improvements, several tools can be used to analyze and improve the production processes. The lean tools deemed relevant for this paper is presented in the following section.

##### *Value Stream Mapping*

In order to build understanding of the studied value stream, and see where potential improvements can be made a value stream mapping (VSM) is extremely useful. A VSM is an illustration of the current state of operations, with all of the steps (both value adding and not) from raw material to end-customer. It is used to investigate and improve the entire flow, rather than each unique process (Petersson et. al, 2010). The relevance of this tool in construction is strengthened by e.g. Josephson & Björkman (2011) as these authors suggest, among other things, that value stream mapping should and can be used in a construction process.



The process of creating a value stream map is rather practical and consists of four major phases as described by Rother and Shook (1998); Choose a product family, Draw a present state, Draw a desired future state and Develop an action plan. A primary philosophy that should be employed in the VSM process is the “see for yourself” philosophy which means that no second hand data should be used when drawing the present state - all data should be gathered from within the actual process by the person(s) applying the VSM method. Rother and Shook (1998) describes this process in detail, each step is summarized by the authors of this report and an example of how the result may look like is presented below.

#### *Choose a product family*

Choosing a product family aims to both simplify the VSM process by delimiting the study as well as focusing efforts to a specific value flow. This conduct is more important should the production make many products in the same factory and thereby consist of a large amount of separate flows. The idea is to choose a product family consisting of products which shares productions assets.

#### *Draw the present state*

The first step in drawing the present state is visualizing the production process, from arriving goods to release of product. This should be done starting with the process closest to the defined customer (typically upstream). The rationale is that the process closest to the customer should decide the production pace - takt time. Important metrics here are; Cycle time (C/T) - the time it takes for a product to flow through a processing step, Value adding time (V/A) - the time utilized in a processing step which the customer sees as value, Lead time (L/T) - the time it takes for a product to flow through the studied processes and Throughout time (T/T) - the time it takes for a product to flow through the physical production site.

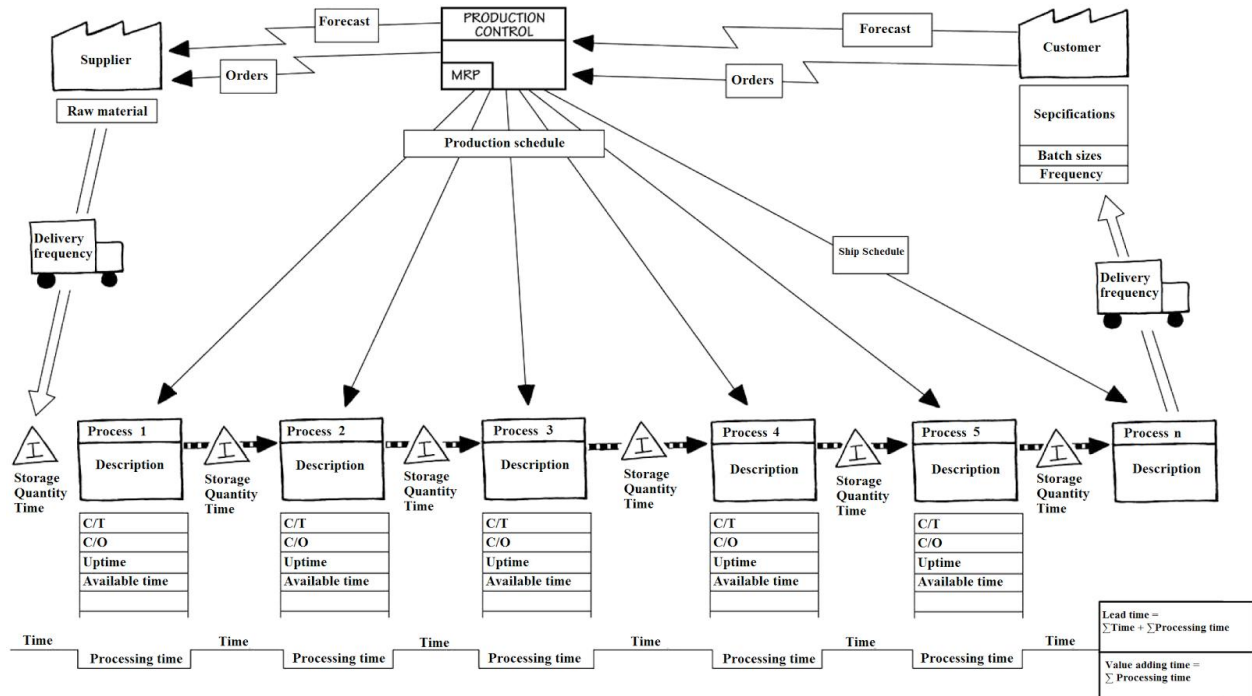
The second step is adding under which circumstances material and completed product is transported to and from the factory respectively, for example which days in which quantities material are delivered and which days at which quantity is produce shipped to the customer. The third step involves adding required overhead functions that affect the studied process thereby mapping the present information flows between the production, production planning, supplier as well as the customer.

#### *Draw a desired future state*

The desired future state is drawn after the present state is done *and* analyzed - the future state should be based on issues and identified improvement areas seen in the present state. This could include incorporating new processes, parallel processes, changing the information flow etc. depending on current issues. The goal is to reach a value flow that is resource efficient and based on the client's *actual* needs typically this means reduced L/T and non-value adding time.

#### *Develop an action plan*

An action plan needs to be established based on the requirements established from the desired future state, this includes practical changes to achieve the future state. It is important to realize, however, that transcending from the present state to the perhaps ideal future state in one giant step could be both detrimental and / or impossible. Therefore taking small steps with intermediate future states is recommended.

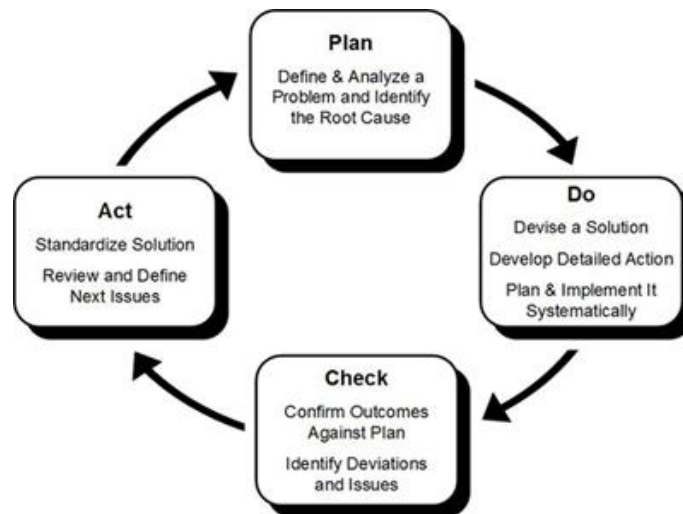


**Figure 10** - Example of a finished present state (Womack, 2006)

In Figure 10 a typical result of the present state is illustrated, in more cases than not the lead time is much larger than the value adding time, which means the process can be improved immensely. Important to note is that the method is tightly linked to the realization of a production *line* meaning the product (or value) flows through discretely separated and definable processing steps, this has little to do with the physical disposition of the factory or location in which the process is utilized.

### PDCA

PDCA stands for Plan, Do, Check Act and is a method used to deal with and enhance continuous improvements in practice. Figure 11 describes the four stages of the PDCA cycle.



**Figure 11** - The PDCA cycle (Allen, 2013)

As can be seen in the figure, the method is based on many lean concepts like standardization and systematic planning, thus such aspects must be present in the production environment where the method is to be used. Important to note is that the PDCA cycle is a never ending process - there is always room for continuous improvements which means the method can and should be integrated in the production processes (Petersson et. al, 2010).

### *5 Whys*

The method of 5 whys is yet another framework used within lean manufacturing. The 5 whys is used as a root cause analysis, meaning that it aims to solve the single root of a problem, and thus solving all problems that come with the root. The method is rather simple - you ask yourself why the problem exists, each time going deeper and deeper until you find the root. An example can be put forth as follows (IMS, 2013):

- Why did the equipment fail? Because the circuit board burnt out.
- Why did the circuit board burn out? Because it overheated.
- Why did it overheat? Because it wasn't getting enough air.
- Why was it not getting enough air? Because the filter wasn't changed.
- Why was the filter not changed? Because there was no preventive maintenance schedule in place informing the operator to do so.

You then find the root of the problem, possibly in conjunction with PDCA (Petersson et. al, 2010) and solve that problem instead of the symptom of the underlying issue. This method is used, in this report, as a method of inquiry to find root causes of observed issues.

### *5S*

The lean method of 5S is a method used to structure and sort the workplace. In order to improve productivity, the workplace needs to be well sorted so employees know where to find the right materials at the right time. By applying the 5S framework to a process environment lower set-up times and a better overall work environment is facilitated. The 5S concept is illustrated in Figure 12 below.



**Figure 12** - The 5S and its definitions (Epa, 2014)

As 5S is a core method within lean to reduce set-up times; the concept is used as a conceptual method for investigation as well as for possible improvement suggestions (Pettersson et. al, 2010).

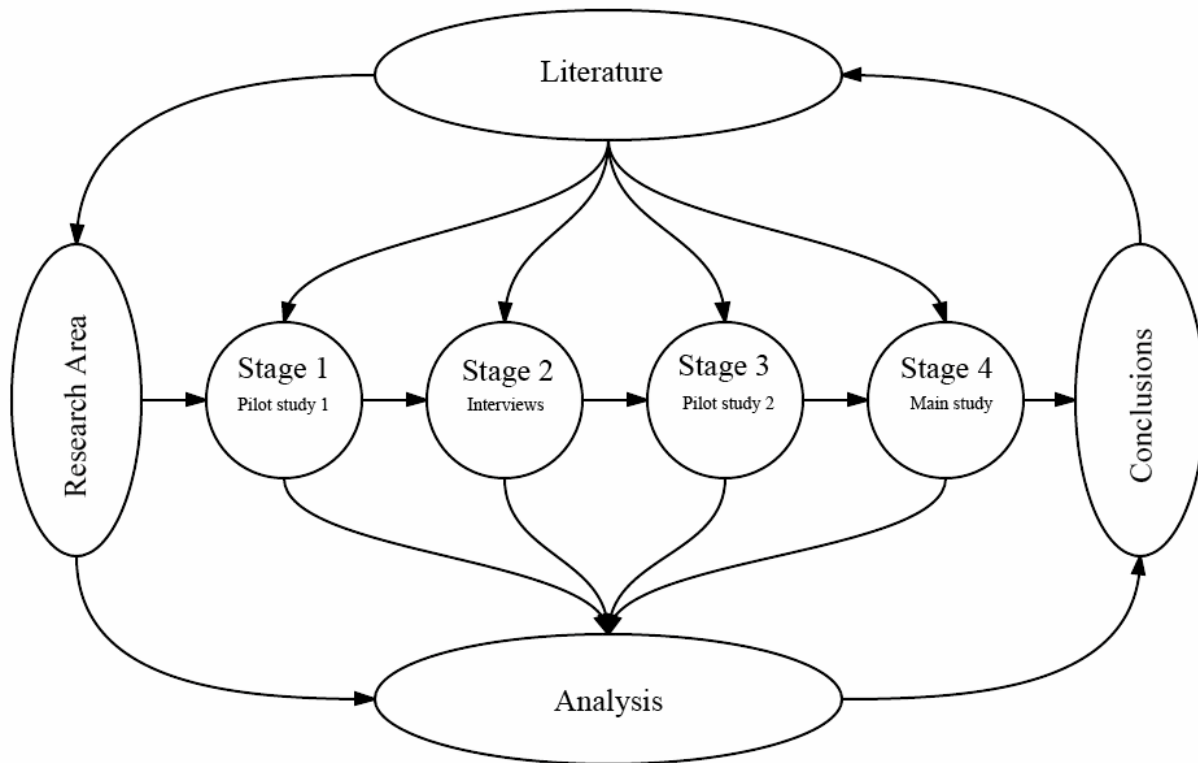
According to several authors (Ballard, 2000, Diekmann et. al, 2004; Josephsson & Björkman, 2011) in the industrial construction discourse, lean philosophies and in extension lean tools are applicable in the construction industry. Further, Diekmann et. al (2004) argue for that the construction industry could significantly benefit from adopting lean principles and behaviors.

### 3. Methodology

*In this chapter a logical exposition of the research methodology and the chosen research methods are presented and argued for.*

The research methodology does not only include the methods on which the research is built upon but also serves as a framework in the light of which the goals of the research can be analyzed and achieved. In this report, a company specific production site is investigated in-depth, as part of a larger study regarding the area of industrialized construction. The research is primarily conducted using an inductive approach where reality is first observed and understood. Then a relevant conceptual framework is applied in order to derive relevant metrics for analysis, in this case the framework is derived from the lean production philosophy.

The research is based on a case study which serves as a practical example for industrial construction based on, among other things, prefabricated concrete elements. This is then supported by more shallow investigations of similar cases and traditional construction. The reason for this is to increase the comprehension of the investigated area, and specifically build context in order to understand the fundamental aspects tied to the construction industry. Such a methodology is required since there are certain rules and aspects about the industry that separates it from the manufacturing industry, aspects that are required to be understood in order to conduct research applicable to the studied case.



**Figure 13 - The research process**

Since the case studied consists of a relatively small group of individuals (one company), the research is based on qualitative methods. This means that a case study is appropriate and that the data collected is qualitative in nature (Collis & Hussey, 2009). Below the methods used for this report are presented and discussed.

### **3.1 Case Study**

Based on the purpose of this study a case study is conducted at NCC AB (henceforth “the company”), one of the largest construction companies in Sweden currently working with projects dealing with industrial construction. This approach leads to the ability to gain in-depth knowledge about the area under study, i.e. industrial construction. A case study does, according to Collis and Hussey (2009) facilitate the collection of such knowledge, specifically since the phenomena is evolving and complex in nature. Included in this case study is a study of the company, a previous initiative, as well as a specific project currently conducted described as a project based on industrial construction. This means the study is conducted in three dimensions, i.e. theoretical (literature), industrial (the company) and practical (the project). Important to realize though, is that the theoretical and industrial part of the study serves as a platform for understanding the practical part, i.e. in order to understand the observations, context is required.

The study was done in four stages; A pilot study during one week at location of production, Interviews and theory, a second pilot study and the main study. These stages are explained, briefly, below and elaborated upon in chapter 3.2.

#### *Stage 1: Pilot study 1*

During one week an on-site participatory study was performed where knowledge about the production site at the company and current processes was gained. At the end of this week observed issues was compared to material from on-site interviews and preliminary areas of interest were formalized.

#### *Stage 2: Interviews*

Using the material from the pilot study, interview material was constructed in conjunction with theory around industrial construction. Further, using the knowledge about how the project was related to the organization, relevant candidates in the organization could be defined and contacted for interviews. Further, this stage involved extensive interviews with key individuals related to this study.

During this stage relevant metrics for investigation were concretized using interview material, gathered in this stage, and theory in order to conduct a structured study, aimed to answer previously formalized questions. Also, a method for data gathering and analysis about the production processes was derived in the end of this stage.

An important aspect in this stage was the application of the industrialization characterization and exemplification of level of achievement model, presented in chapter 2 and appendix 1. This model was applied to evaluate the degree of industrialization in different project types across the company in relation to the characteristics of industrial construction.

### *Stage 3: Pilot study 2*

The method for data collection about the production processes designed in the prior stage was tested on-site during a 2 day trial period. This was done in order to, if needed, modify the method or the conceptual framework to further fit the objective and research questions of the study, which was constantly in the mind of the researchers.

### *Stage 4: Main study*

After these three stages the main study was conducted during three weeks including; on-site observations, production measurements and interviews, using the methods and the conceptual frameworks derived in the prior stages. The data was collected and compiled for analysis and compared to empirical data gathered in stage 2.

## **3.2 Data Collection**

In order to be able to gather data in a satisfactory and structured way, different methods of data collection was used, for both primary and secondary sources. Data triangulation was used to further strengthen the relevance of the data. This means gathering data from several different sources to describe the same phenomenon (Collis & Hussey, 2009). This was done through interviewing several people about the same areas as well as conducting repeated interviews with the same person. The main parts of the data were gathered through a combination of a literature study, interviews, and participatory observations.

### **3.2.1 Data Handling & Analysis**

The collected data was analyzed in a quantitative manner; recurring topics of certain interest were noted, sorted and compared to previously acquired empirical data as well as to theoretical material within the area of research. Further, the research was conducted by two researchers which meant frequent discussion, both with each other as well as with site-management, about observations and interview material on several levels of detail.

### **3.2.2 Literature Study**

From a research perspective it is of grave importance to gain a holistic view of the object being studied. A literature study based on both primary and secondary sources was conducted. This was then used to understand and analyze the empirical data as well as constructing a conceptual framework from which analysis could be done. Areas covered in the literature study were as follows: Traditional construction, industrialized construction, lean production, continuous improvements and lean tools.

The sources used were comprised of both electronic and printed publications from online databases such as JSTOR, Emerald Insight and Scopus as well as the Royal Institute of Technology library. Further, both newly published as well as older publications were used in order to capture the essence of the studied area in a multi-faceted way. Also, as new publications cite older publications it is relevant to investigate both cited and non-cited older publications to find out why certain theory are developed and others are not.

### **3.2.3 Interviews**

An extensive part of the gathered empirical data is in the form of interviews with people involved in the studied case and phenomenon. The conducted interviews were both unstructured and semi-structured based on several important topics related to the study's purpose and goals (see appendix 2 for interview

guide). The interviews were conducted with both researchers present and varied in duration from around 30 minutes to one and a half hour. One researcher acted as an interview leader whilst the other took notes, no interviews were recorded. This conduct led to important knowledge not being omitted while still allowing for deeper knowledge about the studied phenomena to be extracted through the method of semi-structured interview (Collis & Hussey, 2009).

Below a compilation of interviewees, and their area of competence is presented in table 5. It should be noted that many of the interviewees were interviewed several times in order to make sure that the extracted material was as unbiased as possible. This is especially important when interviewing on-site personnel in an unstructured fashion, as the mere presence of the researchers could be interpreted as questioning their work efforts. As such it can be assumed that the early material gathered is biased toward a more problem free state of operations.

**Table 5** - List of interviewees

<b>Interviewee</b>	<b>Role (previous role if relevant)</b>	<b>Interview type</b>
A	Concept Site-manager	Semi-structured & unstructured
B	Head of technical platform	Semi-structured
C	Project officer (Site-manager, assembly supervisor NCC Komponent)	Semi-structured
D	Traditional site-manager (assembly supervisor, NCC Komponent)	Semi-structured
E	Implementation & Process manager (Researcher industrial construction, project manager NCC Komponent)	Semi-structured
F	Head of concept	Semi-structured
G	Head of concept II	Semi-structured
H	Trainee	Semi-structured
I	Concept assembly supervisor	Semi-structured & unstructured
J	Assembly team member	Semi-structured
K	Foreman, wood	Semi-structured
L	Foreman, concrete	Unstructured
M	Assembly team member	Unstructured
N	Assembly team member	Unstructured
P	Crane operator	Semi-structured

#### *Semi-structured interviews*

Semi-structured interviews were predominantly used when inquiring about, for the researchers, known issues or interesting topics related to the study. The reason why such an approach is useful given the purpose of the interview is because in-depth knowledge about the interviewees relationship to the inquired areas are captured (Collis & Hussey, 2009). This is useful when the integrity of the answers are not at risk, i.e. dealing with areas or issues not related to the work efforts of the interviewee. Also, it facilitates getting answers to direct questions, i.e. questions where the answer is a fact rather than an opinion in a structured way.



### *Unstructured interviews*

Unstructured interviews were used when probing for areas of interest or issues closely related to the interview subject's work efforts. The data gathered through such interviews lack in reliability but instead offers higher validity (Collis and Hussey, 2009), further this method of inquiry is useful dealing with sensitive areas of data extraction. During this study, such interviews were conducted as spontaneous everyday talk for the interviewee which meant the researchers could build context but also build a relationship to the interviewee which, through recurring interviews, reduce bias.

### *Snowballing*

In conjunction with every interview the topics discussed often led to information about other interesting topics and corporate functions related to this study. This was exploited, through snowballing, by asking the interviewee about contact information to the individual specialized in that particular area. Not only does such a method lead to deeper knowledge about an area, but also it pinpoints interview subjects based on their function and area of expertise (relevance) rather than availability to the researchers.

### **3.2.4 Participatory Observation**

As a part of studying the case a participatory observation in one of the company's production sites was conducted. This was done in two distinct ways as described by DeWalt et. al (1998):

- Active participation - the researcher engages in that being studied to a vast degree in order to understand the phenomenon or situation researched.
- Moderate participation - the researcher is present at the location for research but does not engage or interact with that being studied.

According to DeWalt et. al (1998) such a research method enhances the quality of the gathered data as well as facilitates in the analysis of the data. Active participation was used in the first stage of observation as the primary concern was to understand the studied process as well as finding areas of interest. This meant being part of the assembly team and to actually perform the same tasks as they did. An important implication of this was that problems within the production was observed and evaluated by the researchers and as such it was easier to see and describe them in a more thorough manner. Especially when it comes to issues affecting the work flow, such as deliveries, quality problems etc. Further, this stage allowed the researchers to create a situation of mutual trust with the studied individuals, thereby enhancing the validity in data extracted later on.

In the final stage, however, a method relying on moderate participation was applied in order to affect the studied phenomena as little as possible. This is useful as this stage of the study aimed to investigate the process as it was, without the participating influence of the researchers. Since the researcher presence, at this time, was accepted by the on-site personnel it assumed that the researcher presence does not impact the studied phenomena.

The observations were documented in an observation diary for later review and analysis, it was then possible to note and structure common issues and the implications these had on the production. Further, ideas from both the production team as well as the researchers were also noted and compared to the theory in the field to support its relevance and implications.

### **3.2.5 Production Evaluation Method**

The data regarding the actual production processes was developed during stage 2 and utilized in stage 3 and 4. The data was gathered through measuring, using stop watches, activity times in the production, this was done in conjunction with unstructured interviews regarding issues observed during the measurements. The time data as well as notes regarding the production processes was then stored in spreadsheets as well as in an observation diary.

### **3.2.6 Seminars and Lectures**

Several seminars and lectures have been attended during the course of this study, among other things a full day with the Lean Forum Bygg, including lectures revolving industrialized construction. These seminars were held by people representing different Swedish construction firms which brought forward different issues and ideas regarding the industrialization of the Swedish construction industry.

### **3.3 Reliability & Validity**

Since the thesis in its entirety is built upon a case study and a qualitative study, the validity will due to natural reasons be of a high degree (Collis & Hussey, 2009). The reliability of the results will on the other hand be slightly lower, especially regarding the generalizability to other market contexts and project categories. What is important to understand though is that the results of this thesis is to a large extent applicable in similar situations (e.g. other contractors working with the same production type of projects) and to some extent to project based organizations seeking to apply industrial concepts on its operations.

As previously discussed, interviews were held several times with the same interviewee in order to both reduce bias and to increase the reliability of the findings. The same rationale was applied to activity time measurements as the same activity was measured several times to ensure that the data does reflect reality. Further, during interviews questions were posed as neutral as possible to avoid leading questions which could impose issues on both the validity and reliability of the study (Collis & Hussey, 2009).

Further, during the main study the reliability and validity is strengthened through non-participatory techniques as such an approach reduces the impact of researcher presence on the studied phenomena (DeWalt et. al, 1998). Another key aspect that was considered during this research was that of anonymity, it was decided that all interview subjects was granted anonymity as it reduces bias and enables the extraction of information describing reality as it is, especially when it comes to problems (Collis & Hussey, 2009).

### **3.4 Method and Source Criticism**

A downside with participatory observation is that the researcher changes that which is being studied, solely by being part of it. Further, the fact that only part of the entire construction process was studied, potential critical activities in the process is not included in the study. This was, however, to some extent managed through interviews with experienced workers that were part of prior projects of similar type. This data is, however, considered secondary and treated as such.

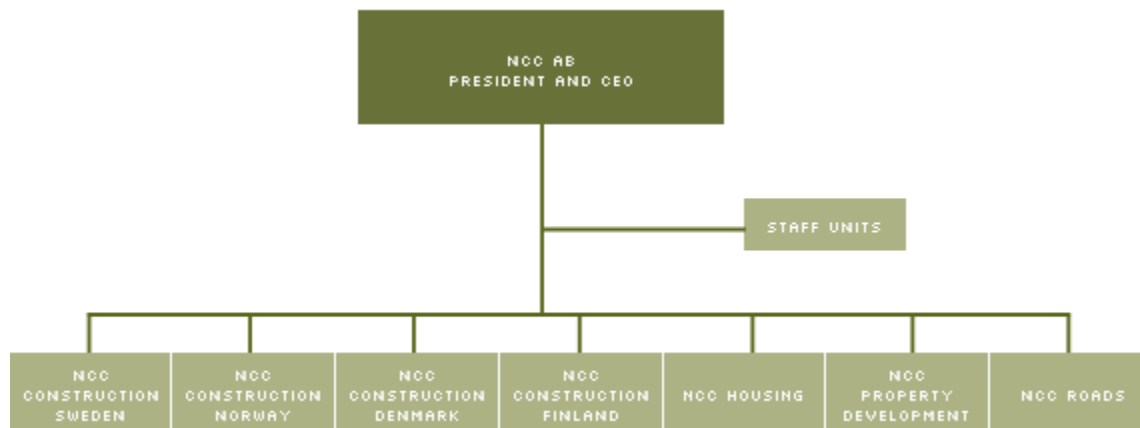
A portion of the gathered academic literature is based on studies performed in other countries than Sweden, which means that that the literature is not built upon Swedish terms for the industry. Due to this, an analysis is made regarding the generalizability of these publications to a Swedish context regarding

branch and industry cultures, unions, infrastructure etc. before being utilized.

Due to the inherent reluctance of companies to share their specific competences to competing companies it was decided not to conduct a benchmark study. This would possibly be feasible if the authors of this thesis were not hired by a specific construction firm, a fact that had to be disclosed due to ethical reasons. As such a study was not conducted it could impose issues with the generalizability of the findings. Due to the chosen methodology, namely a qualitative approach, this is not a primary concern since such a method inherently comes with comparably low generalizability. A certain amount of comparative studies was, however, done. Case studies performed by other researchers on comparable cases were analyzed, and a body of comparison could thereby be achieved. However, such material is often very specific, and as such the results of the analysis is on a high level of aggregation.

### 3.5 Company Background

NCC AB is a Swedish construction and property development firm based in Solna, Stockholm. It was formed through the merger of ABV (Armerad Betong Vägförbättringar) and JCC (Johnson Construction Company) in 1988 (NCCa, 2014). In 2013, the company had a revenue of 57,8 SEK billion and an employee base of 18 thousand. The company's vision is to "renew our industry and provide superior sustainable solutions" (NCCb, 2013). Studied in this paper is a division of NCC AB called NCC Construction Sweden, related to the other divisions as seen in Figure 14.



**Figure 14 -** Organizational structure of NCC (NCCc, 2014).

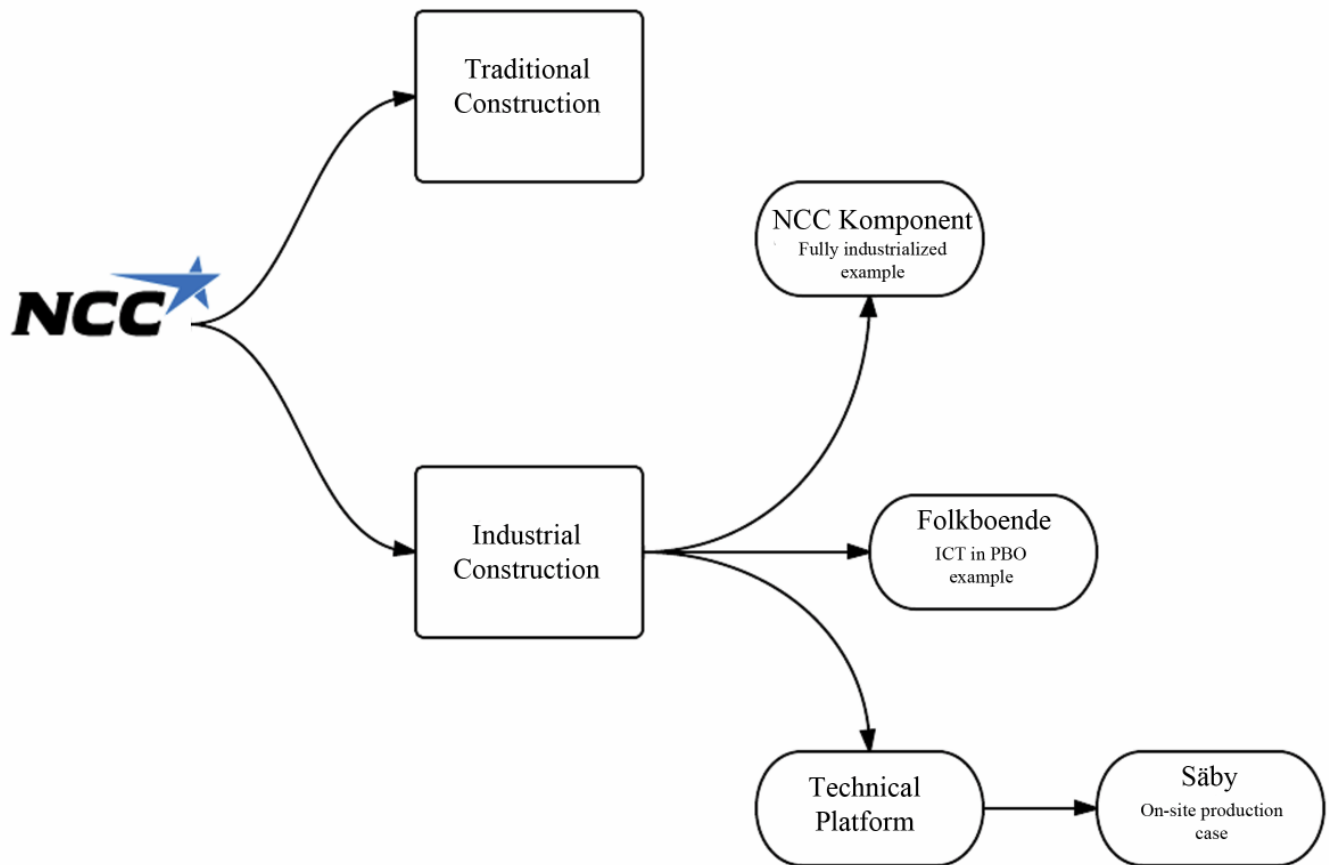
NCC Construction Sweden constructs residential and office properties, industrial facilities, roads, civil-engineering structures and other types of infrastructure. The business is mainly conducted in a project based setting where client demand is met through unique projects tailored to meet the needs of the client.

## 4. Results

*This chapter presents the studied on-site case in depth as well as a discussion of the results, where relevant. Further, observations and interview material are presented here along with other gathered empirical data.*

### 4.1 Project based construction at the company

This section presents and discusses relevant aspects of project based operations linked to the studied company. Further an example of a fully industrialized initiative is presented followed by a discussion about technical platforms and an example of successful ICT usage in the company. After this the thoroughly studied sub-case is presented and discussed. The studied areas and their relation to the case company is presented in Figure 15 below.



**Figure 15** - Areas of investigation at the case company

Traditionally the construction industry is described in theory as completely project based (Johnsson et. al, 2011; Koskela, 1993) and the general notion is that the projects themselves are unique to the extent that one project's performance cannot be improved by utilizing experience, solutions, designs etc. made in a past project. This is manifested as projects having a beginning, a composition of people, a task and upon

completion the project is considered done and the people involved are engaged in new projects. Often the people involved in one project does not continue working together in another (Interviewee A & C). An effect of this philosophy is that the outcome of any one project relies heavily on the experience gathered by the people involved in the project, in all of its phases. In essence, the competence lies within personal, tacit, knowledge instead of codified explicit knowledge (Nonaka, 1994) available for reuse by other individuals, which is focused upon in the manufacturing industry.

The reality is, however, not entirely as grim as presented in the above paragraph as there are, in this case, common resources and tools available for the different phases of the project life-cycle. During interviews with site-managers at the company, a production system was described including routines for material handling, time planning and general management tools and support. The tools and routines in this system are, according to Interviewee D, useful and serve as support in how to manage a project. The same interviewee said, however, that the project outcome and performance relies heavily on the composition of people within it, the example made was that:

*“The areas under focus and methods used depend heavily on who the project owner is”* - Interviewee D

a fact that is further supported by site-workers as they expressed that their work is affected by who the site-manager is. This can be seen as evidence that the existing project support system is generic and handles basic functions for project management rather than detailed best-practices, thus leaving room for project managers to work in an autonomous way. In projects dealing with unique constructions utilizing the ETO production philosophy, this is not as big an issue as it is in a project based on an ATO or a MSP production philosophy. The reason for this is that the advantage of such philosophies lies within economics of reuse and as such standard procedures are sought. Due to the traditional way of working - value delivery based on unique projects, this should be an issue for the entire industry. This notion is strengthened through interviews regarding this specific case as nearly every interviewee expressed issues with knowledge capture and transfer:

*“... Knowledge capture and reuse is something that works poorly at the moment”* - Interviewee B

*“The construction workers sit on trade-knowledge, which means they are, for example, instructed to build a wall according to specifications, how it is built is up to them”* - Interviewee D

*“The methods used in and the outcome of a project relies heavily on the project owner and site manager”*  
- Interviewee C

The experience in focus here is tied to how the production should be planned, how the construction should be produced and how the production should be evaluated and measured.

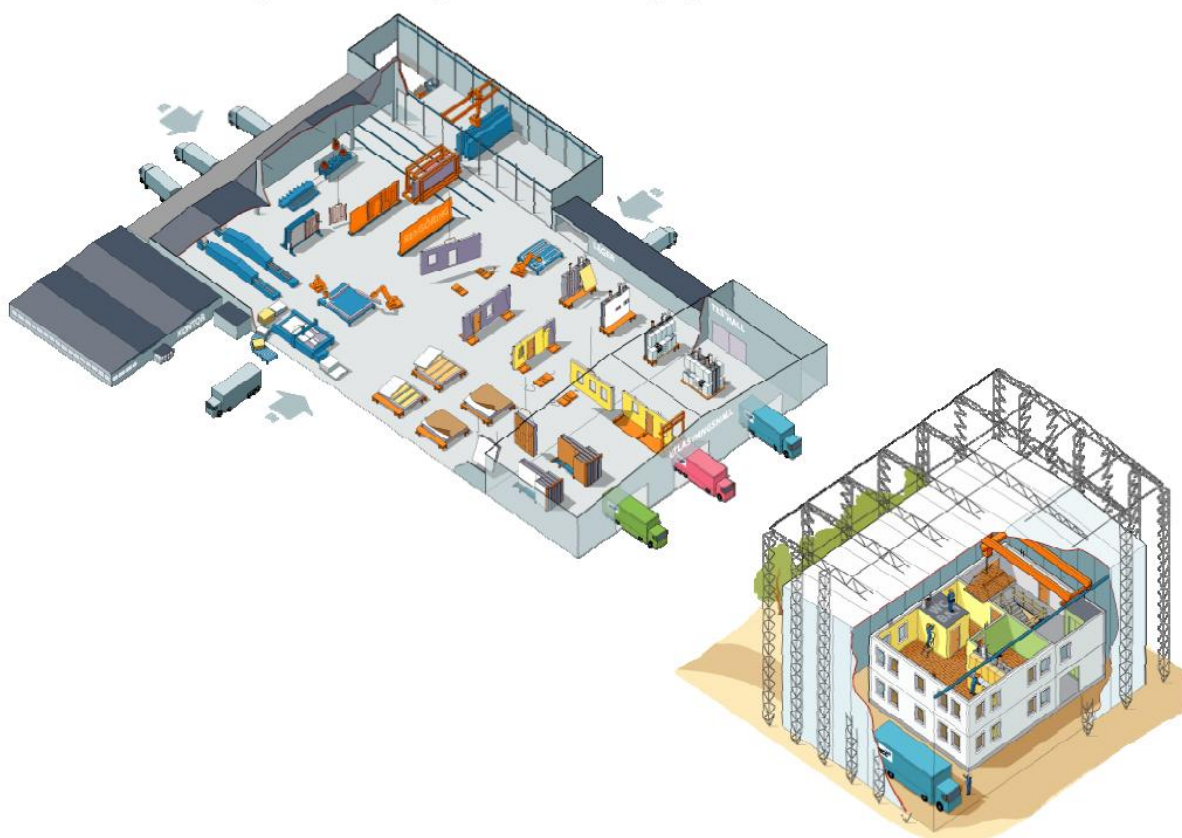
As previously presented there are two main production philosophies within construction, the traditional and the new production philosophy (Table 1), each with its own advantages and disadvantages. NCC Construction has had several projects in the past with the aim to industrialize the processes and production. Such an initiative is NCC Komponent which, in this report, serves as an example of a fully industrialized construction concept. A comparison is made between Komponent and the studied on-site

case based on the Säby concept which is presented later in this report.

## 4.2 NCC Komponent

In 2002 an initiative was made at the company regarding industrialized construction in the form of a pre-study on what to construct and how to construct it. The team was comprised of people from the company as well as people with a background from the manufacturing industry and the goal was to create a value chain with heavy influence from that industry, especially the automobile industry. This initiative was sanctioned by the CEO at the time, who previously had worked within the manufacturing industry for several years (Andersson, 2013). The pre-study lead to a concept based on prefabricated flat elements (as opposed to volume elements) produced in a factory owned by the company, as seen in Figure 16. The entire concept was owned and developed by a company called NCC Komponent, a sister company to NCC AB dedicated to this concept of industrialization (Andreasson & Thibaud, 2008).

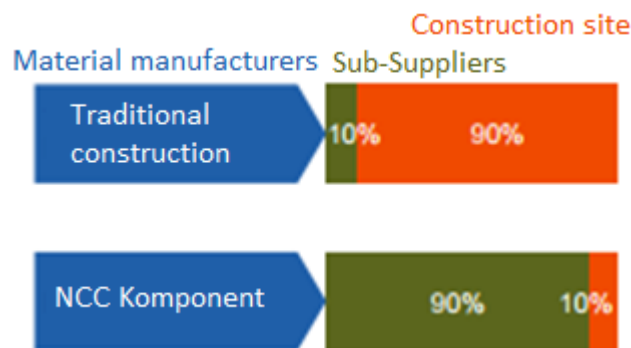
The idea was to *produce*, rather than *construct* residential buildings through assembling prefabricated parts on location. The level of prefabrication was vast with pre-painted surfaces, tiled walls, windows, flooring etc. which required the assembly location to be controlled mainly in terms of weather to prevent the parts from being damaged. This issue was solved using an assembly hall - similar to a huge tent encapsulating the entire volume in which the house was assembled. The assembly hall was equipped with a lifting device capable of transporting elements from arrival to assembly position, visualized in Figure 16.



**Figure 16** - The production factory and the assembly hall of NCC Komponent

Interesting to note was that the time to market (the time from pre-study start to first building) was relatively short (about three years), which indicates that the initiative was seen, by the company, as something extremely important. The attention from the public was also intense and even the prime minister of Sweden at that time attended both the manufacturing plant as well as the first constructed house. Further, the entire construction industry was, at the time, very keen on industrializing their methods of construction and the company was, through NCC Komponent, on the absolute forefront of the ongoing race for industrialization.

The system was capable of delivering highly customizable buildings through modularization of well thought through components. The goals of the initiative was to move as much of the production as possible into the controlled prefabrication environment without hindering customization, and through this philosophy apply industrial concepts such as takt flow, continuous improvements and a stream-lined supply chain delivering just in time to the assembly location. This should be seen in relation to the traditional way of construction where around 90% of the production takes place on location, a difference illustrated in Figure 17 below.



**Figure 17** - The difference between NCC Komponent and traditional construction (NCCe, 2014)

As seen in the figure, the bulk of the production is moved from the construction site to sub-suppliers and production facilities, and through owning the production facility the value chain is to some extent vertically integrated which gives full control of the processes and the potentially competitive knowledge. In terms of competitive advantage the head of the initiative, Fredrik Arnheim, envisioned that the total production time could be shortened by 50 % and the time spent on project location reduced by 75 %. Further, improvements in terms of work environment, cost reductions, design freedom, quality as well as weather protected production from cradle to grave were also areas where this concept was seen as superior.

In order to ensure continuity and continuous improvements in this initiative the production processes, both in terms of prefabricated elements as well as the on-site assembly, were rigorously documented in assembly handbooks. In these handbooks the function of the modules, how they should be assembled, which tools were to be used as well as how the work should be controlled was described (Andreasson & Thibaud, 2008). According to both interviewee C and D these handbooks were used as a supportive tool at the assembly location and if better methods of assembly were found they was communicated to concept management which then updated the handbook if needed.

In spite of all these positive aspects NCC decided to disband the sister company in November 2007, merely 5 years after its initiation, and the last module was produced in early 2008. The reason for this decision stemmed from the fact that the fixed costs rose with volume and the assumptions made in the beginning turned out to be too optimistic in terms of capacity, production cost and production time. At the end an insightful reflection from the head of the R&D department was made:

*“The project was too difficult for a [traditional] construction company that does not have the industrial mindset or **perseverance** required for such an endeavor. The shutdown decision is a sad thing for the entire industry”* (Andreasson & Thibaud, 2008, p. 122) (Freely translated and bolded by author)

This is an aspect verified through interviews with two other people involved in the initiative, both Interviewee C & E, said that one of the prime reasons for disbandment was that the company was not ready and that the time-table for delivery was too rushed. This implied solving problems in all aspects of the supply chain in parallel with using the system, which naturally means that the system does not perform as intended. Further, lacking the long-term commitment to the idea imposed unrealistic demands on economic performance in a too narrow time frame. Both interviewees did however express a positive attitude towards the initiative, Interviewee E even went so far as to saying that such an initiative is *required* to gain full advantage of industrial concepts in the context of construction.

In essence, the expectations and the short time-frame could have been the prime reason this industrialized system for construction failed. Looking at experience from the manufacturing industry as a whole and the companies applying lean principles in specific, change should happen in incremental steps while constantly evaluating the effect of the change, as exemplified by the fourth principle of the Toyota way:

*“Level out the workload (work like the tortoise, not the hare.”* (Liker & Meier, 2004)

Further, the first principle states that:

*“Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals.”* (Liker & Meier, 2004)

Considering these two principles and the fate of the initiative it can be deducted that the delivery targets and the decision of shutting down the initiative was in direct violation of at least two of the fundamental lean principles.

Another issue that was discussed during interviews regarding NCC Komponent was the cultural differences between the construction sector and the industrial sector. This was mitigated through recruiting staff primarily from the industrial sector to NCC Komponent and even the staff performing the on-site assembly were not construction workers, instead industrial workers were used. This is something both Interviewee C & E saw as a positive decision as it helped in specializing the workforce to their particular tasks, as well as reducing staffing cost. Further, a fundamental aspect of industrial concepts and lean are standardized work and processes whereas a prime aspect within the construction industry is to rely on the individual skill of the workforce and solve issues as they arise on location and move on. This



is also something that is mitigated by having a majority of the workforce comes from different backgrounds than construction.

#### **4.3 Technical Platforms & Conceptual products**

In parallel with NCC Komponent an initiative working with technical platforms and conceptual products was made. The technical platform is an aggregate of solutions regarding construction, for example plans for walls, bathrooms and roofs etc. where the interfaces between them allow for customization of the products derived from the technical platform (Lessing, 2006). According to this author the technical platform should be supported by a process platform including but not limited to; information flows, client information, logistic processes and processes for supplier collaboration. This is something that is supported by the definition of industrialized construction brought forward by Johnsson et. al (2011), where the technical and the process platform are separated.

During an interview with Interviewee B it was said that NCC Construction's technical platform includes both of these aspects. What is not yet included but is to be included in the future is production support tools. This could be an indication that the technical platform is relatively well developed but the process platform requires further development. The technical platform is used, at the company, to derive products targeted at the middle to low cost segments of the housing market and the strategy is to develop the platform in conjunction with the initiated projects. Input from on-site production, customers and purchase is used to improve upon the platform. This is done, according to Interviewee B, semi-annually and project-end feed-back is the prime source of information (e.g. common issues with produced units are considered to be platform specific, while individual project issues are not).

The platforms are used to derive conceptual products through combining parts of the platforms into fully functioning constructions. Two concepts utilizing a technical platform currently in production was investigated, namely the concepts Säby and Folkboende. The Säby concept was investigated in depth through practical observation in the production of this concept whilst Folkboende was investigated through interviews with the concept owner.

#### **4.4 Folkboende**

The Folkboende concept is based on a technical platform and constructed solely through location based production. During an interview with the concept owners, Interviewee F and G, the authors of this report were presented with the ITC tools used in this concept.

The system was web-based and contained all of the necessary documentation for production, including construction blueprints and descriptions of production methods for several construction parts. This system was used to gather feedback from production in order to constantly update the technical platform and its related production assisting documentation. The projects using the concept in production used the system as guidance and, voluntarily provided feedback through the web interface. This web based system was described as functioning well in terms of production feedback and process development:

*"When visiting production using the concept for the third time vast improvements could be observed."* - Interviewee F

*“The feedback system is used continuously and we are constantly taking in the feedback and incorporating it in the technical platform.” - Interviewee G*

This means this concept can be seen as an example of how to use ICT tools in construction using location based production. One key observation though is that this concept cannot be seen as an industrialized construction concept as prefabrication is not used which is why the Säby concept was investigated in depth.

#### **4.5 Säby**

With the aim to develop a standardized concept from the technical platform in order to make the production more efficient in terms of both production time but also in terms of material purchasing, distribution etc., NCC Construction Sweden has developed a multi storey concrete building concept called Säby.

The concept is based on a high degree of prefabricated concrete elements as well as volume modules (prefabricated bathrooms and kitchens), and the building consists, to a great extent, of standardized parts that are assembled at the construction site according to a pre-planned order. The project Säby served as a pilot project for the concept with the same name and from this the company means to study the concept further by building more houses using this concept and improving the processes tied to the construction of the buildings. The concept can be used to produce buildings of varied size and shape through either a multi-stairwell house of 4-6 levels or a single stairwell house of 6-8 levels and 5-6 apartments per level. An example of a finished house can be seen in Figure 18 below.

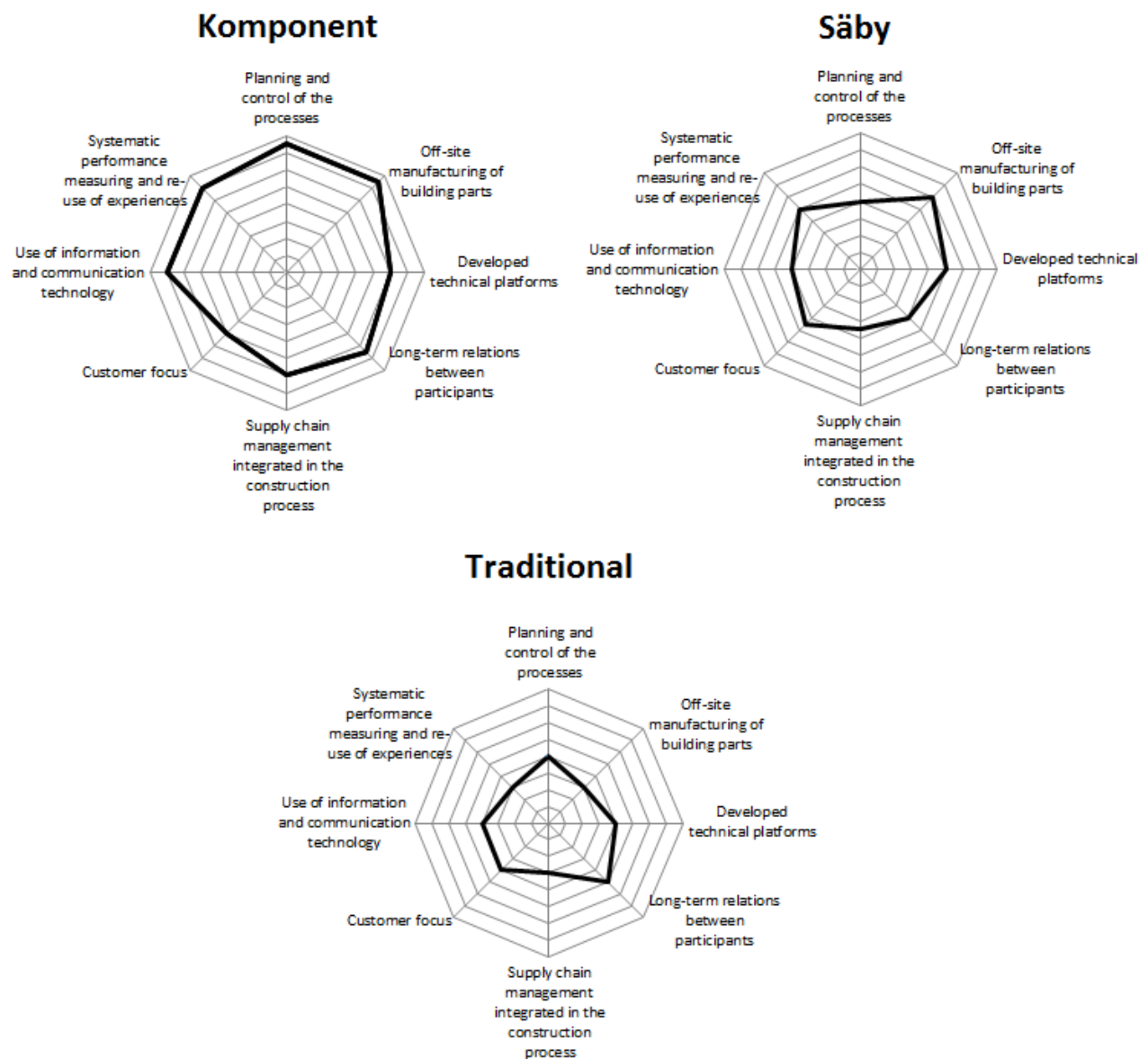


**Figure 18** - A finished house based on the Säby concept (NCCd, 2014)

In terms of production time, the aim is to go from gravel to living space in nine months through shortening the time spent on planning and projecting as well as the time spent on the construction site through prefabrication.

#### 4.5.1 Industrial processes in the Säby concept

Using industrialization criteria or characteristics presented in the literature chapter the concept Säby concurs to all eight characteristics as well as the process and technical platform. Thus, the concept can be defined as a concept of industrial construction. However, to what extent is the concept industrialized? During a selection of interviews (Interviewees; B, C, D and F) with employees working with the industrial concepts, the evaluation model of industrialization was applied. The interviewee was handed the evaluation matrix and was asked to fill it in based on his or her own experience within the areas of: the Säby concept, traditional construction projects and/or NCC Komponent. The results (as an average of interviewee answers) were then visualized as seen in figure 19 below.



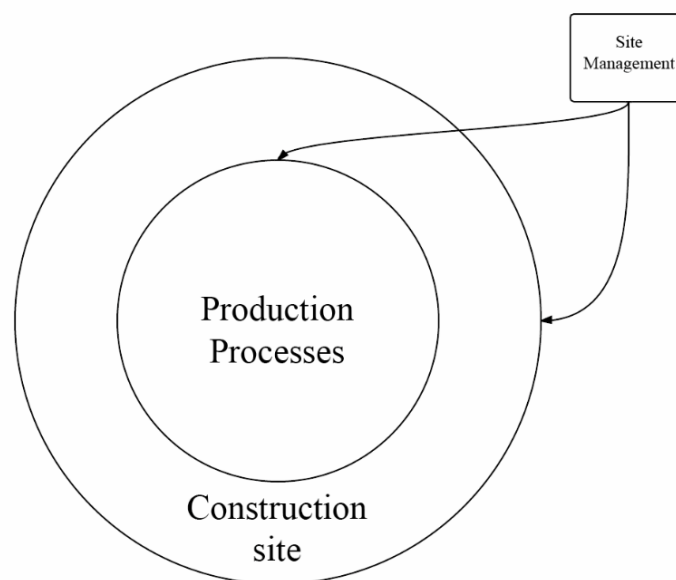
**Figure 19** - The level of industrialization of different projects at the company

As can be seen, NCC Komponent was tremendously more industrialized than both the Säby concept and traditional projects. An interesting observation regarding these results is that Säby, currently the most industrialized concept used at the company is only marginally more industrialized than traditional projects.

#### 4.6 The production site case

The on-site case study was conducted at the second house being built using the Säby concept, which was under construction at the time of this report. The timeframe of the project from start to finish is two years, without taking into account the time of the projection. When completed this project will deliver 4 structures comprising 8 stairwells, each being 6 storeys high. The total budget of the project is estimated to be just short of SEK 200 million. The skeleton of the building is constructed using fully prefabricated concrete walls, floor slabs and bathrooms. The walls and floor slabs are delivered by truck from a concrete factory in Poland, and the bathrooms from a factory in Italy. All three components are delivered using principles of Just-in-Time. In parallel to the skeleton assembly several other activities were in progress, e.g. groundwork and concrete foundation work. These activities are not part of the concept and are unique for the specific project, thus these activities were not included in the case study since the aim was to investigate industrial construction.

During the pilot study a holistic approach was taken where as much as possible was observed and data was gathered for analysis. After the first pilot study three main areas of interest were identified, both tied to the concept as well as the work-site as such, these areas are; The assembly process, assembly site and the site management functions. The reason why these areas are of certain interest is because the assembly process is the practical manifestation of the concept (i.e. how the conceptual building is realized) and is required in order to produce the building. The assembly site and specifically its structure is a support function for the assembly process in the sense that it should be structured in a way that makes the assembly as easy as possible. The site management function is the area which controls and structures the aforementioned areas as well as plans and manages the production. This relationship is depicted in Figure 20 below.



**Figure 20** - The relationship of three areas of the production site

These areas were investigated during a 3 week on-site observation and the findings of these observations are presented and discussed in the following sections. Below a description of the production of the concept is presented, the focus is upon issues related to previously presented material. All of the material here is, if not otherwise specified, based on on-site interviews and observations.

#### **4.6.1 Site Management**

The site-management, tied to assembly, is comprised of one location officer (platschef), one assembly supervisor (montageledare), one labor foreman (bas) and a team of four assemblers (yrkesarbetare). There are, of course, other functions on location with other responsibilities such as ground work, concrete work, installations etc. not specifically linked to the concept as such. This study, however, only deals with the part related to the Säby concept and the construction of the skeleton of the building specifically.

The location officer is responsible for everything that happens on the construction site, and also serves as the voice between the project and the line organization. The assembly supervisor orders the elements based on a production schedule up to two weeks in advance due to supplier lead times and also functions as an overall supervisor of, and instructor for the assembly team. Both the location officer and the assembly supervisor make frequent rounds in the production to monitor the progress and discuss certain issues. The assembly team is officially led by the labor foreman who, in this case, handles the reception of the elements and is responsible for connecting the crane and the element for transport to the assembly location.

These three functions, as well as the foremen for the other functions (ground work etc.) meet once a week to discuss issues using a structured meeting agenda with work environment as a top priority. The authors of this report partook in one of these meetings and a multitude of issues were discussed, mostly regarding the following weeks work plan and issues regarding functions not related to the concept. It was noted that no discussion of the assembly process was done in this meeting, most likely because the purpose of the meeting was to discuss issues regarding the entire construction site in which the assembly is, at the moment, a relatively small part.

Prior to the start-up of the assembly of concept related parts an assembly meeting was initiated, present at this meeting was the assembly team (including the assembly foreman), the assembly supervisor who acted as a meeting coordinator and also an observer from the company's headquarter specialized in implementation. The meeting agenda was comprised of 16 areas of discussion regarding the work to be initiated the week after as follows:

**Table 6 – Meeting Agenda**

<b>Area</b>	<b>Description</b>	<b>Area</b>	<b>Description</b>
<b>1. Goals and organization</b>	Safety first, adherence to time plan	<b>9. Machines, equipment, tools</b>	Some new information, same tools used as in the assembly of sub floors
<b>2. Documents &amp; Guidance</b>	Walkthrough of assembly blueprints part by part	<b>10. Material, delivery, transports</b>	Deliveries are visible on the whiteboard (note: different location than the assembly teams)
<b>3. Time plan</b>	Walkthrough of time plan, order of assembly is discussed	<b>11. Clean construction site</b>	Walkthrough of waste handling routines, the focus is environmental
<b>4. Sub contractors</b>	Electricity work on day 3	<b>12. Work environment</b>	Workplace routines, safety is the prime topic
<b>5. Interference &amp; proactive work</b>	Be observant on errors in delivery and assembly	<b>13. Self evaluation</b>	Self-evaluation documentation and routines on how to work with it. One person elected responsible for it.
<b>6. Tips and ideas</b>		<b>14. Education</b>	n/a
<b>7. Methods &amp; material selection</b>	Walkthrough of the parts, prefabricated concrete	<b>15. Follow-up</b>	n/a
<b>8. Fasteners</b>	Make sure that fasteners are in stock	<b>16. Miscellaneous</b>	n/a

Each topic was covered and the floor was open for questions and thoughts, further pictures from a visit to the element factory were shown. The meeting ended with a study visit to another project working with the same concept which had just finished the tasks presented at this meeting. After this meeting, interviews with the assembly team were conducted asking about their perceived value of the meeting. The meeting and the study visit was appreciated by the assembly team, one thing that was brought up though was that the team wanted continuous structured meetings to talk about issues during the assembly. The authors of this report got a clear picture of what was expected of the team, what was to be done and how this should be done and the study visit enabled the team to see the expected results in practice. These meetings are a perfect platform for spreading knowledge about the processes and can be used as a tool to incorporate experience from other projects to the one currently under way.

Interesting to note is the foci on work environment and safety, this is something that has been pushed from the company head-quarter as a strategy to achieve the vision of zero work related accidents. It is important because the construction workers traditionally had to omit safety (and still do to some extent) to get the work done in time or at all. This has resulted in an adverse attitude towards work place safety, however the workers appreciate and to their best ability adhered to the safety protocols. This implies that the will to change and improve is great within the teams, albeit with some resistance and questioning.

Another key function of the site-management is planning the production. It is, today, planned using the Critical Path Method (CPM) technique where the different phases of construction is placed in order of dependence e.g. ground work needs to be completed before the foundation work is initiated (Mubarak, 2010). The input data used is based on experience from the ones planning the work, including things like actual time required as well as margins for disturbances such as weather, non arriving material, sick-leaves etc. This means that both type I and type II waste is already planned before the project is even initiated. However a weekly and semi-weekly planning method is also used, and this time plan is subject to change depending on how production proceeds.

There are other methods available for production planning in literature, such as Line of Balance and The last planner method (Lundqvist & Martinell, 2009), however in the case of this report the method of production planning is not considered critical as other measures needs to be taken before these types of production planning can be utilized. For now it suffices to say that detailed planning requires detailed knowledge of the activities to be planned in terms of resources, especially required amount of time and personnel.

#### *Summary, site management*

- The site management's prime function is to plan, manage and control the production of the building. Further, the function serves as the link between the project and other, non-project, functions such as the technical platform and the production of elements.
- Currently, the assembly process is planned, managed and controlled by the site management through the assembly leader and preparation meetings.
- These meetings are used as a forum to instruct the assembly team what should be done, and to some extent how it should be done.
- The meetings prove that there is infrastructure in place for potentially capturing and especially using methods of best practice.
- Seeing as it is site management who orders elements from production it can be concluded that this function should be considered the client of the element supplier, which means demands on the supplier can be voiced by site-management.

#### **4.6.2 The assembly process**

The assembly is carried out during a cycle of three days, and when a full cycle is complete one level of the current stairwell is completed, meaning all work is done so that work on the next storey can be initiated. The main processes included to complete one storey are presented below (in dependent order):

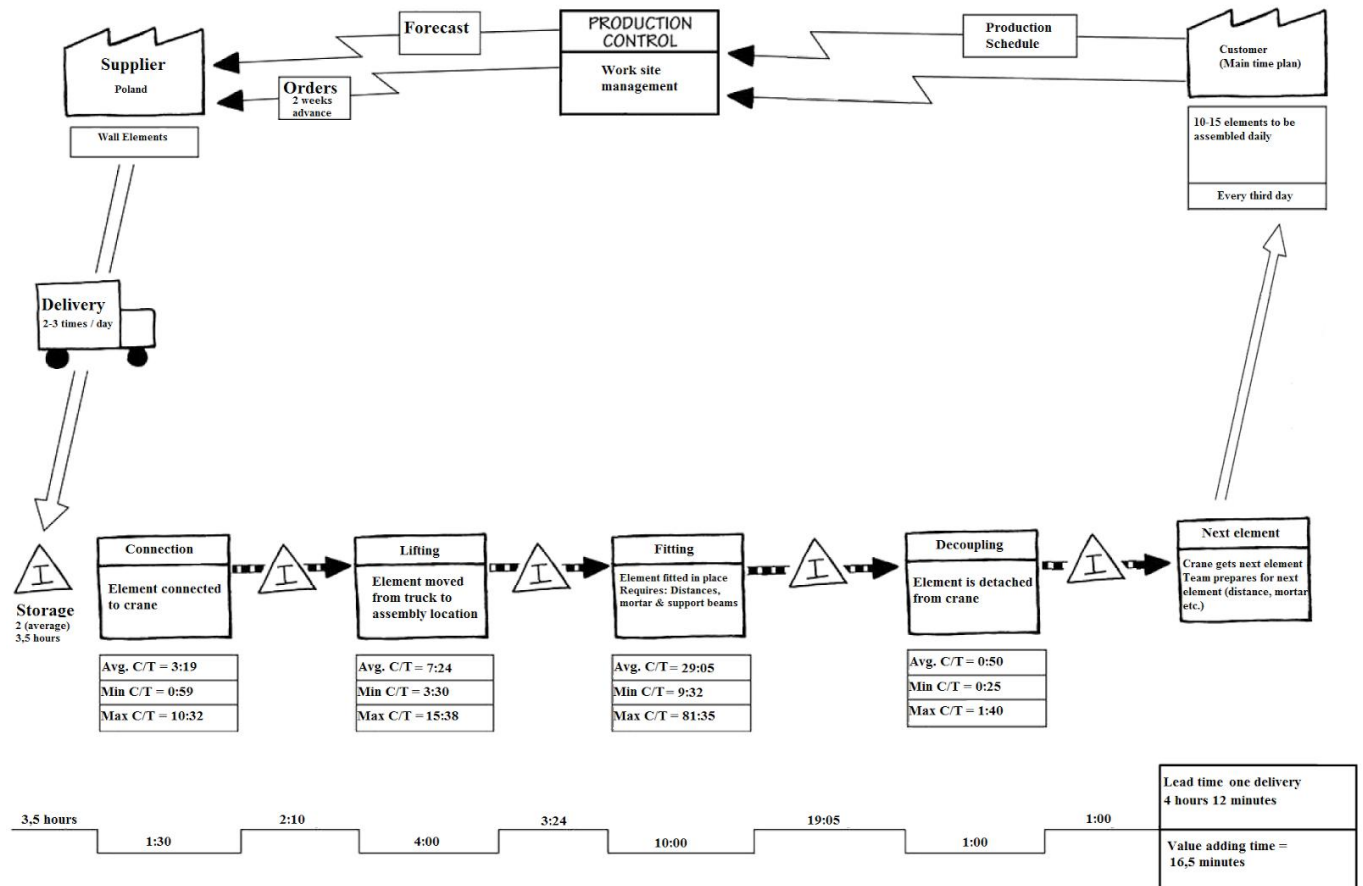
- (Day 1) Walls (both inner and outer) needs to be assembled, fixed and fastened to adjacent elements, attachment steel rods as well as to the floor slabs of the current storey (or roof slabs of the level below)
- (Day 2) Bathroom modules, drywall required for internal walls and stairs needs to be positioned on the current storey.
- (Day 3) Roof slabs and balconies are assembled for the current storey and the floor slabs are joint with concrete

This process is then repeated six times (once per storey), and this is then repeated for every structure. As this process is subject to repetition using standardized parts and assembly methods it is possible to incorporate continuous improvement work cycles in the process.

The material used in this process (elements and concrete) is moved from the distribution trucks to the building using a crane positioned at the center of the construction site. This crane is a critical resource for assembly as it transports the elements from the delivery truck to the assembly location as well as assists in the assembly process as a supportive function until the element is fixed in position.

In order to gain full insight and understanding of the processes and their relative importance to the value flow a value stream map was made. The focus of this VSM is not of the traditional type where the product flow is investigated directly, instead the most critical resource is studied and the flow through it mapped. In this case, the crane is considered the most critical resource as it is required to perform any kind of value adding work related to skeleton assembly. Through mapping it all other critical activities are brought forward and visualized as well. This decision was made due to the fact that the process being studied is *not* a traditional production line as the product (read: the house) is stationary and the processing resources are moved to and around it. The results of such an analysis are that not only is it possible to map the value flow (as it flows through the critical resource) but also an analysis of the resource itself is achieved. Below are the results of this analysis based on processing data (measured by the authors of this report, see appendix 3) as well as overhead data extracted from interviews with on-site management.





**Figure 21 - VSM of the assembly of prefabricated walls (A larger version available in appendix 3)**

It should be noted that the processing and storage times used to map the value flow are averaged measured times as each element (product) currently requires different processing times in each process step. This means the VSM acts as a process overview illustration to describe and understand current operations. Further, it is assumed that through improving the process the cycle time can be decreased to correspond to the lowest cycle time recorded. This insight is useful in order to find the actual value adding time (the time required to progress), since there are no actual buffers or storages, the difference between this ideal cycle time and the recorded average time are considered storage (non-value adding time). As can be seen, the deviations in cycle times are rather large, especially for the fitting process. Using this rationale the average *waste* can be calculated as the sum of the between process storage times, which is not actual storage (25m 39s **per element**). Finding the root cause of and eliminating this waste is of great importance as it impacts the available time directly.

The process under focus - skeleton construction, is the process, which at this stage, utilizes the crane the most and as such this method of value mapping is best applied in this case. Another key factor as to why the study of the crane is of utmost importance is due to its processing times in relation to the takt time. The processing time for lifting the elements from the truck to the assembly location as well as supporting in the assembly of the elements are the two activities with the highest cycle time, which means the activities involving the crane sets the production pace.

The *ideal* takt time for day 1 is calculated using equation 1 as:

$$\text{Takt Time} = \text{Available time (day)} / \text{Number of elements (day)} = 8 \times 60 / 22 = 21,8 \text{ minutes / element, (1)}$$

this is the amount of (crane) time available for each delivered element in order to keep up with delivery. It should be noted that the assembly itself can be seen as driven by a push system, since elements are ordered two weeks in advance (due to lead times) and deliveries are made JIT (in this case spread out over the day based on a pre-planned schedule), which means that disturbances in the assembly process will result in either a que of delivery trucks or the need for intermediate storage of elements. Intermediate storage requires crane work as well as manual work, which consumes time that is also deductible from the crane's available time.

The assembly of wall elements depends on two critical activities, unloading and fitting. Unloading is the activity defined as moving the element from the delivery truck to the assembly location and the fitting activity starts when the element has reached the assembly location and ends when the element is detached from the crane. These definitions are useful as the crane is considered the critical resource and as such any activity that requires crane time and carries dependencies with downstream activities are considered critical. Such activities' processing times are naturally deductible from the available time, and therefore influence the takt time or production capacity.

Other support activities, albeit required, carries much lower processing times and as such can be performed in parallel to the crane work. This means that from a value flow point of view these activities are *not* critical so long as they are performed within the required time span. These activities are presented in table 7 below.

**Table 7 - Non-critical required activities**

Activity	Description	Activity	Description
Placing distances (1:54)	Distances are required to ensure that the elements are horizontal	Insulation (1:30)	Outer walls need insulation between elements
Placing mortar (2:20)	Mortar is required to support the element and plug for later concrete work	Support beam assembly (2:05)	2 or more support beams are required per element
Insulation (1:35)	Outer walls require insulation against the floor	Leveling (1:30)	Leveling the elements ensures horizontal and vertical fit against adjacent elements
Mortar (1:55)	Mortar surface connections to floor slabs.	Mortar (1:33)	Mortar surface connections to adjacent elements.

For example, the placing of distances are required prior to placing an element in that location, however this activity takes around two minutes while transporting the element from the truck to the assembly location can take up to 30 minutes. Therefore, this activity is only critical if it isn't finished before the element arrives which makes time variances (sub 30 minutes) in this particular activity irrelevant from a value flow point of view.

This is important because such supportive work is more or less always performed in time, the issue is the main critical activities which carries enormous amounts of time variances. During the observations the times for each activity was measured for 28 elements and it was found that the average time for unloading a wall element was 10 minutes and 43 seconds, while the same for fitting an element was 29 minutes and 5 seconds. Adding these two numbers together yields a time greater than the theoretical ideal takt time of 21,8 minutes which could be observed through queues of delivery trucks.

The issues observed are the huge time variances in the two aforementioned activities, lifting and fitting. For the first activity the max, min time values are 26:40 and 00:56 and for the second activity 81:35 and 9:32 respectively (see appendix 3). The reason for these variances is not tied to issues with the required non-critical activities but instead due to non-required critical activities. Such activities are related to, for example, delivery issues (the truck is loaded in the wrong order), unbalanced elements, too high tolerances making it difficult to fit the element to adjacent surfaces, quality issues with delivered elements etc. The reason why these activities are labeled non-required critical activities is because they can be omitted through for example loading the trucks in order or lowering the tolerances. But if the problems are there, working around them is critical. In essence the solution to these problems lies up-streams in the value chain (factory, blueprints and distribution respectively). The rationale comes from studying the assembly of the ideal element, typically an inner wall that is delivered in the right order as specified by the blue prints and with few adjacent surfaces, such elements corresponds to the lowest cycle times and should be the target cycle time for *all* comparable elements.

An interesting observation in the assembly process was that when the production was subject to time pressure due to issues with the assembly, the leader of the assembly team started handing out tasks to the assembly team. Such tasks included placing mortar and distances for the next elements which resulted in an argument since the assembly team interpreted the action as critique of their work (they also felt that the assembly functioned poorly). The reason why this is interesting is because it signals that the focus and understanding of the activities and their relative importance to the flow are misplaced. Such activities are not affecting the production time in any way, granted they are done when needed. This misunderstanding of flow was further observed during a spontaneous discussion with another supervisor regarding the issues observed with assembly and is illustrated with the quote below:

*“The assembly team could work smarter by performing activities beforehand, such as placing mortar, distances etc.”* - Interviewee K

This could seem like a good idea, but in fact any preemptive work not affecting a) the available time and/or b) the critical processing times will not improve the overall production capacity or performance. This insight is linked to production theory and bottlenecks in specific. In this case the activities of

“loading” and “fitting” are the bottlenecks. This means that the focus should be on reducing these times rather than on performing unnecessary preemptive work. Especially since, for example, placing mortar too early will render that activity useless since the mortar sometimes hardens before that element is assembled due to issues with the previous element. This makes that activity pure waste and it needs to be redone, often rendering a previously non-critical activity critical as the hardening is discovered when a new element arrives.

Considering the assembly of slabs and bathrooms, which work really well in terms of time variances, it can be acknowledged that the assembly team is a well-working unit in terms of flow which, overall, performs necessary preemptive work in a structured manner. The reason why these activities work relatively better is because the level of standardization is higher, i.e. each slab and bathroom module look more or less the same and the complexity in fitting surfaces is far less and more alike. Specifically, the slabs are fitted against two or three adjacent surfaces and the bathroom modules against three or four while the walls sometimes needs to be fitted against five surfaces plus the attachment steel rods, which by themselves impose problems on assembly. Further, some elements are outright impossible to assemble without either modification of the assembly location, the element itself and/or using other methods for assembly.

Mostly, the time variances observed are due to three things; poor quality in delivered parts meaning they are not produced according to the specifications, blue-print tolerances are too high making elements extremely difficult to fit with adjacent elements and poorly designed elements imposing problems in assembly. All of these issues are not related to the assembly site as such but rests within the production of the elements and within the technical platform of the concept. In order to manage these problems it is of great importance to shed light on the issues and notify the appropriate agent.

Currently, this is not done in a structured manner, e.g. when problems occur the assembly team solves the problem by adapting to the situation by using non standardized methods, for example through modifying the assembled element. Further, the problem and the solution are neither documented nor communicated to site-management in the generic case which means that the very same problem will most likely arise in the future. When asked about this one assembler said:

*“It feels like everything [issues, solutions] remain within this construction site”* - Interviewee M

The issue with production feed-back could stem from the inherent culture of the people involved in the construction process using skilled labor with individual areas of expertise (carpenter, concrete worker etc.). During the observations it was apparent that problems and issues were solved as they arose by the assembly team with little to no feedback even to the construction site management. Instead, the site managers were notified if the problem was of such magnitude that it couldn't be solved without engaging them. This is a behavior that needs to be dealt with as it is of great importance that issues stemming from upstream functions that hinder optimal production performance are reported to the appropriate functions in order to improve the overall performance of the value stream.

Further, the site-management articulated issues regarding this area and they feel that they are not included in the improvement of the concept as such.

*“...we do not partake [per invitation, not choice] in improvement meetings regarding the development of the technical platform or the concept...” - Interviewee A (clarification by authors in brackets)*

Instead, the feedback is sent from the construction site directly to the design engineer or the production in a general manner. This implies that the concept is not updated through the technical platforms, instead details are revised within the blueprints. This leads to recurring problems with later projects based on the same technical platform.

The root cause of these issues revolves around both communication issues in the value stream but also within the project itself. This means not all important information reaches the site-management, and the information that does is not forwarded to the technical platform or the supplier of the concrete elements which means that the development of the concept is hindered and competitive advantage through continuous improvements are severely hampered.

In NCC Komponent this was dealt with using an assembly supervisor with responsibilities similar to that of a production technician, someone responsible for monitoring the production in a structured manner and finds areas of improvement (Interviewee D & E). This worked because of the level of detail in production planning which meant that less effort had to be put in solving issues linked to the particular place of production. According to Interviewee D, this worked very well and the information distance between production and assembly was described as small. This could be due to both relatively small distances between production and assembly (same country) as well as a vertically integrated value stream - the production of the parts and the assembly of the parts was incorporated in the same company. Further, the entire company was formed with the sole purpose of industrializing construction and as such it should be assumed that great effort was made to manage information feedback from assembly to production.

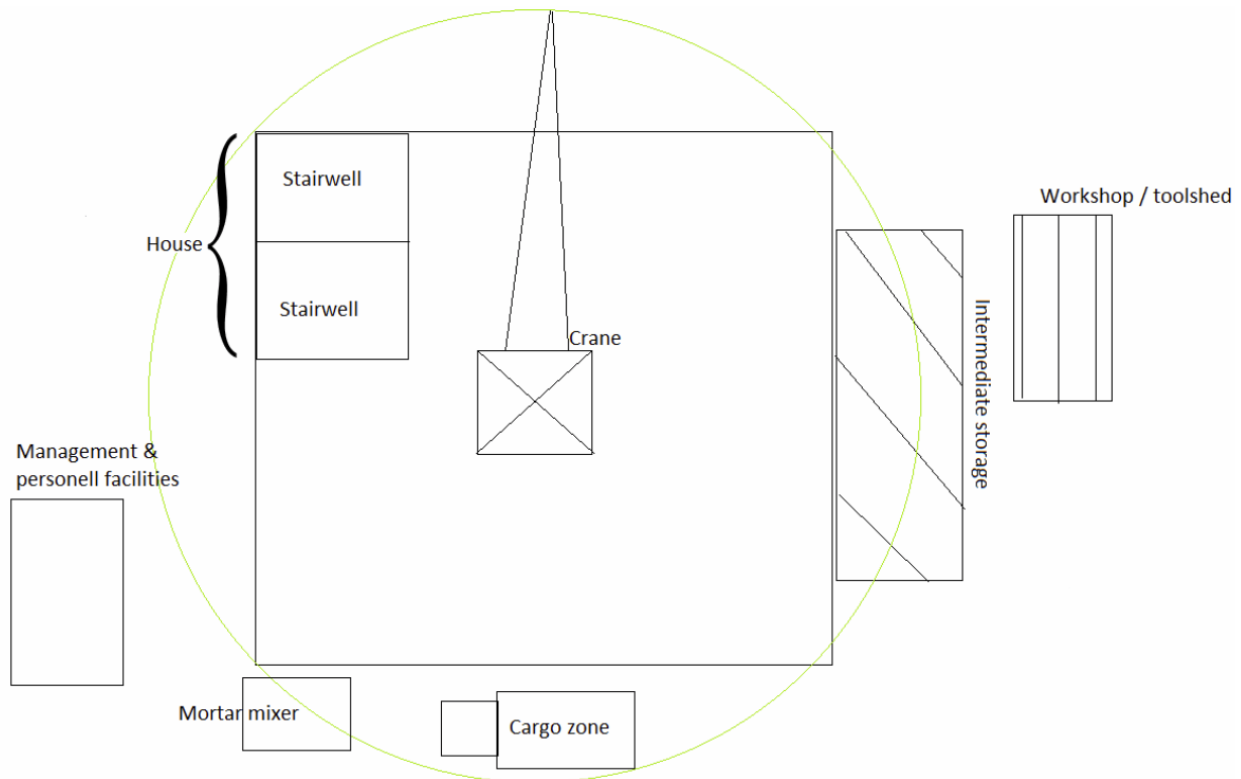
#### *Summary The assembly process*

- The assembly was carried out in a cycle of three days in dependant order, each including different activities.
- The team was comprised of 4 assemblers (2 on assembly location, one receiving elements and one crane operator) working eight hours per day.
- Currently 20 elements were delivered during day 1, implying a takt time of 22,8 minutes per element.
- A Value stream map was drawn and from it issues with time variances were observed.
- These issues were analyzed and the root cause derived, using the 5 why method, as; problems with the design of the elements causing difficulties with assembly and quality issues with delivered elements which in turn caused deviations in activity times.
- There are issues with upstream communication, problem codification and process standardization hindering continuous improvements

#### **4.6.3 The assembly site**

The assembly site is made up with the building itself in focus and all other resources, including personnel, is transported to and around the building. The crane, which is a critical resource for assembly, is located in the middle of the construction site, thereby enabling it to reach all of the possible assembly and production locations. Present on site are mobile tool sheds containing tools, fastening material, safety

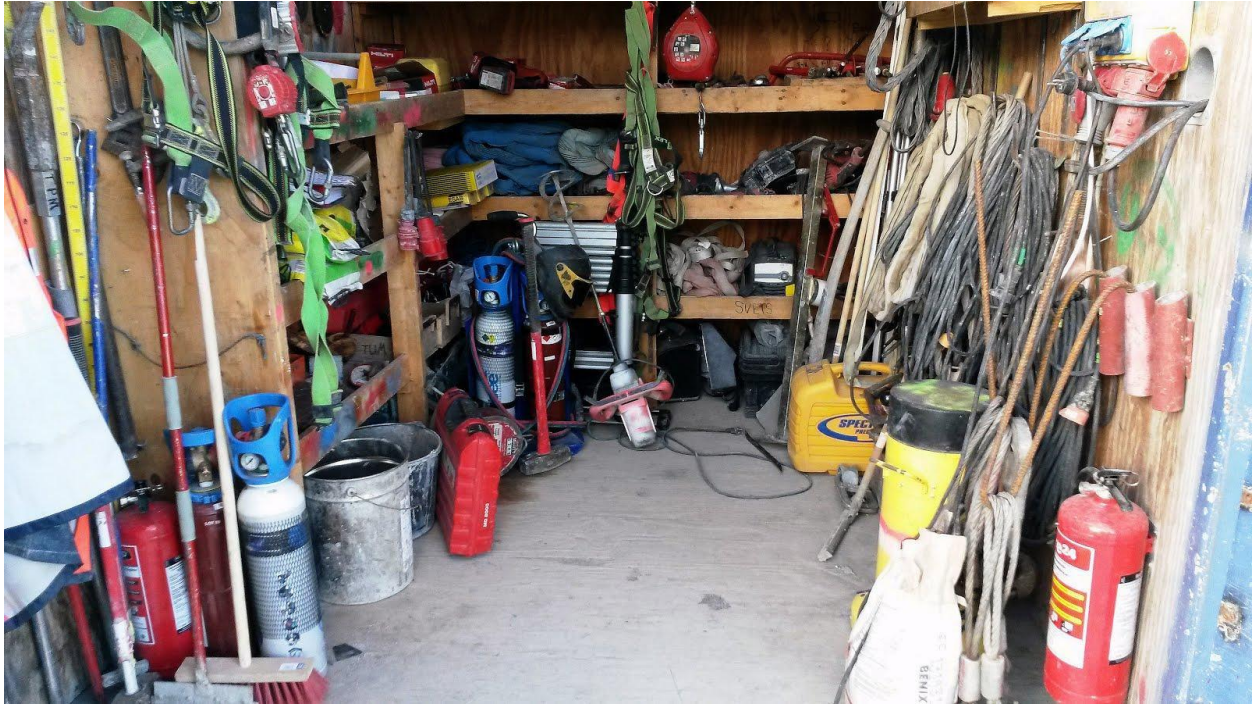
equipment etc. The site leadership is located in temporary barracks about 200 meters from the building itself, which enables management to continuously visit the production site. The location in its entirety is visualized in Figure 22 below:



**Figure 22 - Conceptual illustration of construction site**

Critical assets, such as the crane or tool sheds are either positioned ideally or are movable, which means they are virtually available everywhere on site. However, the tool sheds are not functionally sorted, meaning there's no dedicated shed for assembly or supportive work etc. Instead the sheds contain tools for basically any type of work and are shared between work teams. Further, the sheds lack in tidiness as only some positions are marked and ordered as seen in the pictures below.





**Figure 23** - Entrance to toolshed



**Figure 24** - Tools mixed with documentation

As seen in the pictures presented above the order in the tool sheds got room for improvement, and there is no valid reason as to why a structured order couldn't be achieved. The assembly team spend around 30-45 minutes each morning preparing for assembly, included in this time is getting the tools from the shed to the assembly location, preparing for unloading elements etc. This time is directly deductible from the productions available time and therefore influences the takt time (time per element) or production throughput (number of elements per day).

There are other functions at the construction site apart from the assembly team, such as ground work and installations, this means that to uphold an adequate amount of safety, the assembly team needs to be aware of what other work is being conducted in proximity to the assembly. The biggest risk lies in moving the heavy elements from the delivery truck to the assembly location. This awareness is made mostly through oral awareness and is supported by safety zones marked with plastic ribbons (no one apart from the assembly team should cross these ribbons).

This is linked to another key observation regarding this area, namely how elements for intermediate storage are handled. Obviously there is an ambition not to lift objects over people as this imposes risk in case of crane failure, as such required material should be as close to the assembly *location* as possible. It was, however, observed that parts in intermediate storage (in this case staircases and balconies as well as the mortar mixer) were placed near the perimeter of the construction site (marked in Figure 22). This implies two things: lifting times longer than necessary as longer distances than needed had to be covered as well as imposing risks for anyone on the construction site.

When prompted about these issues the assembly team articulated that they wanted the mortar mixer in the assembly location to avoid unnecessary lifts and for convenience:

*"We have said that we want the mortar mixer at our location, and previously we did, however our foreman decided to relocate it to its current position."* - Interviewee N

The labor foreman decided the mortar mixer to be located at its current position in order to provide parallel work for the element unloader to perform whilst an element is assembled. These lifts consumes about one hour of the crane's available time per working day (5 minutes per lift and around 10 lifts per day) and has a direct influence on the productions available time which influences production capacity and / or takt time.

Regarding the disposition of intermediate storage it was deducted that the chosen locations was due to convenience and to avoid the stored items blocking paths and locations on the work-site. Some items, namely balconies and staircases did not arrive JIT, instead these items arrived as a batch for the entire current house, which meant longer storing times. Longer storing times implies having to store such items on a location that does not hinder movement and / or construction in any way during the storing time. Walls and bathroom volumes that arrived in either the wrong order or at the wrong time (due to suppliers distribution routines or errors in delivery respectively) was stored close to the assembly location as these storing times are shorter.



In NCC Komponent these issues were coped with using a standardized work location facilitated by the assembly halls. Each hall was nearly identical, which meant each assembly location looked more or less the same. The difference is that within Komponent, everything was unloaded from the delivery truck immediately to the assembly location because material was delivered in the right quantity, right order and at the right time which meant no intermediate storage was required.

*Summary The assembly site*

- The crane is a critical resource for the assembly process positioned ideally from a flow perspective
- Morning routines and preparation takes around 30-60 minutes of available crane time each day
- Tool sheds are not structured based on flow efficiency and lack in tidiness
- Intermediate storage is, in some cases, not positioned ideally
- Unnecessary lifts are performed due to poor on-site structure especially regarding concrete mortar which consumes available crane time

## 5. Discussion

*This chapter contains an in-depth analysis and discussion about the empirical data, and the identified problems are sorted into three main areas of importance. These areas are then discussed in relation to the studied case as well as the construction industry.*

The research on which this report rests set out to answer three research questions, as a reminder these were:

- *How does a large construction firm use industrial construction to produce residential buildings?*
- *What hindrances arise in the application of the industrial construction concept?*
- *How can lean concepts be used to investigate and improve the production?*

From the results it can be deduced that the studied firm currently focus their industrialization efforts on conceptual products derived from technical platforms. These products, in this report exemplified by the on-site case, are based on a relatively high degree of prefabrication and standardization which enables the processes to be industrialized to a great extent, at least in theory.

The scope of this report includes the on-site practical case, and specifically the construction of the skeleton and its associated processes which is why the focus is mainly upon the assembly and its sub processes i.e. the value chain is analyzed in a bottom up fashion. This practical case was strengthened by a study of a past initiative for industrialization from which lessons can be learnt since the initiative failed.

Prior to the case study the authors of this report assumed that the production and organization tied to the Säby concept was developed enough to enable application of industrial production and lean principles directly. This assumption was made due to the massive degree of industrialization present in the Komponent initiative and the already implemented technical platforms. However, during the practical study it became clear that this assumption was overzealous. This was observed through lacking communication, a poorly structured workplace and poor understanding of flow. This conclusion is fortified through the results acquired when applying the industrialization categorization model in interviews (Figure 19). The results show that the Säby concept is only marginally more industrialized than a traditional construction project and the gap between the concept and NCC Komponent as well as theory in the field of industrial construction is striking.

The differences lies, not surprisingly, in the processes applied but also to some extent within the product (the concept). As theory within industrial construction (presented in chapter 2) suggests there are two prime aspects of industrialization that are of great importance; Continuity (economics through repeatability) and continuous improvements (kaizen). According to lean theory the continuous improvement work should be done primarily where the value is created, typically in the production. Because of the way work is organized in the studied case i.e. project based production, these two aspects are even more important to manage as the temporary nature of production imposes problems on these two aspects.

In order to move forward in an initiative of industrialization there are some areas which requires attention both within the perimeters of the assembly location but also upstream as well as in the line organization. During the observations and interviews it became clear that there are problems with industrialized construction in practice, in this case observed as; issues with **large** variances and deviations in activity times, the organization is not designed to handle project continuity and that the set-up times between activities are high. These observations were elaborated upon by inquiring the assembly team as well as the site leadership using the 5 why method of inquiry which resulted in three focus areas. These areas deals with the mitigation of the observed problems through continuous improvements as it is through continuously improving the concept and the production processes these deviations are best dealt with.

The structure of the following section is comprised of two parts, first the findings of the case are sorted according to area, discussed and afterwards generalizations are made regarding the specific area.

### **5.1 Reducing deviations through kaizen**

As previously presented one major current issue with the assembly is variation in processing times, as seen in Figure 21, of different elements, not only does this disturb the flow at the workplace but it also incurs direct monetary cost. The assembly team is created with the master time schedule in mind, meaning a certain amount of activities should be performed each working day to keep up with the time plan. Whenever a disturbance occurs in the production parts of, or the entire assembly team, is inactive for the duration of the disturbance. Depending on where the disturbance occurs (unloading or fitting) 1-5 people are inactive. Aside from this direct cost the overall production is delayed, which means that the integrity of the master time plan may be at risk.

A prime source of these issues are related to the technical platform and the supplier of the concrete elements rather than the on-site production itself, therefore a key activity for dealing with these problems is continuous improvements of both the technical platform as well as the production of elements. In order to enable this improvement work it is required to evaluate the production and use the data extracted in upstream processes which requires some sort of production feedback systems.

#### **5.1.1 Self evaluation**

In order to understand the production processes, find deviations and thus be able to continuously improve the current situation it is required to evaluate and measure the production. This is currently not done in either a structured manner or in enough detail. This is a primary activity that is both done in practice and described in theory in the domain of the manufacturing industry (Liker & Meier, 2004). Not only does it provide data for detailed planning and staff requirements but furthermore it creates thorough understanding for the production processes as well as highlights issues in production as the measuring function gets a bird's eye view of production. This thesis validates these statements as it was through measuring, evaluation and inquiry of the production process the problems discussed here were found.

In order to do this in a structured way the authors of this report suggest that such measurements should be done using the method of value stream mapping in conjunction with defining required critical activities, e.g. activities with the highest processing times that carries dependencies with other activities. The reason for this is presented in the previous section, but as a reminder:

*Critical required activities are activities that need to be done in order for the current phase to progress. Typically this activity is tied to a critical resource, e.g. the crane in this case.*

Measuring these activities makes it possible to level other, non-critical required activities, in order to improve the flow. Further, during these measurements non-required critical activities are easily observable and can therefore be removed through changing the process or working in a different way. Other support activities should also be measured and evaluated, but the critical activities should be measured first.

The production evaluation should be a recurring activity during the entirety of any project with production resources tied to it. This is especially important in a project based on a relatively young concept as teething problems are expected and as such needs to be captured and dealt with. Further, such evaluation gives data related to the production of the concept and should serve as production planning data as well as data for concept improvement.

This calls for the establishment of a specific function dealing with such measurements and production analysis during the course of the entire project which, if implemented, closes the PDCA cycle and facilitates continuous improvements.

### **5.1.2 Incorporating feedback loops**

In the studied case the owner of the technical platform is located at the company headquarters, the element blueprints supplied by a sub-contractor and the elements are produced in Poland and Italy making the information flow more complex. Therefore rigid systems for problem communication and standardization thereof needs to be established; the first hand experience of the assembler needs to be codified, sent and understood by the supplier of the elements and the function dealing with the technical platform. The authors of this report suggest that such a system should be in the form of a bulletin board at the assembly location where the work is documented in previously agreed upon parameters filled in by the assembly team with a focus on the quality and technical rigor of the assembled parts.

This kind of system is fundamental in order to make continuous improvements possible, through establishing feedback loops from assembly to the element supplier and the technical platform (Josephson & Björkman, 2011; Diekmann et. al, 2004). The information should, in this case, be as detailed as possible to visualize the source of deviations; element number, deviation and problem should be readily available in terms of input and output.

The purpose of the suggested system is to gather production data in a structured way, this data then needs to be forwarded to the appropriate agent, in this case the technical platform and the sub-supplier of elements. This transference also needs to be conducted in a structured and practically achievable way. Considering the system utilized in the “Folkboende” concept for knowledge transfer, which was described as functioning in terms of input from production as well as output of the concept owner it is suggested that a similar system should be used here: a web-based interface tied to the concept and its processes.

Establishing such a system can be seen as a prerequisite of industrialization as such an initiative is motivated through realizing economical and efficiency benefits through repeating processes and

knowledge indefinitely as well as improving the parts on which the concept rests are key to long-term survival. As such, it can be seen as one of the most important aspects of industrialization and thus any construction company seeking to benefit from industrialization needs to realize its potential. Therefore, this system needs to be supported by resources dedicated to generating data, sorting data and make sure that the information from production is used in the technical platform and production of elements.

The observed issues with time variances at the case are symptoms for the underlying reality of poor or non-existing systems that facilitate upstream feedback from the project. This underlying issue is most likely common for projects in general and similar projects in specific within the construction industry, especially in construction companies of similar size and history as the studied company. This means that such feedback systems, focusing on transferring practical data related to specific functions, is of great importance for every construction company seeking to exploit the benefits of a business model based on industrialization. It cannot be stressed upon enough that such a system, regardless of its design, is required to achieve an organization capable of working with continuous improvements as this is a prime driver for competitive advantage and long-term profitability (Womack & Jones, 2003).

The development, through kaizen, of the concept, the technical platform and the production of the parts comprising the building is only one of the major aspects of industrialization. Another important aspect is improving the assembly processes and applying experience made in previous projects to new projects. In order to facilitate this, the organization needs to be designed for project continuity.

## **5.2 Establishing Project Continuity**

In order to improve the project performance in terms of cost and production time it is required to reuse past experience in both project planning and methods for production and assembly (Johnsson et. al, 2011). The current systems used are, as previously argued for, designed for a traditional construction environment based on unique projects. Important to note though is that the infrastructure for continuity is present but needs to be developed and adapted for an industrialized business model.

The industrial production philosophy is characterized by *continuity* and use of *stored* information regarding the production methods utilized (especially in the case of CTO or MSP typologies). This continuity could be achieved through using the same staffing resources across projects, e.g. when one project is finished the people involved are utilized in the next project of the same type. This is, however, not sustainable in the long term as it requires a new project to be initiated when the current one ends. Further, the projects can be tied to different geographical locations making it difficult to assign, for example, staff living in the north of Sweden to projects located in the south of Sweden.

Therefore, in order to achieve this continuity standardized methods and practices needs to be documented and stored for later reuse. This requires defining recurrent activities and practices and making them a standard for every project dealing with the same concept to use. The information should be relevant and easily utilized as well as sorted per described activity.

Regarding the assembly, such information should be stored as directions for assembly as done in the Komponent case through the assembly handbooks. These directions should be as detailed as possible in order to ensure they are adhered to and as such result in the desired effects of a constant quality of work.

On the outset such instructions dictates what is to be done, e.g. fit the element to that surface or place the support beam here. In the long run these instructions should incorporate best practices meaning a detailed description on how the activity should be done in the best known way is present in the assembly instruction. This requires, however, that the activity is subject to repetition and following the documented standard leads to that the activity is completed.

These instructions should be supported by having meetings where the production material is communicated and discussed both prior to the initiation of the activity *as well* as at the end of the activity. This is to ensure that the instructions are used and constantly improved upon. Such meetings are already present at the studied case and should be utilized in every production phase including people that are to be involved in the process at hand.

The same philosophy should be applied to every activity that is recurring in projects; the projection, production planning (based on gathered production data rather than the personal experience of the planner), purchasing, required resources etc. An important realization is, however, that certain aspects of even the most industrialized project are impossible to standardize (for example groundwork, specific customer demands etc.). These aspects needs to be dealt with using a traditional approach as it is tailored to solve unique problems utilizing the personal skill of the people involved.

Having these systems for codification of knowledge, assembly instructions based on best practices supported by start-up and recurring meetings regarding the specific process means that both types of knowledge is captured and available for reuse. The explicit knowledge tied to the process - how something should be done is codified through instructions (assembly) and production data (planning). The meetings serves as an enabler of making personal, tacit, knowledge available for the personnel performing the work which is currently of utmost importance as disturbances are frequent and handled through hands-on problem solving.

Further, if possible, study visits to similar projects should be part of any industrial project portfolio as it enables knowledge sharing through personalization between projects where common issues and solutions can be discussed and observed in practice. This means that experiences from one project naturally transfers to another which means issues are known beforehand and the possible solutions as well.

### **5.3 Organizing the construction site for flow**

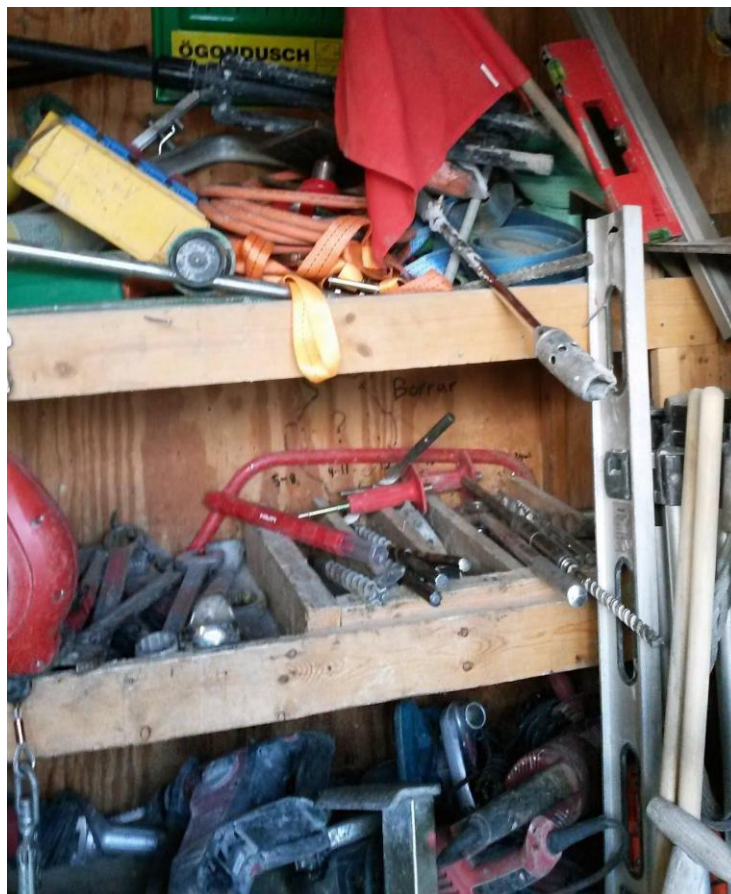
The third area of focus stems from observing the work-site disposition and its effects on the flow of assembly. Since the critical resource is, in this case, the crane the construction site should be designed to minimize the effects on available time due to poor site-planning. Such issues involves morning start-up times, getting the right tools, and moving material through the site. Organizing the work-site for flow will lower the amount of consumed available time (type I and II waste) as well as reducing other waste associated to non-critical activities. Although not affecting production throughput, waste associated to non-critical activities should also be subject to minimization as it carries a monetary cost without providing additional value.

There are mainly three observed areas in which improvements in this aspect can be done at the studied case; tool-shed organization, placement of intermediate storage as well as critical assets location / planning.

### 5.3.1 Tool-shed organization

Regarding the tool shed organization it can be said that it definitely lacks tidiness and structure which inflicts problems on set up-times between activities as a construction worker will have to spend more time than necessary to find the correct tools to perform the work at hand. In some cases, this time is deductible from the available time e.g. when the tool is required for work related to the crane (and is therefore critical) and in some cases it is pure waste. In both cases, however, it creates non-value adding activities and should, according to lean theory, be eliminated.

Below is an example of how the sheds are organized today, followed by a illustration on how they should be organized according to the 5S method, in Figure 25 and 26 respectively.



**Figure 25** - Toolshed present state



**Figure 26 - Tool shed desired state (Global Titanium, 2014)**

Organizing the tool-sheds could seem like a small action in terms of industrialization as there are bigger issues to deal with. However, the current status of the sheds can be seen as evidence that the industry is very far behind in terms of industrialization and lean work. This is because within the lean concept, a tidy and organized work-place is a fundamental principle from which methods and tools should be derived. Further, there is really no reason as to why having a cluttered and unorganized work-place is preferable over a tidy and structured ditto.

### **5.3.2 Placement of intermediate storage**

This area concerns choices regarding where to place intermediate storage of parts required for later assembly, most notably as; balconies, staircases, bathroom modules and wrongly delivered elements. Often such storages are located in a convenient place, and the rationale is that such storage should not hinder movement through the work-site. Since the concept of flow and specifically improving the flow is a core concept within lean production storage should be placed where it best facilitates flow rather than convenience.

Consider the hypothetical example of a production line within the manufacturing industry, where the line is comprised of several process steps each requiring its own material besides the raw material to process. Such material includes for example screws, paint, rubber seals etc. There are mainly two ways to manage the required material, either it can be placed in a common storage facility, for example a storage shelf, in a central location in the production facility (convenience) or in smaller shelves near the machines containing the material required for that particular processing step (flow). It is not intuitive which method of storage is the best, but from a flow perspective locating required parts close to the processes is preferable as it reduces waste in terms of unnecessary transport.



Applying this theoretical example on this particular case all stored material should be located as close to the related process as possible to reduce time spent on transporting the material. This is especially important as such transport often requires crane work and is thus deducted from the productions available time. Using, for example, the 5S and 5 Why methods can facilitate such decisions to a great extent as these two methods aims to structure the workplace as well as finding out the root cause of a current behavior.

### **5.3.3 Critical production assets location & planning**

Within any production facility there are critical assets, these are assets defined, in this report, as *required* for processing raw material or sub-parts into a finished product valuable for a customer. Examples of critical assets in the studied case are; the crane, the assembly team, tools and material (such as fasteners, mortar etc.). Using the same concept as above, namely that of flow, it should come as no surprise that such assets should be handled primarily from a flow perspective.

The crane, for example, is now positioned ideally from a flow perspective, i.e. it has access to every location of the production site, what is lacking, however, is the planning of this asset. Poor planning of the crane leads to waste in the form of idle time (type two waste) or lifts that are not ideal from a flow perspective (type one waste) i.e. performing a non-critical lift when critical lifts are possible. The planning of this asset should be done with a relatively short time-span as the work environment is subject to unforeseeable circumstances and the planning needs to be able to handle this reality. The person best suited to handle this planning is the goods receiver (typically the foreman), positioned at the unloading area. Currently, this function deals with connecting elements and mixing mortar, between these activities there are times of inactivity (while the assembly team assembles the current element), and this time could be used to plan the crane use making him or her the controller of the crane. This suggestion is feasible because the required infrastructure is already in place, i.e. he or she possesses a radio communication device and is in contact with both the assembly team and the crane operator. Further, this function is positioned ideally for gaining insight in the flow of the process as it receives the elements.

Another prime source of type two waste is related to the positioning of the mortar mixer, which is a critical asset. Because of its current position (at the goods receiver location) it requires lifting mortar from this location to the assembly location. This activity was measured and it was found to consume about five minutes per lift, at around ten lifts per day this equals to around an hour per day. Important to note is that the crane was utilized during these lifts, which means this time is deductible from the cranes available time and as such directly affects the production capacity or takt time. Stemming from the argumentation above it is suggested that the mortar mixer is moved to the assembly location to avoid type two waste affecting the production capacity.

These examples illustrates how production assets should be located and planned using a flow perspective in a construction project. Further, applying a flow perspective when analyzing and improving a production process is, obviously, relevant for construction as it brings forward both types of waste in the process, and the case exemplifies that such a perspective is not currently utilized in the industry.

## 6. Conclusion

*Conclusions and theoretical implications from the discussion are presented here. Further, conclusions about this research's implications on the construction industry are made followed by conclusions regarding three aspects of sustainability. The chapter ends in proposing further research based on the findings herein.*

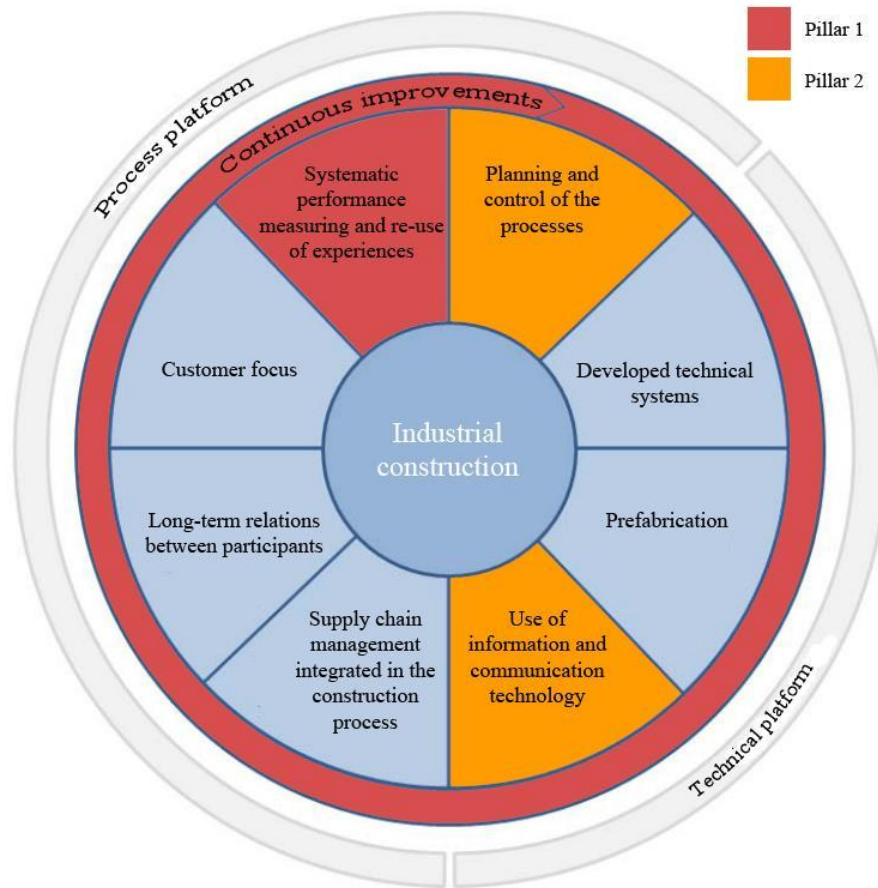
### 6.1 Theoretical conclusions

The research with which these results were found is based on a holistic approach in the field of industrial construction. A primary observation that was made during this research was the difference between theoretical material and the practical application of the concepts within industrial construction. Considering the degree of industrialization in the studied on-site case both derived through observations and interviews (Figure 19) it can be concluded that practice is far behind the academic literature in many aspects. There are mainly two reasons for this situation; either the theoretical concepts are *not* at all applicable to the industry or the industry is not mature enough to be industrialized. Included in the second statement things like organizational structure, implementation methods etc. are included in organizational maturity.

This study does, however, to great extent show that theory within industrial construction and lean production *is* applicable in practice to a great extent. The problem is to realize what aspects of industrialization are the most important - it is not enough to implement one aspect of industrialization, for example using prefabricated construction parts, but utilizing the same production processes or production philosophy. Instead the enablers or hindrances for industrialization must be identified and dealt with firsthand to ensure an environment that facilitates industrialization to an adequate extent.

The case study (which serves as an example of industrial construction in practice within in a well developed construction company) was conducted without prior bias toward a certain area or issue present at the studied case. As such, areas presented here are to be viewed as the most important areas of investigation in the studied case and in extension in the realm of industrial construction in practice. Viewing the gathered data from a perspective of industrial construction and specifically applied lean principles the authors of this report suggest that a) the three presented areas should be dealt with at the current case and b) the areas could very well serve as fundamental pillars for enabling industrialization of construction.

This is motivated through considering the model of industrial construction from Johnsson et. al (2011) as the first pillar (**5.1 Reducing deviations through kaizen**) deals with Continuous improvements and Planning and control of the processes and the second pillar (**5.2 Establishing project continuity**) concerns Systematic performance measuring and reuse of experiences as well as use of ICT tools to a large extent. This is illustrated in Figure 27 below.



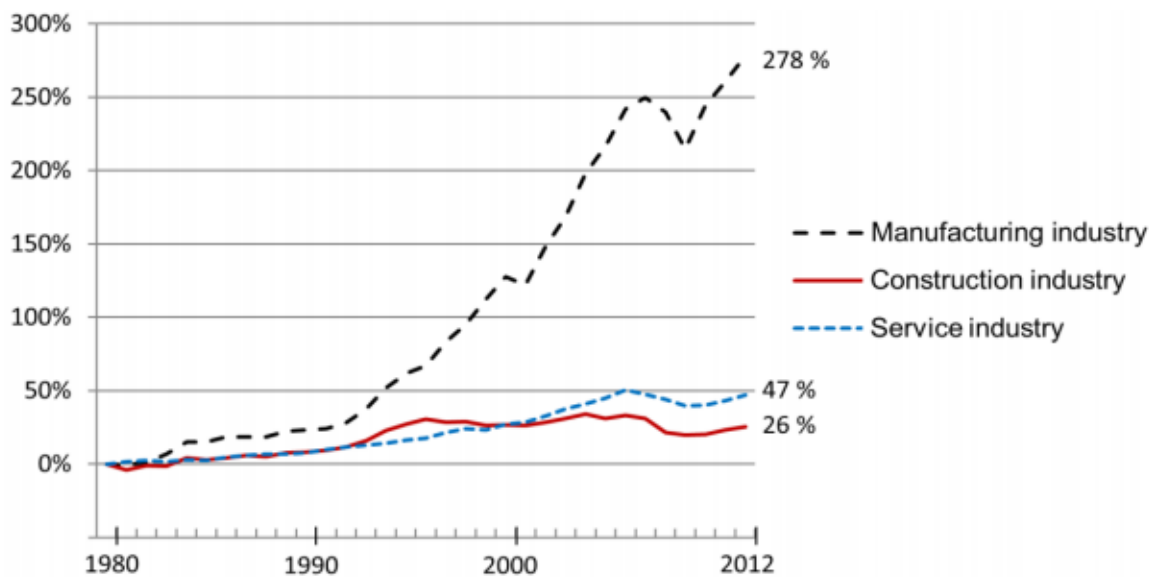
**Figure 27** - The three pillars in relation to theory

Further, it is proposed that the third pillar (**5.3 Organizing the construction-site for flow**) should be added to the model of industrial construction as this perspective is currently not incorporated in said model. Instead, the model states that

*“Projection, manufacturing, production, assembly and supporting work demands a sound structure and control from cradle to grave. This makes sure that efficient processes and maximum value are delivered to the end customer. Planning and control is important to minimize error and non-value adding activities as well as to create an even work-flow. It is important that each phase of the process is planned, from idea to completed construction and that the buildings conformation is established prior to construction start. Through well developed technical systems supported by structured methods of planning the actualization of the project is supported and errors and faults are avoided.”* (Johnsson et. al, 2011, pp. 112) (Directly translated)

which does not to an adequate extent emphasize the importance of planning the work-site disposition and critical production assets from a flow perspective. This research validates such a claim as it shows the importance of that particular perspective because it identifies and deals with waste currently present in the processes. What is important to realize though is that the other aspects of industrialization are important and should remain, but without the presence of the presented pillars (especially the first pillar) the other aspects will most likely not lead to the lean definition of perfection.

Considering the bigger picture of the construction industry and the industrialization thereof a fundamental conclusion that can be drawn is that continuous improvements is a key to the industry's long term success. This conclusion is connected to the comparably poor productivity figures for the sector and the realization that continuous improvements could be the prime source of the manufacturing industry's great success. Studying the difference in productivity between the construction and manufacturing industry (Figure 28) an important conclusion can be drawn.



**Figure 28** - Productivity comparison, different sectors in Sweden (Konjunkturinstitutet, 2014)

Looking at the productivity development for the manufacturing industry it should be noted that the improvements have been made stepwise over time observed as a constant increase in productivity, with an exception for the years 2008-2009, which could be explained by the financial crisis at the time. The situation was dealt with cutting production output (as sales dropped) while still having employees contracted for work - the output dropped having the same level of staffing due to period of notice times. This insight leads to the conclusion that the manufacturing industry is exceptional in its continuous improvements work as the effects of such work are tightly linked to a step-wise increase in productivity through eliminating waste.

Considering the same situation for the construction industry it can be deduced that it is indecisive whether or not the productivity trend is positive. Using the same rationale as above, the conclusion drawn is that the continuous improvement work in this industry is severely behind as the relationship in Figure 28 above implies.

This research has shown that even a large construction firm dealing with industrialized concepts fail to continuously improve. This is underpinned by the results and the discussion presented in previous chapters regarding the observed problems but especially how these are handled in practice. Further, the Komponent case presented in this report is an excellent example of a, in theory, good concept which was shut down due to a failure to realize that benefits from industrialization lies within long term commitment

and improving over time. This claim is further supported by the history of the lean manufacturing philosophy itself, taking several decades to develop in contrast to Komponenten relatively short life-span of five years. The conclusion is, therefore, that structured methods for continuous improvements are a fundamental requirement for industrialization of construction, without it every other initiative risks to fail regardless of its theoretical benefits. This means that the journey toward fully industrialized construction should be done in small, incremental steps over a long period of time. The technical platform and conceptual products is a good initiative for achieving this, granted that it is paired with continuous improvements of the entire process, especially using production data to improve upstream processes.

## **6.2 Sustainability**

Another area of fundamental importance for the industrialization of construction is the strategy's implications on sustainability. In the introduction to this paper it was shown that the construction industry as a whole impacts the environment to a great extent through, above all, landfill material and energy consumption. Because of this it is imperative that the industry is successful in industrializing their processes because doing so will, in the long run, lead to environmental sustainability through eliminating waste in construction. Since the construction processes requires enormous amounts of material, eliminating waste leads to less material requirements and therefore less energy consumed per constructed unit.

From the economical perspective it is argued for, in this report, that industrialized processes and continuous improvements in specific leads to increased productivity which is tightly linked to long-term profitability, which is equivalent to economic sustainability. A construction industry working toward increasing its productivity will in extension deliver social sustainability through enabling the existence of affordable residence for the population to purchase. This counters one of today's largest social issues in Swedish metropolitan areas - housing deficit, through making it profitable to invest in affordable rental estate.

Therefore, it is of outmost importance that the construction industry succeeds in industrializing its processes which should be done successfully if considering the pillars of industrialization presented in this report.

## **6.3 Limitations**

This research is primarily limited in terms of scope since only one (albeit large) company was studied and within that company only one industrialized project was subject to in-depth practical research. This approach means that projects specific issues are not to be seen as general issues for the industry. Further, since the researchers were based in Sweden many of the conclusions drawn are applicable solely to the Swedish market and even more specifically, in a context of construction in a metropolitan area. The reason why this is relevant is because the market demand for housing in a metropolitan area is naturally higher than in rural areas. Lower demand of product implies lower and less concentrated production which both hinders project continuity (because of less projects and project frequency) as well as the economical incitement for industrialization measured in monetary units.

Another consideration that was made is the relatively small economic scope of the project itself, MSEK 200, which could undermine the will to implement process improvements as the economic benefit is

smaller than in a larger project. The smaller the economic scope of a project is, the smaller the benefits of improvements are if measured in monetary units. This holds true for any given producer that seek to gain from process improvements. The size of the project, and the fact that other gains than just economic can be achieved (environmental, safety and especially application to similar projects) it is concluded that this issue was not detrimental for this research.

The purpose of this research was to understand the area of industrial construction in-depth and therefore a qualitative approach was chosen which, by default, lowers the generalizability of the findings and in extension the results. Connected to this limitation is also the fact that only one example of industrialization (conceptual products based on a technical platform using concrete elements) which could mean that the results are only relevant for cases of similar type since using other technical platforms or other products could render different problems or areas of interest not concretized here.

#### **6.4 Further Research**

Included in the discussion in the previous chapter are recommendations for the studied on-site case as well as for the organization when applicable. Also, a more general discussion about the suggestions are made. What is not covered though is the implementation aspect of these suggestions which will be handled in the following.

The derived pillars of industrialization should be seen as fundamental aspects for industrialization and as such these areas should be considered first. For example, if there are no structured systems for production feed-back to upstream processes such systems needs to be established. There are mainly two aspects to consider when designing such systems - functionality and usability. The functionality aspect relates to that the system achieves set goals, in this case that the information can flow from production to the technical platform and the supplier of elements with preserved integrity. The usability aspect relates to making sure the systems are used, if they are not the functionality of such systems are irrelevant. Since the purpose of this report was to evaluate and improve industrial construction using a perspective based on lean production, implementation is out of scope. Therefore it is suggested that research should be conducted in the two aspects discussed above - system functionality and usability, i.e. how should such systems be *designed* and *implemented*.

During this study the authors of this report had an important, although out of scope, insight. One cause for the industry's poor continuous improvement work could very well be found in the organizational structure. Considering how the market demand is captured and translated into projects using the same rationale in both industrial and non-industrial projects it can be deduced that the business model discourages long-term commitments (which is a major aspect of industrialization). This is because each project is evaluated on its own merits in terms of construction time and profitability, which means that projects that aim to improve the processes over time (and therefore underperforms short-term to over perform long-term) is a far greater risk than a traditional project where value is delivered with each project. Therefore it is suggested that research is conducted in the domain of organizational structure and business models tied to the construction industry to find possible solutions to ensure that the industrialization proceeds and is successful.

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# Appendix 1 – Industrialization evaluation model

*Industrialization characterization and exemplification of level of achievement model (Lessing et. al, 2005)*

Area	Levels	Characteristics
Planning and control of the processes	0	Scarce structure of process planning and control. Time schedules are not definite, unclear responsibilities and management has poor control of the process.
	1	A clear holistic structure of the project processes. All participants respect delivery dates and schedule.
	2	Developed planning in early phases of projects where key participants collaborate to give input to schedule. Developed structure for design delivery.
	3	Clear gates between sub-processes where certain tasks must be fulfilled. Detailed planning of all processes supported by structured planning system. All tasks in manufacture and assembly are thoroughly prepared.
	4	Planning and control systems supported by advanced ICT-tools and integrated with planning of supply chain activities. Performance measures give important input to planning.
Off-site manufacturing of building parts	0	No off-site production
	1	Simple parts of the building are manufactured off-site. Examples are roof trusses and concrete elements.
	2	More advanced parts are pre-assembled off-site. It can be façade elements, complete wall- and slab-elements and stairs with ready surfaces.
	3	Advanced parts are pre-assembled and integrated with other pre-assembled parts. It can be volume-elements with all surfaces completed, completely equipped bathroom modules and pre-assembled service elements.
	4	Advanced parts are pre-assembled, design and manufacture are supported by IT-tools, advanced logistics principles and planning system.
Developed technical systems	0	Minimal use of developed technical systems. Hand craft methods dominate.
	1	Developed technical systems are used occasionally but without a clear strategy. Systems can be frame-, façade- or service systems.
	2	Developed technical systems are designed and used for certain parts of the building, based on a technical strategy.
	3	Complex technical systems used for a majority of the parts of the building. Systems are designed to fit each other and developed in partnership with suppliers.
	4	Complex technical systems are used, continuously developed in partnership with other participants, based on experiences from projects and supported by IT-tools
Long-term relations between participants	0	No long-term relations are established.
	1	Some relations are identified as more important than others. Relations are established but not in a systematic way.
	2	Long-term relations are established with key participants. Activities to strengthen the relations are done. The partnering concept is used occasionally
	3	All participants are involved on long-term basis. The participants work together as a team. Strategic partnering with key participants
	4	A structured program is used to work actively to develop the relations and cooperation. Evaluation is supported by IT-tools. Strategic partnering is thoroughly used.

Supply chain management integrated in the construction process	0	Logistic activities are not on the agenda.
	1	Solutions for better materials handling are used. Sufficient storage, delivery patterns and information exchange with key suppliers are examples of efforts.
	2	Just-in-time principles are applied. Strategic work with low storage levels, adjusted deliveries, packages and developed relations with key suppliers.
	3	Supply chain activities integrated in the construction process. It includes developed supplier services and information flow enabling advanced technical solutions.
	4	Supply chain activities are fully integrated as natural parts of the construction process. Supported by ICT-tools for planning, purchasing, scheduling and design.
Customer focus	0	The customer is anonymous and un-known.
	1	General insight about basic end-customer priorities, e.g. equipment preferences, apartment size. Clear perception of who the company's customer is.
	2	Basic investigations about end-customer needs and priorities for different cost levels and customer segments. Topics for investigation can be equipment, service needs and apartment layout.
	3	Systematic investigations about customer needs and priorities, follow-ups with moved-in tenants. ICT-tools supporting investigations and analysis of the material.
	4	The customer investigations and follow-ups are integrated with other areas, e.g. the technical development, manufacturing and assembly process and the project planning. ICT-tools make the information transparent in the whole process.
Use of information and communication technology	0	No ICT-tools are used.
	1	ICT-tools are used by some participants in the process.
	2	All participants are using ICT-tools to support their own activities. No common strategy is used.
	3	All participants are using ICT-tools integrated with each other. A common strategy is applied for the area.
	4	Advanced ICT-tools used by all participants to support other developed areas. ICT-tools support and integrate design, manufacturing, planning, performance measuring and purchasing.
Systematic performance measuring and re-use of experiences	0	No measuring and no systematic re-use of experience.
	1	Experience exchange in some parts of the process like regular meetings with manufacturing staff or the design team. Limited documentation.
	2	Measuring of tasks in some parts of the process. It can be key activities in manufacturing, assembly time, follow-ups in design. Documentation handled by individual participant.
	3	Performance measuring in all parts of the process but limited co-ordination. Experiences well documented by process owner.
	4	Performance measuring in a number of areas, experiences collected and spread systematically, with developed ICT-tools. This supports work with customer focus, relations, planning and the industrial manufacturing.

# Appendix 2 – Interview guide

*An example of interview questions in regards to industrial construction and NCC Komponent. All of the interviews were conducted in Swedish.*

## Industriellt byggande

- Vad var din roll i NCC Komponent och dess projekt?
- Kan du beskriva idén bakom NCC Komponent?
- Vad var det som gjorde att NCC komponent lades ned?
- Hur planerades produktionen på plats vid NCC komponent?
- För och nackdelar med ett så “industriellt” projekt som NCC Komponent?
- NCC komponent vs endast prefab betong?
- Tycker du att utveckling av väldefinierade koncept baserat på exempelvis hög prefabriceringsgrad är ett bra sätt att industrialisera byggandet?
- Hur ser du på implementering av IB hela vägen ut i projektet? Hur får man YA att ta till sig nya arbetsmetoder?
- Vilka brukar vara de vanligaste problemen när man använder industriella koncept i byggandet?
- Yrkersarbetare vs “industriella arbetare” vid prefabriceringsmontage?
- Ett problem som uppstår, vad vi sett, är hur man bemöter marknadskraven med högstandardiserade produkter i branschen. Investeringar i den tekniska- och processplattformen motiveras av återupprepning av projekten; hur förhindrar man att dessa satsningar bli värdelösa i framtiden?
- Vilken tycker du är den absolut största utmaningen för industriellt byggande?
- Det finns olika sätt att planera själva platsproduktionen på, tex. CPM och LoB, i just fallet prefab vilken anser du vara bäst?
- Vad har du för erfarenhet av LoB planeringsmetod och vad är dina tankar kring hur bra/effektiv denna är?
- Har du någon erfarenhet av Last planner planeringsmetoden och vad tycker du om denna?
- En tanke vi har haft om den största skillnaden mellan tex. TPS och Scantias produktion är det taktade flödet, alltså att det inte finns utrymme för waste i form av idle time eftersom processerna är beroende av varandra och balanserade till samma takt. På ett bygge, däremot, finns inte samma struktur (produktionslina), utan av naturliga skäl är det processerna som måste flyttas till olika platser för att kunna tillföra värde. Detta medför ju bland annat ställtider och slöseri. Hur tror du detta påverkar det industriella byggandet?
- Hur ser du på en workable backlog (från last planner) dvs. att man har värdeadderande arbete som kan göras vid eventuella produktionsstopp?
- Vilket system anser du vara det bästa, ett öppet eller stängt byggsystem?

## Erfarenhetsåterföring

- Hur anser du att erfarenhetsåterföringsmodellen bör se ut?
- Att definiera best practice och sedan införa montageanvisningar (i pappers eller filmformat) utifrån detta en bra metod för erfarenhetsåterföring och för att jobba med continuous improvements (då dessa kan uppdateras) (vid själva montaget av prefabdelarna)?

## **Övrigt**

- Vilka är de största kostnadsdrivarna i ett projekt baserat på IB?
- Var i processen, tror du, man kan göra mest besparingar och effektiviseringar?

## **Standardiserade moment**

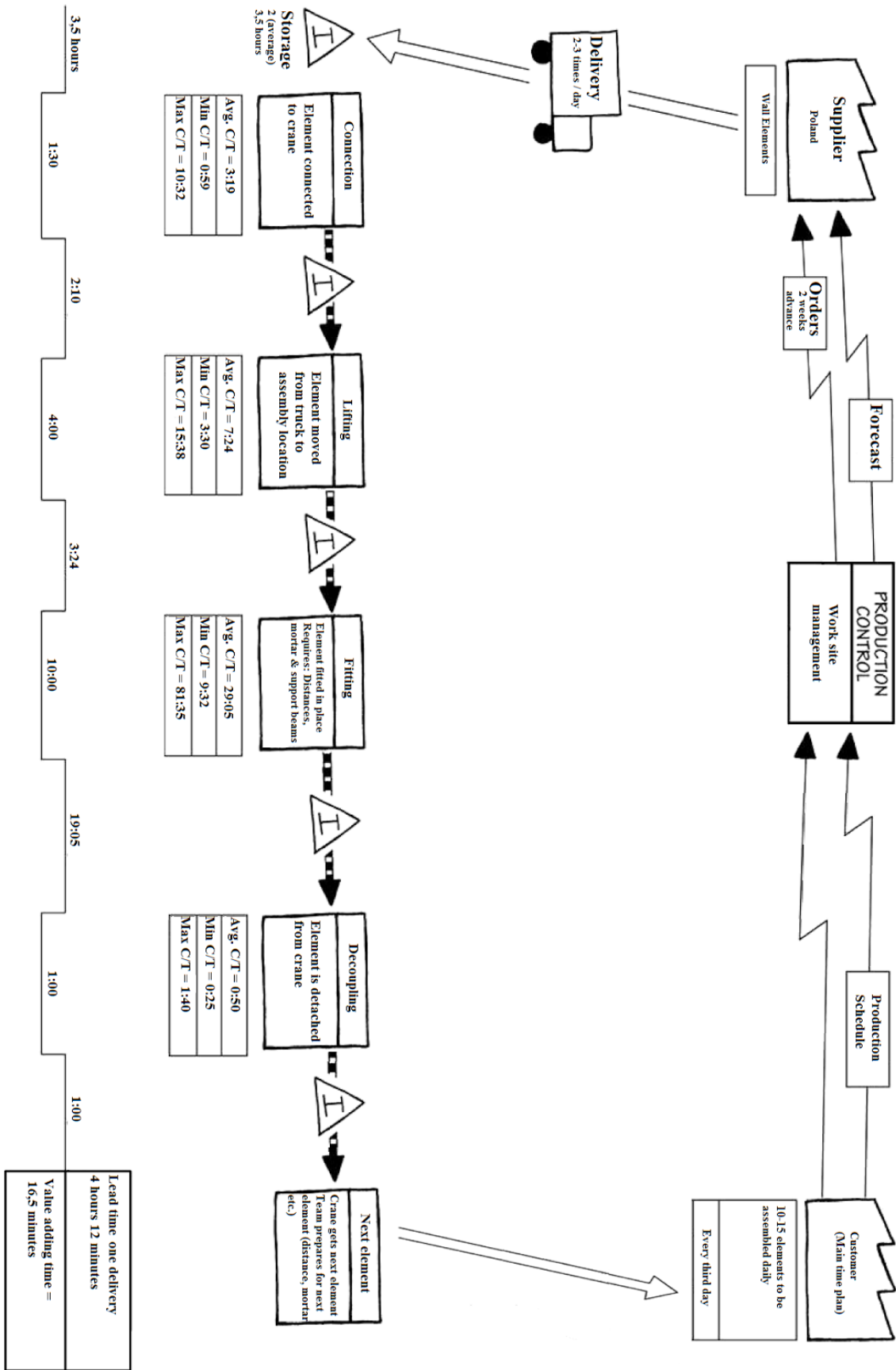
- Hur bestäms standarden för ett moment, dvs. vilka krav finns för att moment skall bli standardiserat och hur vet ni att detta är best-practise?
- Vilken funktion följer upp dessa moment och utvecklar dessa?
- Hur inkorporerar ni ständiga förbättringar i processen?
- (Hur samlas förbättringsförslag in och granskas? Vem beslutar vilka som implementeras och vilka som inte gör det?)
- Hur får man yrkesarbetarna att följa standardprocessen?

## **Montageanvisningar**

- Vilka typer har ni?
- Hur tas dessa fram, vilken input tas hänsyn till, involveras yrkersarbetare?
- Används dessa? (Om inte, varför? Om ja, i hur stor utsträckning?)
- Har ni märkt någon skillnad i produktionen sedan ni började med montageanvisningar?
- Kan vi få tillgång till en eller ett par av era montageanvisningar?

# Appendix 3 – Value stream map

VSM of the wall assembly process



## Appendix 4 – Time data

*The production time data gathered from the on-site production case is presented here. The data is in Swedish as it made communication with the production site employees easier.*

### *Krananalys 1*

#### **Benämning: W31004**

<b>Rutinlyft + idle time</b>	36:00:00
<b>Koppling av lyftöglor till element</b>	3:48:00
<b>Lyft</b>	5:18:00
<b>Inpassning</b>	11:06:00
<b>Lossning av element</b>	1:40:00
<b>Kran tillbaka till lastbil</b>	1:00:00
<b>Totalt</b>	58:52:00

#### **Benämning: W31005**

<b>Koppling av lyftöglor till element</b>	2:29:00
<b>Lyft</b>	4:13:00
<b>Inpassning</b>	9:32:00
<b>Lossning av element</b>	0:56:00
<b>Kran tillbaka till lastbil</b>	0:40:00
<b>Totalt</b>	17:50:00

#### **Benämning: W31007**

<b>Bruk + Bockar</b>	6:50:00
<b>Koppling av lyftöglor till element</b>	10:32:00
<b>Lyft</b>	5:10:00
<b>Inpassning</b>	19:35:00
<b>Lossning av element</b>	0:25:00
<b>Kran tillbaka till lastbil</b>	0:43:00
<b>Totalt</b>	43:15:00

#### **Benämning: W31008**

<b>Hämta bruk + UE bod</b>	6:12:00
<b>Koppling av lyftöglor till element</b>	1:06:00
<b>Lyft</b>	10:30:00



<b>Inpassning</b>	11:22:00
<b>Lossning av element</b>	1:25:00
<b>Kran tillbaka till lastbil</b>	1:29:00
<b>Totalt</b>	32:04:00

**Benämning: W31006**

<b>Koppling av lyftöglor till element</b>	2:14:00
<b>Lyft</b>	4:54:00
<b>Inpassning</b>	31:10:00
<b>Lossning av element</b>	1:02:00
<b>Kran tillbaka till lastbil</b>	0:40:00
<b>Totalt</b>	40:00:00

**Benämning: W31010**

<b>Hämta bruk + Idle time</b>	9:00:00
<b>Koppling av lyftöglor till element</b>	3:50:00
<b>Lyft</b>	7:15:00
<b>Inpassning</b>	20:00:00
<b>Lossning av element</b>	
<b>Kran tillbaka till lastbil</b>	
<b>Totalt</b>	40:05:00

**Benämning: W31009**

<b>Koppling av lyftöglor till element</b>	0:59:00
<b>Lyft</b>	3:32:00
<b>Inpassning</b>	21:26:00
<b>Lossning av element</b>	0:30:00
<b>Kran tillbaka till lastbil</b>	0:48:00
<b>Totalt</b>	27:15:00

**Benämning: V31006**

<b>Hämta bruk</b>	2:28:00
<b>Koppling av lyftöglor till element</b>	0:57:00
<b>Lyft</b>	2:34:00
<b>Inpassning</b>	12:21:00
<b>Lossning av element</b>	0:37:00

Kran tillbaka till lastbil	1:08:00
Totalt	20:05:00

#### Benämning: V31007

Kärra bruk	4:22:00
Koppling av lyftöglor till element	26:40:00
Lyft	2:08:00
Inpassning	10:30:00
Lossning av element	0:30:00
Kran tillbaka till lastbil	0:57:00
Totalt	45:07:00

#### Benämning: V31008

Idle tid	33:00:00
Koppling av lyftöglor till element	2:10:00
Lyft	0:56:00
Inpassning	9:29:00
Lossning av element	0:15:00
Kran tillbaka till lastbil	4:07:00
Totalt	49:57:00

#### Benämning: V31009

Benämning	
Koppling av lyftöglor till element	1:08:00
Lyft	18:44:00
Inpassning	6:52:00
Lossning av element	0:46:00
Kran tillbaka till lastbil	0:48:00
Totalt	28:18:00

#### Benämning: v31010

Koppling av lyftöglor till element	2:10:00
Lyft	3:40:00
Inpassning	45:50:00
Lossning av element	0:55:00
Kran tillbaka till lastbil	1:03:00

<b>Totalt</b>	<b>53:38:00</b>
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### *Krananalys 2*

<b>Benämning: W31010</b>	
<b>Rutinlyft + idle time</b>	<b>24:00:00</b>
<b>Koppling av lyftöglor till element</b>	<b>2:40:00</b>
<b>Lyft</b>	<b>7:15:00</b>
<b>Inpassning</b>	<b>61:35:00</b>
<b>Lossning av element</b>	<b>0:30:00</b>
<b>Kran tillbaka till lastbil</b>	<b>3:00:00</b>
<b>Totalt</b>	<b>99:00:00</b>

<b>Benämning: W31011</b>	
<b>Koppling av lyftöglor till element</b>	<b>1:23:00</b>
<b>Lyft</b>	<b>2:00:00</b>
<b>Inpassning</b>	<b>24:35:00</b>
<b>Lossning av element</b>	<b>2:02:00</b>
<b>Kran tillbaka till lastbil</b>	<b>1:03:00</b>
<b>Totalt</b>	

<b>Lyfta maskin</b>	<b>4:00:00</b>
<b>Lyfta bruk</b>	<b>3:02:00</b>
<b>Lyfta gipsbockar</b>	<b>8:28:00</b>
<b>Lyfta bock och brukpulver</b>	<b>13:00:00</b>
<b>Lyfta reglar</b>	<b>7:50:00</b>
<b>Lyfta gipsskivor</b>	<b>5:30:00</b>
<b>Lyfta gipsskivor</b>	<b>5:30:00</b>
<b>Lyfta gipsskivor</b>	<b>5:00:00</b>

### **Benämning: WC/D 7**

<b>Koppling av lyftöglor till element</b>	<b>2:55:00</b>
<b>Lyft</b>	<b>2:33:00</b>
<b>Inpassning</b>	<b>6:30:00</b>

Lossning av element	3:50:00
Kran tillbaka till lastbil	1:05:00
<b>Totalt</b>	

#### Benämning: WC/D 3

Koppling av lyftöglor till element	6:10:00
Lyft	2:45:00
Inpassning	3:30:00
Lossning av element	1:10:00
Kran tillbaka till lastbil	1:00:00
<b>Totalt</b>	

#### Benämning: WC/D 2

Koppling av lyftöglor till element	4:00:00
Lyft	3:30:00
Inpassning	39:34:00
Lossning av element	1:03:00
Kran tillbaka till lastbil	0:59:00
<b>Totalt</b>	

#### Benämning: WC/D3 Lager

Koppling av lyftöglor till element	1:28:00
Lyft	2:00:00
Sätta ner i lager	2:43:00
Lossning av element	1:35:00
<b>Totalt</b>	

#### Benämning: SB 1

Lyft av balk	4:03:00
Inpassning	24:39:00

**Benämning: SB 2**

**Lyft av balk** 3:41:00

**Inpassning** 3:33:00

**Benämning: SB 1**

**Lyft av balk** 3:03:00

**Inpassning** 8:01:00

**Benämning: WC/D2 Lager**

**Koppling av lyftöglor till element** 2:30:00

**Lyft** 1:15:00

**Sätta ner i lager** 2:04:00

**Lossning av element** 1:04:00

**Lyfta bruk** 5:30:00

**Idle** 4:55:00

**Lyfta container** 4:53:00

**Totalt**

**Benämning: PS31007**

**Koppling av lyftöglor till element** 2:15:00

**Lyft** 2:00:00

Inpassning	3:55:00
Lossning av element	1:10:00
Kran tillbaka till lastbil	0:50:00
<b>Totalt</b>	

**Benämning: PS31006**

Koppling av lyftöglor till element	0:44:00
Lyft	2:54:00
Inpassning	3:48:00
Lossning av element	0:22:00
Kran tillbaka till lastbil	1:14:00
Lyfta bruk	11:04:00
<b>Totalt</b>	

**Benämning: PS31005**

Koppling av lyftöglor till element	2:28:00
Lyft	2:17:00
Inpassning	2:04:00
Lossning av element	0:21:00
Kran tillbaka till lastbil	1:36:00
<b>Totalt</b>	

**Benämning: PS31018**

Koppling av lyftöglor till element	1:13
Lyft	2:43
Inpassning	3:02
Lossning av element	0:44
Kran tillbaka till lastbil	1:10
<b>Totalt</b>	

**Benämning: PS31016**

Koppling av lyftöglor till element	1:03
Lyft	3:34
Inpassning	3:07
Lossning av element	0:20

Kran tillbaka till lastbil	1:51
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Totalt	
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**Benämning: PS31017**

Koppling av lyftöglor till element	1:24
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Lyft	2:22
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Inpassning	1:54
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Lossning av element	0:27
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Kran tillbaka till lastbil	1:16
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Totalt	
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**Benämning: PS31015**

Koppling av lyftöglor till element	0:44
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Lyft	2:43
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Inpassning	2:14
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Lossning av element	0:20
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Kran tillbaka till lastbil	1:15
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Totalt	
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**Benämning: PS31014**

Koppling av lyftöglor till element	1:27
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Lyft	2:08
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Inpassning	6:02
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Lossning av element	0:28
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Kran tillbaka till lastbil	1:24
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### *Krananalys 3*

#### **Benämning: W31004**

<b>Morgonfix</b>	<b>21:10:00</b>
<b>Koppling av lyftöglor till element</b>	<b>8:00:00</b>
<b>Lyft</b>	<b>1:31:00</b>
<b>Inpassning</b>	<b>2:00:00</b>
<b>Lossning av element</b>	<b>1:15:00</b>
<b>Kran tillbaka till lastbil</b>	<b>1:09:00</b>
<b>Totalt</b>	

#### **Benämning: W31005**

<b>Koppling av lyftöglor till element</b>	<b>4:53:00</b>
<b>Lyft</b>	<b>2:00:00</b>
<b>Inpassning</b>	<b>2:14:00</b>
<b>Lossning av element</b>	<b>0:12:00</b>
<b>Kran tillbaka till lastbil</b>	<b>1:01:00</b>
<b>Totalt</b>	

#### **Benämning: W31007**

<b>Koppling av lyftöglor till element</b>	<b>1:37:00</b>
<b>Lyft</b>	<b>1:11:00</b>
<b>Inpassning</b>	<b>1:59:00</b>
<b>Lossning av element</b>	<b>0:07:00</b>
<b>Kran tillbaka till lastbil</b>	<b>0:50:00</b>
<b>Totalt</b>	

#### **Benämning: W31008**

<b>Koppling av lyftöglor till element</b>	<b>0:45:00</b>
<b>Lyft</b>	<b>1:06:00</b>
<b>Inpassning</b>	<b>3:43:00</b>
<b>Lossning av element</b>	<b>0:10:00</b>
<b>Kran tillbaka till lastbil</b>	<b>1:11:00</b>
<b>Support lyft</b>	<b>12:18:00</b>
<b>Idle</b>	<b>9:00:00</b>
<b>Totalt</b>	



**Benämning: W31006**

Koppling av lyftöglor till element	2:22:00
Lyft	2:17:00
Inpassning	7:43:00
Lossning av element	0:25:00
Kran tillbaka till lastbil	1:48:00
Lyfta bruk	6:27:00
Totalt	

**Benämning: W31010**

Koppling av lyftöglor till element	4:44:00
Lyft	1:46:00
Inpassning	41:22:00
Lossning av element	1:22:00
Kran tillbaka till lastbil	1:30:00
Lyfta armering etc	9:01:00
Totalt	

**Benämning: W31009**

Koppling av lyftöglor till element	1:34:00
Lyft	1:32:00
Inpassning	16:08:00
Lossning av element	0:26:00
Lyfta bod	6:14:00
Kran tillbaka till lastbil	1:49:00
Totalt	

**Benämning: V31006**

Koppling av lyftöglor till element	10:25:00
Lyft	1:12:00
Inpassning	25:04:00
Lossning av element	
Kran tillbaka till lastbil	
Armering lyft	3:42:00
Totalt	

**Benämning: V31007**

Koppling av lyftöglor till element	1:33:00
Lyft	1:29:00
Inpassning	9:10:00
Lossning av element	3:20:00
Kran tillbaka till lastbil	1:07:00
Totalt	

**Benämning: balkong 2**

Koppling av lyftöglor till element	2:05:00
Lyft	1:02:00
Inpassning	5:28:00
Lossning av element	3:18:00
Kran tillbaka till lastbil	1:06:00
Totalt	

**Benämning: V31009**

Koppling av lyftöglor till element	1:40:00
Lyft	2:51:00
Inpassning	8:15:00
Lossning av element	3:52:00
Kran tillbaka till lastbil	0:40:00
Totalt	

#### *Krananalys 4*

<b>Benämning: SS31101</b>	
<b>Morgonfix</b>	<b>45:34:00</b>
<b>Koppling av lyftöglor till element</b>	<b>2:00:00</b>
<b>lyfta bruk</b>	
<b>Lyft</b>	<b>1:45:00</b>
<b>Inpassning</b>	<b>11:06:00</b>
<b>Lossning av element</b>	<b>1:04:00</b>
<b>Kran tillbaka till lastbil</b>	<b>0:57:00</b>
<b>Totalt</b>	

#### **Benämning: WC/D 2**

<b>Koppling av lyftöglor till element</b>	<b>4:19:00</b>
<b>Lyft</b>	<b>1:00:00</b>
<b>Inpassning</b>	<b>3:56:00</b>
<b>Lossning av element</b>	<b>0:54:00</b>
<b>Kran tillbaka till lastbil</b>	<b>0:50:00</b>
<b>Totalt</b>	

#### **Benämning:**

<b>Koppling av lyftöglor till element</b>	
<b>Lagra badrum</b>	<b>6:48:00</b>
<b>Lagra badrum</b>	<b>6:37:00</b>
<b>Lyfta badrum</b>	<b>5:24:00</b>
<b>Lyfta trappa</b>	<b>2:58:00</b>
<b>Inpassning</b>	
<b>Lossning av element</b>	
<b>Lyfta bruk</b>	
<b>Kran tillbaka till lastbil</b>	
<b>Totalt</b>	

#### **Benämning: WC/D 7**

<b>Koppling av lyftöglor till element</b>	<b>3:01:00</b>
<b>Lyft</b>	<b>2:58:00</b>

Inpassning	4:26:00
Lossning av element	0:48:00
Kran tillbaka till lastbil	0:54:00
<b>Totalt</b>	

**Benämning: WC/D 3**

Koppling av lyftöglor till element	1:25:00
Lyft	3:08:00
Inpassning	3:00:00
Lossning av element	
Kran tillbaka till lastbil	0:50:00
Lyfta bruk	
<b>Totalt</b>	

**Benämning: PS31107**

Gips och balkar	60:27:00
Koppling av lyftöglor till element	3:35:00
Lyft	1:33:00
Inpassning	3:20:00
Lossning av element	0:43:00
Kran tillbaka till lastbil	1:06:00
<b>Totalt</b>	

**Benämning: PS31118**

Koppling av lyftöglor till element	1:40:00
Lyft	1:30:00
Inpassning	1:35:00
Lossning av element	0:29:00
Lyfta bod	
Kran tillbaka till lastbil	1:06:00
<b>Totalt</b>	

**Benämning: PS31117**

Koppling av lyftöglor till element	1:10:00
Lyft	2:05:00
Inpassning	4:54:00

Lossning av element	0:33:00
Kran tillbaka till lastbil	0:59:00
<b>Totalt</b>	

**Benämning: PS31106**

Koppling av lyftöglor till element	3:30:00
Lyft	0:58:00
Inpassning	3:12:00
Lossning av element	0:11:00
Kran tillbaka till lastbil	1:11:00
<b>Totalt</b>	

**Benämning: PS31105**

Koppling av lyftöglor till element	1:44:00
Lyft	2:18:00
Inpassning	1:58:00
Lossning av element	0:11:00
Kran tillbaka till lastbil	0:58:00
<b>Totalt</b>	

**Benämning: PS31116**

<b>Benämning</b>	
Idle	15:00:00
Koppling av lyftöglor till element	2:51:00
Lyfta staket (före koppling)	13:45:00
Lyft	1:14:00
Inpassning	1:46:00
Lossning av element	0:13:00
Kran tillbaka till lastbil	0:48:00
<b>Totalt</b>	

**Benämning: PS31115**

Koppling av lyftöglor till element	1:16:00
Lyft	2:04:00
Inpassning	0:51:00
Lossning av element	0:15:00

Kran tillbaka till lastbil	0:57:00
<b>Totalt</b>	

**Benämning: PS31114**

Koppling av lyftöglor till element	1:09:00
Lyft	1:45:00
Inpassning	2:46:00
Lossning av element	0:13:00
Kran tillbaka till lastbil	0:46:00
<b>Totalt</b>	

**Benämning: PS31113**

Koppling av lyftöglor till element	2:03
Lyft	1:02
Inpassning	1:13
Lossning av element	0:14
Kran tillbaka till lastbil	0:54
<b>Totalt</b>	

**Benämning: PS31112**

Koppling av lyftöglor till element	1:46
Lyft	1:34
Inpassning	3:15
Lossning av element	0:15
Kran tillbaka till lastbil	1:20
Lyfta armering	4:40
<b>Totalt</b>	

**Benämning: PS31111**

Koppling av lyftöglor till element	8:55
Lyft	1:15
Inpassning	1:58
Lossning av element	0:20
Kran tillbaka till lastbil	1:10

**Totalt****Benämning: PS31109**

Koppling av lyftöglor till element	2:30
Lyft	1:20
Inpassning	7:14
Lossning av element	0:15
Kran tillbaka till lastbil	0:53
Totalt	

**Benämning: PS31110**

Koppling av lyftöglor till element	3:28
Lyft	0:57
Inpassning	2:46
Lossning av element	0:14
Kran tillbaka till lastbil	1:10
Totalt	

**Benämning: PS31108**

Koppling av lyftöglor till element	1:17
Lyft	0:54
Inpassning	12:37
Lossning av element	0:15
Hämta bruk	4:00
Kran tillbaka till lastbil	0:50
Idle	13:00
Lyfta bruk	5:00
Idle	6:00